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Initiatives by the National Institute for Land and Infrastructure Management in Response to the 2011 Great East Japan Earthquake

－Records of Activities Concerning Emergency Responses and Engineering Contributions－

Emergency Responses and Engineering Contributions by NILIM
for the Recovery from the 2011 Great East Japan Earthquake

National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism, Japan

Foreword

The earthquake off the Pacific coast of Tohoku occurred at 14:46 on March 11, 2011, with the hypocenter located off the Sanriku coast. Estimated to have been approximately 500km long and 200km wide, with the largest slip measuring more than 30m, the focal region of this earthquake extended from the waters off the coast of Iwate Prefecture to those off the coast of Ibaraki Prefecture. It was a megaquake with a magnitude of 9.0, in which multiple focal regions in the Japan Trench became synchronized. As well as strong tremors being observed over an extensive area, a massive tsunami with a wave height of more than 10m and a maximum runup height of 40m caused immense damage.

The number of dead and missing persons as a result of the Great East Japan Earthquake has reached 18,579 (as of January 16, 2013; survey by the National Police Agency). This was the first natural disaster since World War II in which the total number of dead and missing exceeded 10,000. Moreover, tremendous damage has been caused to buildings and public facilities including coastlines, harbors, airports, sewerage systems, rivers, and roads, mainly on the Pacific coast of the Tohoku and Kanto regions. The cost of damage to social infrastructure and other facilities is estimated to be approximately 17 trillion yen (Cabinet Office, disaster management section). As well as expressing our deepest condolences to the families of those who lost their lives in this catastrophe, we at NILIM would also like to convey our heartfelt sympathies to all those affected by the disaster in other ways.

As befits its role as a research institute affiliated to the Ministry of Land, Infrastructure, Transport and Tourism, the National Institute for Land and Infrastructure Management has implemented various endeavors to date, working in partnership with the Public Works Research Institute, the Building Research Institute, and the Port and Airport Research Institute, and dispatching a cumulative total of 592 staff members to the area as part of the Technical Emergency Control Forces (TEC-FORCE) and other bodies, starting in the immediate aftermath of the earthquake.

This report has been prepared as a record of the emergency response and technical support implemented by this institute after the disaster. More specifically, the main content includes emergency damage studies and damage analysis focused on facilities within NILIM’s jurisdiction; details of emergency measures, and deliberations and proposals aimed at recovery and reconstruction; technical support provided on the ground, to such bodies as the Regional Development Bureaus and local authorities; technical support provided in relation to legislation and the revision of technical standards that became necessary as an emergency; and initiatives related to new challenges that surfaced in the aftermath of the disaster. The intention in publishing this report is to provide a permanent record of the measures that NILIM has taken to date in response to the disaster, in order to learn lessons from this disaster and be prepared for future disasters, thereby further improving its ability as a research institute to respond to disasters from the outset.

So far, in parallel with its emergency response and technical support measures and with the aim of contributing to the development of disaster-resistant facilities in light of its experiences of this earthquake, NILIM has conducted surveys, analysis, and research, such as detailed field surveys, including subsurface exploration, as well as verification studies of factors contributing to damage and effective measures, based on model experiments and analyses. The results of these endeavors have already been published as disaster study bulletins or research reports.

However, many challenges remain, so NILIM continues diligently to conduct such surveys, analysis, and research concerning this disaster.

For example, in order to respond to the highest class of tsunami (Level 2 tsunami) based on a combination of hard and soft measures, it is necessary to implement hard measures such as developing robust coastal protection facilities and facilities that apply the principles of defense-in-depth, as well as soft measures focused on evacuation, such as developing hazard maps. However, there is a mountain of issues to be resolved in order to actually apply these measures in the field and achieve steady results, so research in these areas is ongoing. In addition, studies are also being carried out concerning topics including measures to deal with long-period ground motion in high-rise buildings and measures to deal with liquefaction, and NILIM will publish in due course any new results that it obtains from its surveys, analysis, and research.

With a megaquake in the Nankai Trough and an earthquake directly under Tokyo both forecast, contingency planning against an earthquake disaster is an extremely pressing issue, so NILIM must learn as many lessons as possible from this recent major earthquake and make effective use of them in future. NILIM intends to make adequate preparations for a disaster, in order to assist those on the ground.

January 2013

Shuhei Kazusa
Director-General
National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism

Contents

List of Authors

1. Introduction

Hiroyuki KISHIDA, Dr.Eng, Executive Director for Research Affairs

2. The Great East Japan Earthquake and Responses to This by the National Government, MLIT, and NILIM

2.1 Overview of the Earthquake and Resultant Damage

Shigeki UNJOH, Dr.Eng, Research Coordinator for Earthquake Disaster Prevention, Research Center for Disaster Management

2.2 Response by the National Government

Hiroshi TANNO, Coordinator for Research Planning, Planning and Research Administration Department

2.3 Response by the Ministry of Land, Infrastructure, Transport and Tourism

Hiroshi TANNO, Coordinator for Research Planning, Planning and Research Administration Department

2.4 Response by the National Institute for Land and Infrastructure Management

Hiroshi TANNO, Coordinator for Research Planning, Planning and Research Administration Department

Naokazu TAKADA, Research Coordinator for Coastal and Marine Disaster Prevention, Coastal, Marine and Disaster Prevention Department

Shigeki UNJOH, Dr.Eng, Research Coordinator for Earthquake Disaster Prevention, Research Center for Disaster Management

Akio MIZUTANI, Director, Housing Department

(The former Research Coordinator for Disaster Mitigation of Building, Research Center for Disaster Management)

2.5 Other Relevant Developments

Hiroshi TANNO, Coordinator for Research Planning, Planning and Research Administration Department

3. Initiatives Focused on Recovery and Reconstruction Following the Great East Japan Earthquake

3.2 Evaluation and Analysis of Seismic Force and Action

3.2.1. Ground Motion

Shigeki UNJOH, Dr.Eng, Research Coordinator for Earthquake Disaster Prevention, Research Center for Disaster Management

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3.2.3 Soil Liquefaction

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3.3.12 Parks and Green Spaces

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3.3.13 Disaster Management

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3.3.14. Information Field

3.3.14.1 Provision of information during Disaster or Recovery

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Yoshihiro TANAKA, Researcher of Intelligent Transport System Division, Research Center for Advanced Information Technology

Daisuke WATANABE, Researcher of Intelligent Transport System Division, Research Center for Advanced Information Technology

3.3.14.2 Correction of coordinates of road ground control points and fundamental geospatial data of roads

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3.4 Research Study

3.4.2 Research on Multiple Defense Systems and Tsunami Disaster Mitigation

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3.4.4 Research on Risk and Crisis Management Strategy for Excessive and Multiple Actions of Natural Disasters

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3.4.5 Research and Development in Information and Technology Area

3.4.5.1 Research on the platform development for collecting and analyzing movement of people

Syunichi HAMADA, Research Coordinator for Green–Innovation, Research Center for Advanced Information Technology

Koichi SHIGETAKA, Head of Information Technology Divison, Research Center for Advanced Information Technology

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3.4.5.2 Research on supportive use of 3D CAD data for disaster rehabilitation processes

Masataka HIRAJO, Research Coordinator for Advanced Information Technology, Research Center for Advanced Information Technology

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3.4.5.3 Research on the management method of buried debris using computer aided construction technology

Koichi SHIGETAKA, Head of Information Technology Division, Research Center for Advanced Information Technology

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1. Introduction

On March 11, 2011 at 14:46, a megaquake with a moment magnitude of 9.0 occurred, with the hypocenter located off the Sanriku coast. As well as causing strong tremors across an extensive area, a massive tsunami was observed on the Pacific coast, and coastal areas in the Tohoku and Kanto regions in particular suffered catastrophic damage. The Japan Meteorological Agency named this earthquake the "2011 off the Pacific coast of Tohoku Earthquake". The disaster consisting of the earthquake off the Pacific coast of Tohoku and the resultant nuclear power plant accident has come to be called the "Great East Japan Earthquake". According to the National Police Agency, as of January 16, 2013, there had been 15,879 deaths due to the earthquake, while the number of missing persons was 2,700 and the number of those injured had risen to 6,132[1)].

At the time of the Great East Japan Earthquake, as a member of bodies such as the Technical Emergency Control Forces (TEC-FORCE) established by the Ministry of Land, Infrastructure, Transport and Tourism (hereinafter referred to as MLIT), the National Institute for Land and Infrastructure Management (hereinafter referred to as NILIM) conducted emergency damage studies and damage analysis on facilities within MLIT's jurisdiction and NILIM's research fields in partnership with various relevant organizations, including the Public Works Research Institute, the Building Research Institute, and the Port and Airport Research Institute. NILIM has played significant roles to date as a research institute affiliated to MLIT, thorough the implementation of various endeavors including deliberations and proposals concerning emergency measures, as well as providing technical support in relation to legislation and the review of technical standards, and technical support at infrastructure construction and recovery sites. As well as steadily linking results of those efforts to the recovery and reconstruction of damaged areas, it is essential that NILIM identifies further issues and ceaselessly strive for improvements, in order to prepare for future disasters.

This report has been compiled in chronological order, detailing the responses and measures implemented by NILIM, as well as describing the initiatives that commenced in response to new challenges that became apparent from the disaster.

This report contains details of the following.

1) The Great East Japan Earthquake and the responses to this by the national government, MLIT, and NILIM

As well as providing a summary in chronological order of responses by the government and MLIT aimed at recovery and reconstruction, NILIM has compiled a summary of the initiatives that it implemented as part of this disaster response.

2) Initiatives focused on recovery and reconstruction following the Great East Japan Earthquake

As well as summarizing the deliberations concerning such matters as the technical standardization of recovery and reconstruction measures in the fields under MLIT's jurisdiction and NILIM's mission, including erosion control, sewerage systems, rivers, water resources, coasts, roads, harbors, airports, and buildings, NILIM has compiled a summary in chronological order of the specific ways in which it contributed to these deliberations, focusing primarily on the following.

① Status of responses in various situations in relation to damage surveys, damage analysis, deliberations and proposals concerning countermeasures, legislation, establishment of technical standards, and practical application at construction and recovery sites (including starting new studies)

② Participation by NILIM in various expert technical review committees established by MLIT and other bodies in order to consider decisions on such matters as policies on rapid recovery; in addition, specific content such as technical support implemented in partnership with the secretariats of these committees.

③ Proposals for technological policy measures to be included in legislation and technical standards, as well as the results of damage surveys and analyses carried out in order to obtain technical evidence for these

④ Examples of effective responses, and cases in which the response was thought not to have been adequate enough. Items identified as being issues or regarding which improvements could be made.

This report focuses on initiatives by NILIM during the 18 months after the earthquake occurred (up to the end of October 2012). There are fields in which deliberations continue to be carried out, and details of these will be provided in a report to be published at a later date.

Please note that the following abbreviations are used consistently in this report:

・ National Institute for Land and Infrastructure Management → NILIM

・ Ministry of Land, Infrastructure, Transport and Tourism → MLIT

References

1) Emergency Disaster Countermeasures Headquarters, National Police Agency of Japan: Damage Situation and Police Countermeasures associated with the 2011 Tohoku district - off the Pacific Ocean Earthquake. January 16, 2013. http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf

2. The Great East Japan Earthquake and Responses to This by the National Government, MLIT, and NILIM

2.1 Overview of the Earthquake and Resultant Damage

(1) Earthquake and Ground Motion

At 14:46 on March 11, 2011, a megaquake with a moment magnitude of 9.0 occurred, with the hypocenter located off the Sanriku coast (latitude 38.1° north, longitude 142.9° east)[1]. The focal depth was 24km. This earthquake (M9.0) was the largest in Japanese recorded history; even on a global scale, it is the fourth-largest in recorded history worldwide, behind the 1960 Valdivia earthquake in Chile (M9.5), the 1964 Alaska earthquake (M9.2), and the 2004 Indian Ocean earthquake and tsunami (M9.1).

At 14:49 on March 11, the Japan Meteorological Agency announced the earthquake magnitude to be M7.9 (preliminary report). This was the Meteorological Agency's own estimate of the magnitude, calculated from the amplitude of the seismic wave. Subsequently, using the moment magnitude obtained from Centroid Moment Tensor (CMT) analysis, the figure was revised to M8.4 at 16:00 the same day (Meteorological Agency magnitude: provisional figure), to M8.8 at 17:30 the same day (moment magnitude), and to M9.0 at 12:55 on March 13 (moment magnitude).

Figure 2.1 shows the distribution of seismic intensity and location of the epicenter, as published by the Meteorological Agency, with an annotation showing the focal region. As well as the seismic intensity of 7 recorded in Kurihara, Miyagi Prefecture, tremors with an intensity of 6-upper were observed in Miyagi, Fukushima, Ibaraki, and Tochigi Prefectures, while tremors ranging from 6-lower to 1 were recorded over an extensive area ranging from Hokkaido to Kyushu.

Figure 2.2 shows the aftershocks that occurred following the Great East Japan Earthquake[2)-3)]. Table 2.1 provides a summary of these earthquakes in chronological order. In addition to the tremors clustered within the focal region, which measured approximately 500km long by about 200km wide, stretching from the area off the coast of Iwate Prefecture to the area off the coast of Ibaraki Prefecture, aftershocks also occurred over an extensive area outside it, including the eastern side of the trench axis near the focal region, and shallow areas on land in Fukushima and Ibaraki Prefectures. As well as a M7.3 foreshock two days before the main quake, 840 aftershocks measuring M4.0 or more occurred during the 60 days after the main quake, and there were five aftershocks in excess of M7.0. The biggest aftershock was an M7.7 earthquake that occurred off the coast of Ibaraki Prefecture at 15:15 on March 11. Furthermore, earthquakes with a seismic intensity ranging as high as 6-upper were observed in the Izu region of Shizuoka Prefecture (March 11) and in the east of that prefecture (March 15), as well as in northern Nagano Prefecture (March 12); although one cannot deny the possibility that these occurred as a result of the Great East Japan Earthquake, the relationship between them is not necessarily clear.

Figures 2.3 and 2.4 compare the changes over time in the number of aftershocks that occurred following major earthquakes in marine areas and inland earthquakes in recent years. There is a tendency for most aftershocks to occur in the immediate aftermath of the main quake, but the actual number of aftershocks differs considerably between earthquakes. In relation to earthquakes in marine areas, the number of aftershocks following the M9.0 Great East Japan Earthquake was more than three times higher than the number recorded after previous earthquakes.

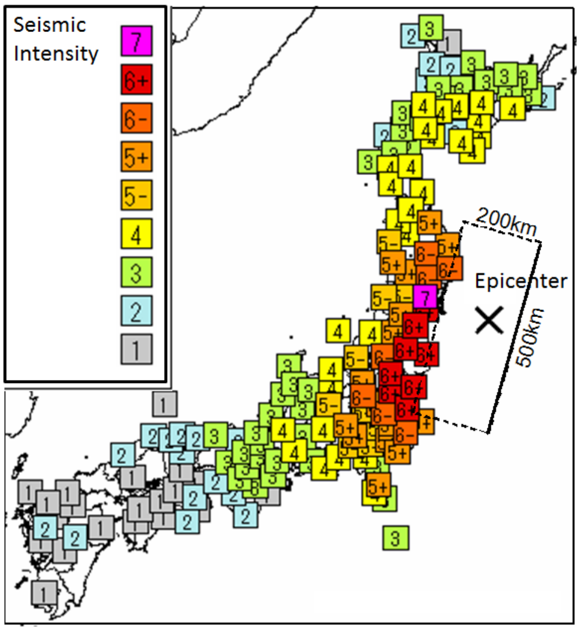


Figure 2.1 Distribution of Seismic Intensity by the Meteorological Agency
(annotated version of diagram published by the Meteorological Agency)

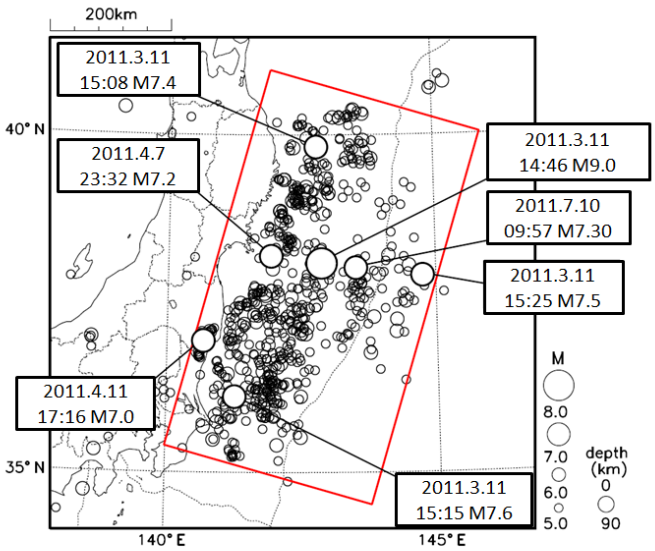


Figure 2.2 Areas Where Aftershocks Occurred Following the Great East Japan Earthquake (M9.0)[2)]

Table 2.1 Earthquake Occurrence (earthquakes with a seismic intensity of at least 5-lower)

Date	Name of Epicentral Region	Hypocenter Latitude (Latitude North) / Longitude (Longitude East) / Depth	Magnitude*	Maximum Seismic Intensity
March 11, 14:46	Off the Sanriku Coast	38°06.2'N/142°51.6'E/24km	9.0	7 (Kurihara, Miyagi Prefecture)
14:51	Off the coast of Fukushima Prefecture	36°44.0'N/142°01.7'E/11km	6.8	5-lower (Kasama, Ibaraki Prefecture)
14:54	Off the coast of Fukushima Prefecture	37°30.0'N/ 141°19.8'E/36km	5.8	5-lower (Namie, Fukushima Prefecture)
	Northern Ibaraki Prefecture	36°43.0'N/140°34.5'E/9km	5.7	
14:58	Off the coast of Fukushima Prefecture	37°40.5'N/141°54.6'E/23km	6.4	5-lower (Ogawara, Miyagi Prefecture)
14:57	Off the coast of Iwate Prefecture	39°11.7'N/142°22.9'E/24km	5.7	
15:06	Off the coast of Iwate Prefecture	39°02.5'N/142°23.8'E/27km	6.4	5-lower (Yahaba & other municipalities, Iwate Prefecture)
15:08	Izu region, Shizuoka Prefecture	35°10.8'N/139°01.5'E/6km	4.6	5-lower (Atami, Shizuoka Prefecture)
15:08	Off the coast of Iwate Prefecture	39°50.3'N/142°46.8'E/32km	7.4	5-lower (Gonohe & other municipalities, Aomori Prefecture)
15:12	Off the coast of Fukushima Prefecture	37°12.2'N/141°39.6'E/27km 39°26.5'N/142°05.7'E/33km	6.1 4.8	5-lower (Kawauchi, Fukushima Prefecture)

	Off the coast of Iwate Prefecture			
15:15 15:17	Off the coast of Ibaraki Prefecture Off the coast of Ibaraki Prefecture	36°06.5'N/141°15.9'E/43km 35°57.5'N/141°04.1'E/33km	7.7 5.7	6-upper (Hokota, Ibaraki Prefecture)
15:25	Off the Sanriku Coast	37°50.2'N/144°53.6'E/34km	7.5	4 (Urakawa & other municipalities, Hokkaido)
16:29 16:28 16:30	Off the coast of Iwate Prefecture Off the coast of Fukushima Prefecture Off the coast of Fukushima Prefecture	39°01.8'N/142°16.8'E/36km 36°54.3'N/141°52.2'E/26km 37°21.3'N/141°16.8'E/27km	6.5 6.2 6.3	5-upper (Osaki, Miyagi Prefecture)
17:40	Off the coast of Fukushima Prefecture	37°25.5'N/141°19.0'E/27km	6.1	5-upper (Tomioka, Fukushima Prefecture)
20:36	Off the coast of Iwate Prefecture	39°10.1'N/142°37.1'E/24km	6.7	5-lower (Takizawa, Iwate Prefecture)
March 12, 03:59	Northern Nagano Prefecture	36°59.1'N/138°35.8'E/8km	6.7	6-upper (Sakae, Nagano Prefecture)
04:31	Northern Nagano Prefecture	36°56.9'N/138°34.3'E/1km	5.9	6-lower (Sakae, Nagano Prefecture)
05:42	Northern Nagano Prefecture	36°58.3'N/138°35.4'E/4km	5.3	6-lower (Sakae, Nagano Prefecture)
22:15	Off the coast of Fukushima Prefecture	37°11.8'N/141°25.5'E/40km	6.2	5-lower (Naraha & other municipalities, Fukushima Prefecture)
23:34	Northern Nagano Prefecture	36°58.0'N/138°34.0'E/5km	3.7	5-lower (Sakae, Nagano Prefecture)
March 13, 08:24	Off the coast of Miyagi Prefecture	38°00.7'N/141°56.9'E/15km	6.2	5-lower (Tome, Miyagi Prefecture)
March 14, 10:02	Off the coast of Ibaraki Prefecture	36°27.5'N/141°07.5'E/32km	6.2	5-lower (Hokota, Ibaraki Prefecture)
March 15, 22:31	Eastern Shizuoka Prefecture	35°18.5'N/138°42.8'E/14km	6.4	6-upper (Fujinomiya, Shizuoka Prefecture)
March 16, 12:52	Off the eastern coast of Chiba Prefecture	35°50.2'N/140°54.3'E/10km	6.1	5-lower (Mito, Ibaraki Prefecture)
March 19, 18:56	Northern Ibaraki Prefecture	36°47.0'N/140°34.2'E/5km	6.1	5-upper (Hitachi, Ibaraki Prefecture)
March 23, 07:12 07:13	Hamadori, Fukushima Prefecture Hamadori, Fukushima Prefecture	37°05.0'N/140°47.2'E/8km 37°02.1'N/140°46.1'E/1km	6.0 5.8	5-upper (Iwaki, Fukushima Prefecture)

March 23, 07:34	Hamadori, Fukushima Prefecture	37°05.8’N/140°47.7’E/7km	5.5	5-upper (Iwaki, Fukushima Prefecture)
07:36	Hamadori, Fukushima Prefecture	37°03.8’N/140°46.2’E/7km	5.8	5-lower (Iwaki, Fukushima Prefecture)
18:55	Hamadori, Fukushima Prefecture	37°06.6’N/140°45.6’E/9km	4.7	5-upper (Iwaki, Fukushima Prefecture)
March 24, 08:56	Southern Ibaraki Prefecture	36°10.6’N/140°02.5’E/52km	4.8	5-lower (Hokota, Ibaraki Prefecture)
17:20	Off the coast of Iwate Prefecture	39°04.6’N/142°21.4’E/34km	6.2	5-lower (Ishinomaki, Miyagi Prefecture)
March 28, 07:23	Off the coast of Miyagi Prefecture	38°23.5’N 142°18.9’E 31km	6.5	5-lower (Ishinomaki, Miyagi Prefecture)
March 31, 16:15	Off the coast of Miyagi Prefecture	38°52.3’N 142°05.0’E 47km	6.1	5-lower (Hanamaki, Iwate Prefecture)

*) Magnitude refers to moment magnitude

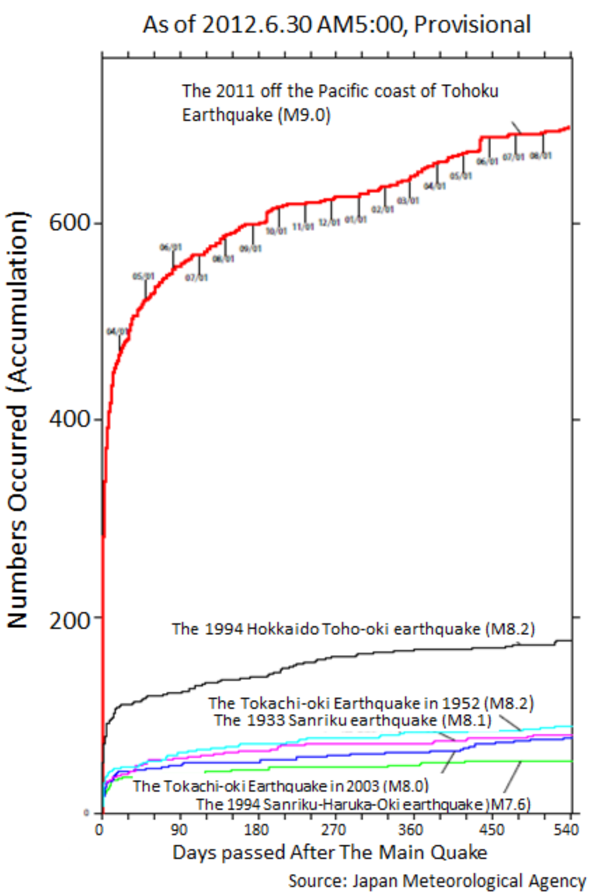


Figure 2.3 Comparison of the Number of Aftershocks Following Major Earthquakes in Marine Areas (including the main quake) (magnitude 5.0 or higher)[3]

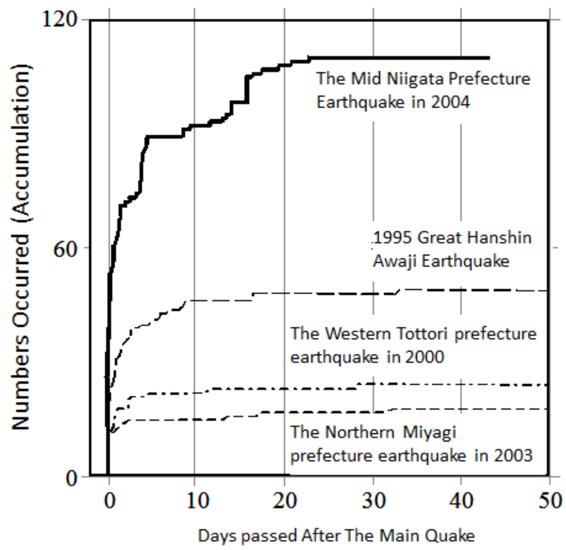


Figure 2.4 Comparison of the Number of Aftershocks Following Major Earthquakes in Inland Areas (including the main quake) (magnitude 4.0 or higher)[4,5]

At the same time, as far as inland earthquakes are concerned, the 2004 Chuetsu Earthquake in Niigata Prefecture is the earthquake that has been associated with the greatest amount of aftershock activity in recent years, with aftershocks increasing the damage from the main quake and hampering emergency activities[4-5].

Figure 2.5 shows the results of a long-term evaluation of a major subduction-zone earthquake by the Headquarters for Earthquake Research Promotion[6]. This evaluation was carried out on January 11, 2011, before the Great East Japan Earthquake. The focal region of the earthquake was projected to extend from the waters offshore from Iwate Prefecture to the area off the coast of Ibaraki Prefecture, measuring more than about 400km long and around 200km wide, with the largest slip estimated to be more than 20m. The areas where large slips occurred are regarded as the southern part of the Sanriku offshore area (near the Japan Trench) and part of the area between the northern part of the Sanriku offshore area and the Boso offshore area, based on the evaluation by the Earthquake Research Committee of the aforementioned Headquarters. The focal region is estimated to have covered an area that also encompassed the middle part of the Sanriku offshore area, the Miyagi offshore area, the Fukushima offshore area, and the Ibaraki offshore area. The Earthquake Research Committee had conducted an evaluation of seismic motion and tsunami in the Miyagi offshore area and individual sectors from the southern part of the Sanriku offshore area (near the Japan Trench), to the east, to the Ibaraki offshore area to the south, but it did not conduct an evaluation involving an earthquake in which all of these sectors were synchronized.

Thus, it has been pointed out that a major feature of the Great East Japan Earthquake was the fact that it was an M9.0 megaquake occurring in synchronization in several focal regions in the Japan Trench, something that could not have been forecast from any records in Japan over the last several hundred years.

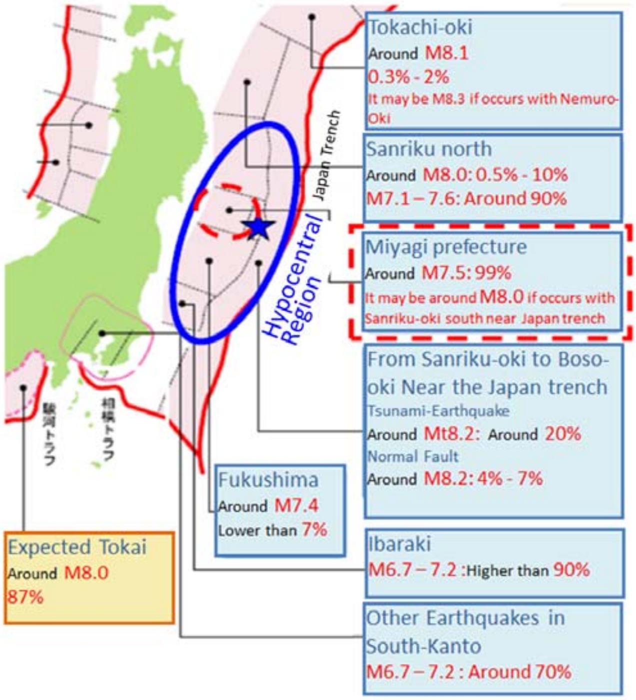


Figure 2.5 Long-term Evaluation of a Major Subduction-zone Earthquake (as of January 11, 2011) by the Headquarters for Earthquake Research Promotion, and the Great East Japan Earthquake[6)]

(2) Tsunami

Due to Great East Japan Earthquake, tsunamis were observed along the Pacific coast of the Tohoku region, as well as in other coastal areas nationwide, causing immense damage. As well as the massive tsunami observed at the Meteorological Agency's tsunami observation facilities in each area, primarily on the Pacific coast of East Japan, such as a wave in excess of 9.3m at Soma in Fukushima Prefecture, and a wave of more than 8.6m in the Ayukawa district of Ishinomaki in Miyagi Prefecture, tsunami measuring at least 1m were observed along the Pacific coast from Hokkaido to Kagoshima Prefecture, as well as in the Ogasawara Islands[1)]. In addition, with regard to the aforementioned tsunami heights, there was a period during which data could not be obtained, as the observation facilities were damaged by the tsunami, so there is a possibility that the waves that followed were even higher.

At 14:49, three minutes after the seismic wave was initially detected, the Meteorological Agency issued tsunami warnings (major tsunami) for the coastal areas of Iwate, Miyagi and Fukushima Prefectures, and tsunami warnings (tsunami) and tsunami advisories for the Pacific coast from Hokkaido to Kyushu, as well as the Ogasawara Islands. Subsequently, a succession of follow-up reports expanding the scope of the tsunami warnings and tsunami advisories were issued, with tsunami warnings and tsunami advisories being issued for the whole of the Japanese coast at 03:20 on March 12 (see Table 2.2). After the alert issued for Kochi Prefecture at 22:53 the same day, the alerts were progressively downgraded to tsunami warnings and tsunami advisories, with all tsunami advisories being lifted at 17:58 on March 13.

Figure 2.6 shows the tsunami heights estimated on the basis of data such as the position of tsunami traces obtained from field surveys conducted by the Meteorological Agency at its tsunami observation facilities and in surrounding areas. In certain locations, tsunami traces in excess of 10m were found. Moreover, Figure 2.7 shows the tsunami inundation heights and runup heights determined through surveys by the 2011 Tohoku Earthquake Tsunami Joint Survey Group (related academic associations, including the Japan Society of Civil Engineers). It has been reported that a tsunami of up to 30m in height struck the coast from Iwate Prefecture to Miyagi Prefecture, causing catastrophic damage.

Figure 2.8 shows examples of tsunami waveforms recorded by the Meteorological Agency[1)]. There are observation points where data was not obtained, due to the massive tsunami, but it is known that there were repeated onslaughts by the tsunami. Table 2.3 shows the observed values for the first wave of the tsunami and the height of the biggest wave recorded at tsunami observation facilities within Japan. The biggest waves hit the coast 30 minutes to an hour after the earthquake struck.

Table 2.4 and Figure 2.9 respectively show the observed values for the first wave of the tsunami and the highest waves recorded using GPS wave meters that were then analyzed by the Port and Airport Research Institute, and the waveform recorded off the coast of Kamaishi (waters 18km offshore from Kamaishi Port, with a depth of 200m)[8)]. Off the coast of Kamaishi, the first wave of the tsunami was the biggest, with records showing that all the waves up to the seventh wave were remarkably high. The largest tsunami height was the 6.7m wave (offshore height) recorded at 15:12; converting the figures to the height at the point where the water was 15m deep, this wave had grown to around 13m by the time it actually reached the coastal area. It was reported that the crest of the first wave was remarkably high, with crest height gradually diminishing between the second and seventh waves; furthermore, the fourth to seventh waves had a different shape from that of the first to third waves, with repeated waves at intervals of around 50 minutes.

The Geospatial Information Authority of Japan interpreted the inundation range of the tsunami using such information as the aerial photographs that it took, and estimated the inundation range and the area flooded in each municipality[9)]. Figure 2.10 shows the tsunami inundation range in the Sendai district. An area stretching more than 4km inland on the Sendai Plain was flooded by the tsunami.

As shown in Table 2.5, the approximate figures for inundation range cover 62 municipalities in the six prefectures of Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba, with the total area flooded estimated to total 561km^2.

Table 2.2 Tsunami Warnings Issued (Pacific Coast of Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba Prefectures)[1)]

Date	Tsunami Warning, etc. (anticipated tsunami height)					
	Aomori Prefecture	Iwate Prefecture	Miyagi Prefecture	Fukushima Prefecture	Ibaraki Prefecture	Chiba Prefecture
March 11, 14:49	Tsunami: 1m	Major tsunami: 3m	Major tsunami: 6m	Major tsunami: 3m	Tsunami: 2m	Tsunami: 2m
15:14	Major tsunami 3m	Major tsunami 6m	Major tsunami At least 10m	Major tsunami 6m	Major tsunami 4m	Major tsunami 3m
15:30	Major tsunami 8m	Major tsunami At least 10m	↑	Major tsunami At least 10m	Major tsunami At least 10m	Major tsunami At least 10m
16:08	Major tsunami At least 10m	↑	↑	↑	↑	↑
March 12, 13:50	↑	↑	↑	↑	Tsunami warning	Tsunami advisory
20:20	Tsunami warning	Tsunami warning	Tsunami warning	Tsunami warning	Tsunami advisory	↑
March 13, 07:30	Tsunami advisory	Tsunami advisory	Tsunami advisory	Tsunami advisory	↑	↑
17:58	Lifted					

Table 2.3 Observed Values for the First Wave of the Tsunami and Size of the Highest Wave Recorded at Tsunami Observation Facilities Within Japan[1)]

(Pacific Coast of Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba Prefectures)

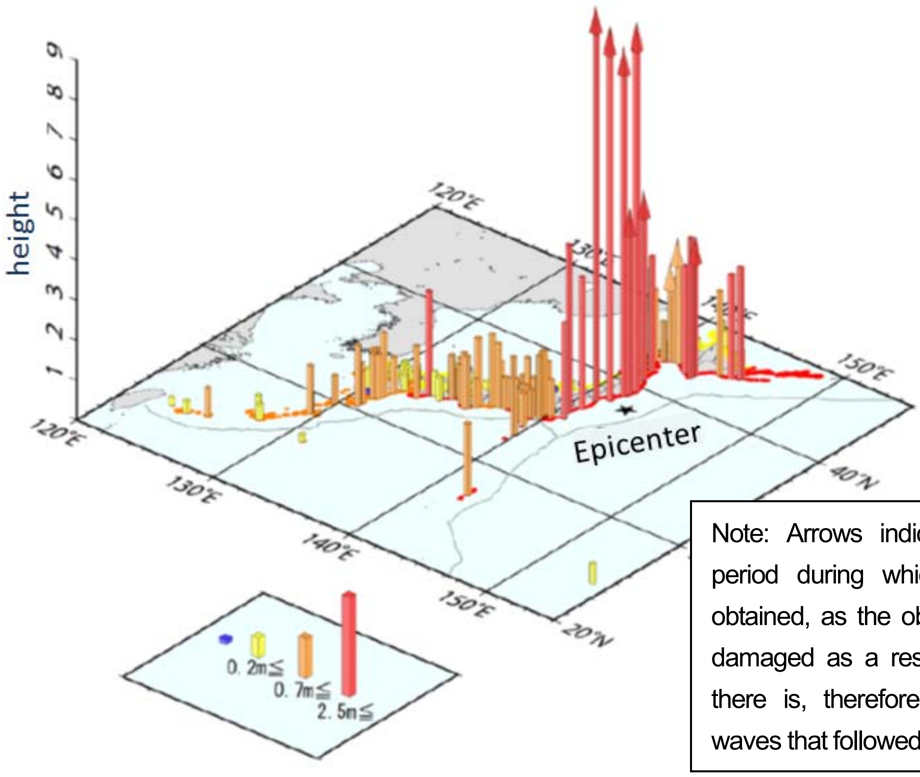
Prefecture	Name of Observation Point	First Wave		Highest Wave	
		Start Time	Height (+: runup; -: drawback)	Time	Height
Aomori Prefecture	Hachinohe	11th 15:21	-0.7m	11th 16:57	At least 4.2m
Iwate Prefecture	Miyako Ofunato Kamaishi	11th 15:01 11th 14:00 11th 14:00	-1.24m -1.0m -1.19m	11th 15:26 11th 15:18 11th 15:21	At least 8.5m At least 8.0m At least 4.2m
Miyagi Prefecture	Ayukawa, Ishinomaki	11th 14:00	—	11th 15:26	At least 8.6m
Fukushima Prefecture	Soma Onahama, Iwaki	11th 14:00 11th 15:08	-1.2m +2.6m	11th 15:51 11th 15:39	At least 9.3m 3.33m
Ibaraki Prefecture	Oarai	11th 15:17	+1.7m	11th 16:52	4.0m
Chiba Prefecture	Choshi	11th 15:13	+2.3m	11th 17:22	2.5m

Note: In some cases, there were periods in which data could not be obtained. Moreover, due to subsidence, there is a possibility that the figures recorded for the first wave are inaccurate.

Table 2.4 Observed Values for the First Wave of the Tsunami and Size of the Highest Wave Recorded Using GPS Wave Meters[1),8)]

Prefectures	Name of Observation Point	Water Depth	First Wave		Highest Wave	
			Start Time	Height (+: positive wave; -: negative wave)	Time	Height
Iwate Prefecture	Off the coast of Kuji	125m	11th 14:56	-0.4m	11th 15:19	Approx. 4.0m
	Off the coast of Miyako	200m	11th 14:48	-0.5m	11th 15:12	Approx. 6.3m
	Off the coast of Kamaishi	204m	11th 14:48	-0.5m	11th 15:12	Approx. 6.7m
	Off the coast of Hirota Bay	160m	11th 14:47	-0.4m	11th 15:14	Approx. 5.7m
Fukushima Prefecture	Off the coast of Onahama	137m	11th 14:49	+1.0m	11th 15:15	Approx. 2.6m
Mie Prefecture	Off the coast of Owase	210m	11th 16:09	+0.5m	11th 16:26	Approx. 0.5m
Wakayama Prefecture	Off the coast of Shirahama	201m	11th 16:23	+0.3m	11th 16:38	Approx. 0.3m

Note: In some cases, there were periods in which data could not be obtained.



Note: Arrows indicate that there was a period during which data could not be obtained, as the observation facilities were damaged as a result of the tsunami, and there is, therefore, a possibility that the waves that followed were even higher.

Figure 2.6 Tsunami Height Recorded at Tsunami Observation Facilities[1)]

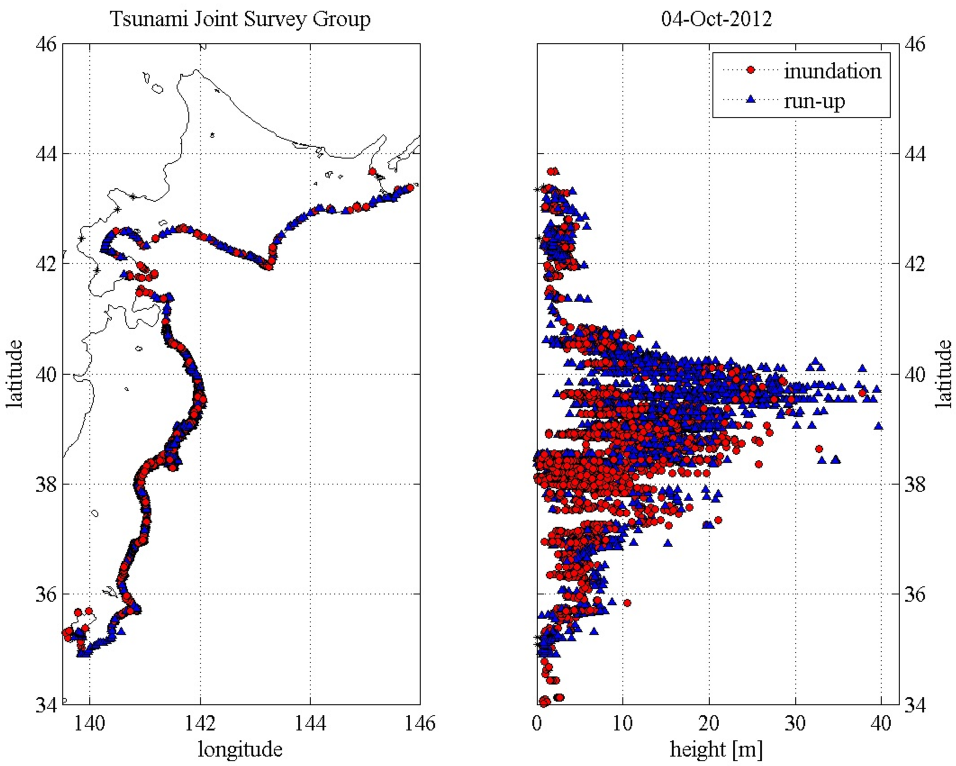


Figure 2.7 Tsunami Inundation Height and Runup Height[7)]

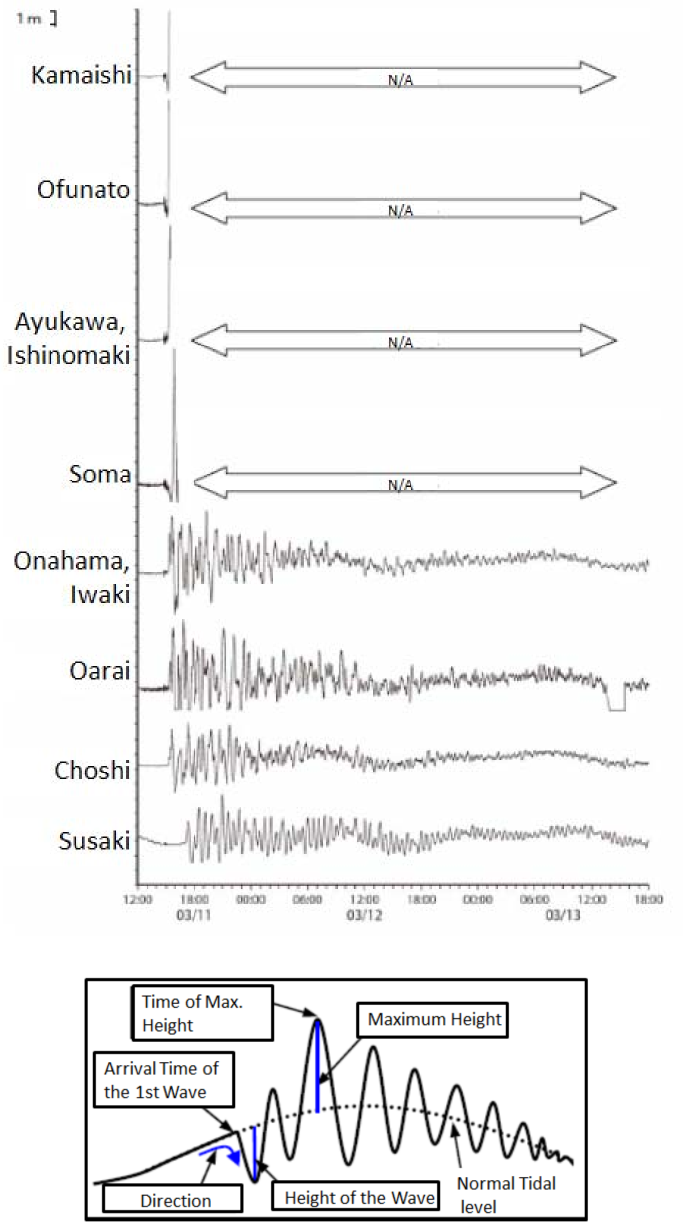


Figure 2.8 Tsunami Waveforms Recorded at Major Tsunami Observation Facilities (2.0m or more)[1)]

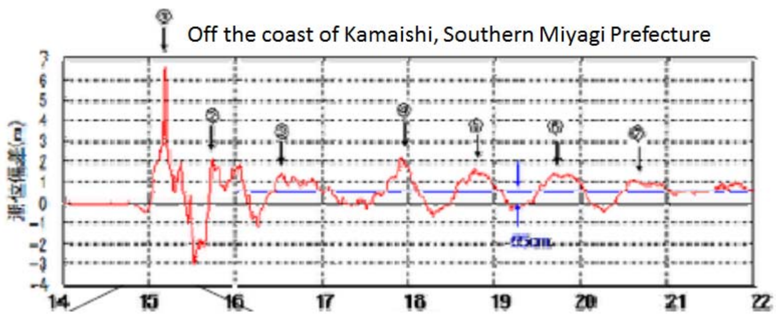


Figure 2.9 Tsunami Waveform Recorded Using a GPS Wave Meter (off the coast of Kamaishi)[8)]

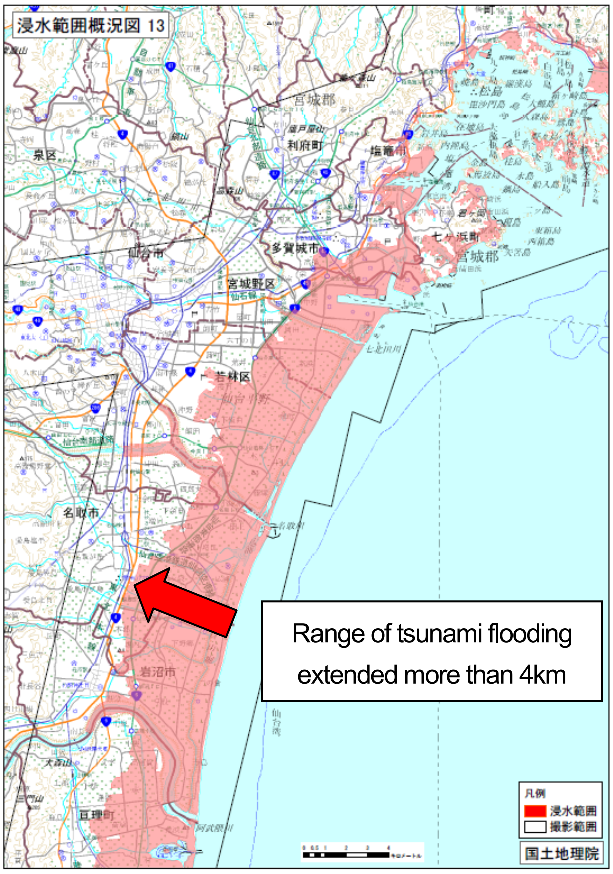


Figure 2.10 Tsunami Inundation Range (calculated by the Geospatial Information Authority of Japan)[9]

Table 2.5 Area Flooded by Prefecture[9]

Prefecture	Inundation Area (km^2)
Aomori Prefecture	24
Iwate Prefecture	58
Miyagi Prefecture	327
Fukushima Prefecture	112
Ibaraki Prefecture	23
Chiba Prefecture	17
Total	561

(3) Ground Subsidence

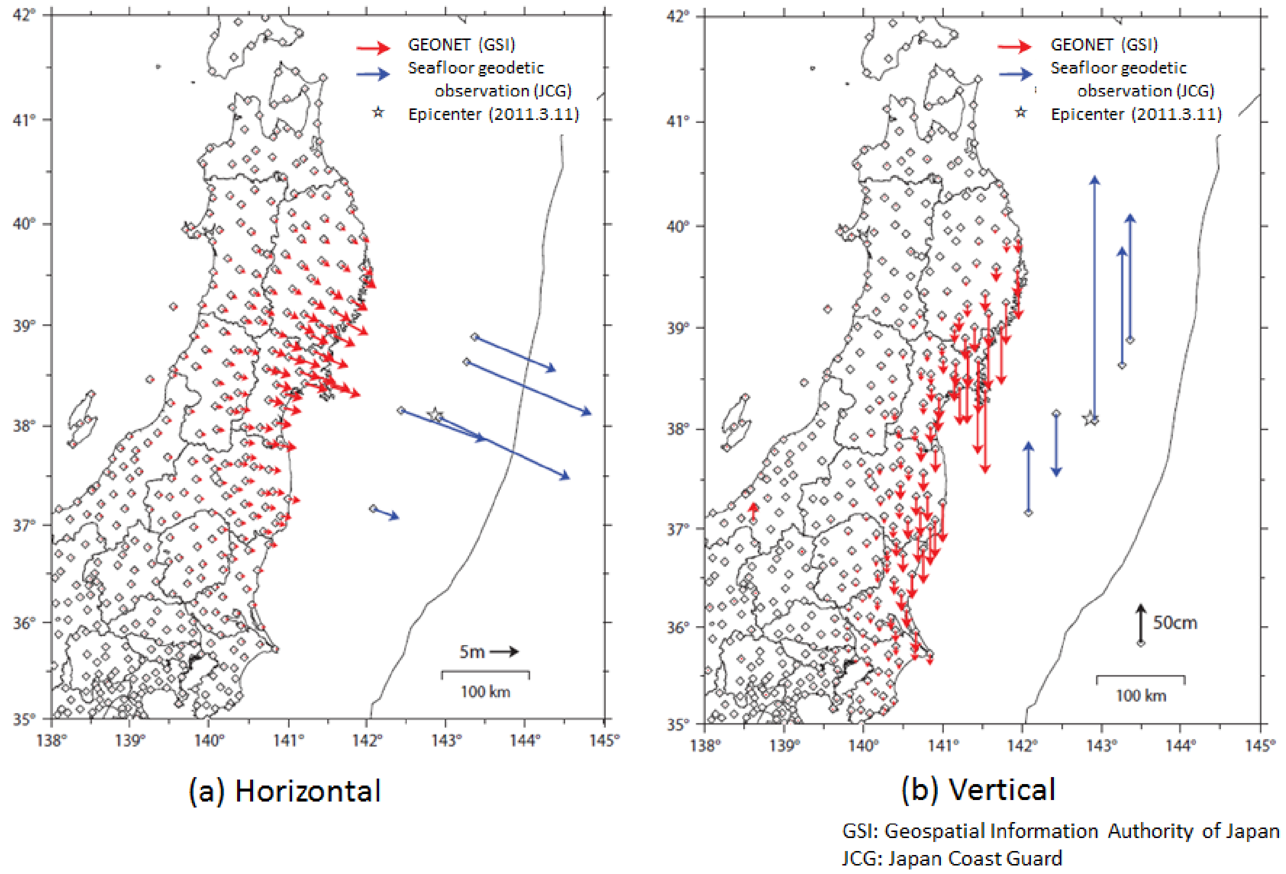
The maps in Figure 2.11 were published by the Geospatial Information Authority of Japan and show diastrophism inland and in marine areas[10]. They show diastrophism identified via the Geospatial Information Authority of Japan's continuous GPS monitoring system (GEONET), in the case of inland areas, and via seafloor geodetic observation carried out by the Hydrographic and Oceanographic Department of the Japan Coast Guard, in the case of marine areas. It was reported that there was displacement on the Pacific side of up to 530cm (Oshika) in a horizontal direction, while in a vertical direction, there was subsidence of up to 120cm (Oshika).

The maps in Figure 2.12 were published by the Ministry of Land, Infrastructure, Transport and Tourism Tohoku Regional Development Bureau and show the situation on the Sendai Plain in relation to subsidence resulting from the earthquake. An overall understanding of the situation in regard to subsidence was gained from data obtained via airborne laser scanning and other techniques. Subsidence was examined in relation to height above sea level and it was reported that $83km^2$ of land had been below the existing highest tidal level before the earthquake, $3km^2$ of which was below mean sea level. In contrast, after the earthquake, the figures were $16km^2$ and $111km^2$ respectively; thus, the area below mean sea level had expanded by about 5.3 times. This subsidence has caused flood damage at high tide.

(4) Liquefaction

Extensive soil liquefaction occurred in the Hokkaido, Tohoku and Kanto regions due to the Great East Japan Earthquake, causing considerable damage to houses, roads, river embankments, port facilities, and lifelines. In coastal areas of the Tohoku region, there were also many areas in which it was not possible to confirm traces of liquefaction precisely, due to the tsunami that followed the earthquake. The map in Figure 2.13 was compiled by the Ministry of Land, Infrastructure, Transport and Tourism Kanto Regional Development Bureau and the Japanese Geotechnical Society, and shows the results of surveys conducted in the Kanto region concerning the status of liquefaction there. Liquefaction was found to have occurred over an extensive area, covering the seven prefectures in the Kanto region, namely Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, and Kanagawa. The northernmost point was in Otawara in Tochigi Prefecture, the westernmost point was Kumagaya in Saitama Prefecture, the southernmost point was Minamiboso in Chiba Prefecture, and the easternmost point was Choshi, also in Chiba Prefecture. Liquefaction was seen to be concentrated along the lower reaches of the Tone River and the coast of Tokyo Bay from Tokyo to Chiba, with other patches of liquefaction spread across areas including the Kawasaki and Yokohama area, the Naka River and Kuji River areas, the middle reaches of the Tone River, the Kinu and Kokai River basin, and the old Tone River basin.

Reports of liquefaction by prefecture and by municipality were as shown in Table 2.6. Liquefaction was confirmed to have occurred in at least 96 municipalities throughout the Kanto region; looking at the situation by prefecture, the largest number of municipalities affected was in Ibaraki Prefecture, close to the hypocenter, where 36 cities, towns, and villages were affected, followed by Chiba Prefecture, where 25 were affected.



(a) Horizontal (b) Vertical

Figure 2.11 Diastrophism Inland and in Marine Areas Due to the Great East Japan Earthquake (compiled by the Geospatial Information Authority of Japan)[10]

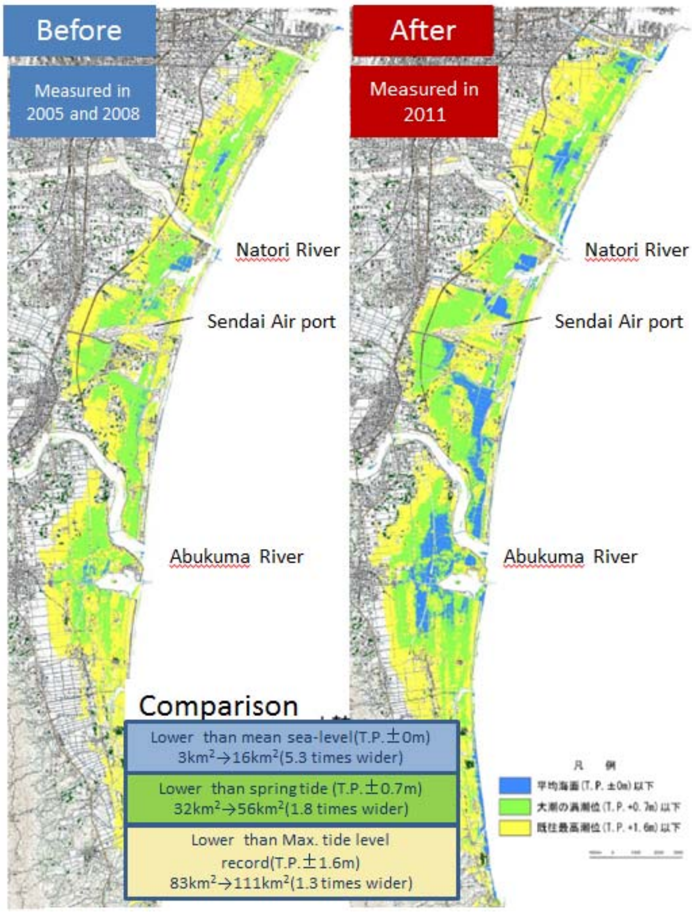


Figure 2.12 Subsidence on the Sendai Plain Resulting from the Earthquake[11)]

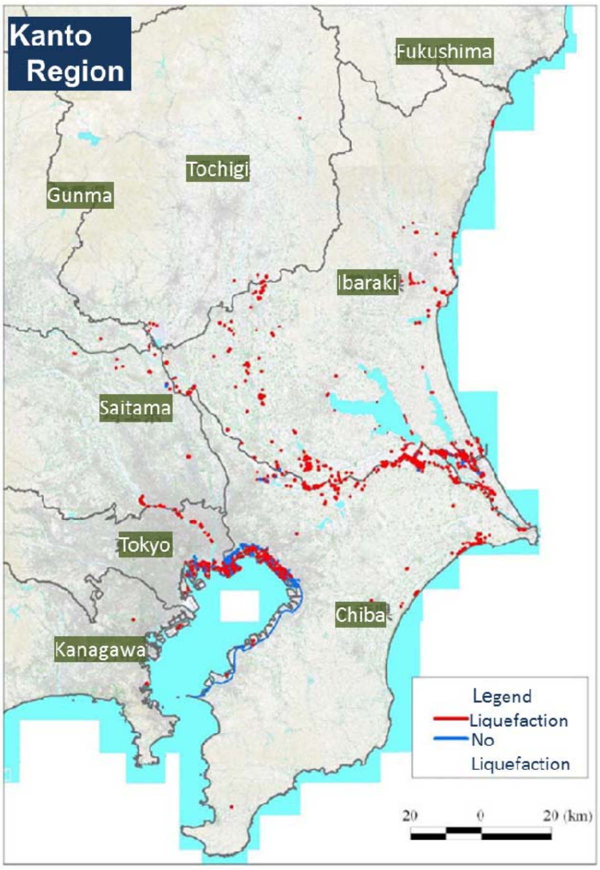


Figure 2.13 Distribution of Areas of Liquefaction in the Kanto Region[12)]

Table 2.6 Municipalities with Areas of Liquefaction[12)]

Prefecture	Municipality	Number of Municipalities Suffering Liquefaction
Ibaraki Prefecture	Mito, Hitachi, Tsuchiura, Koga, Ishioka, Yuki, Ryugasaki, Shimotsuma, Joso, Hitachiota, Kitaibaraki, Toride, Tsukuba, Hitachinaka, Kashima, Itako, Moriya, Naka, Chikusei, Bando, Inashiki, Kasumigaura, Kamisu, Namegata, Hokota, Tsukubamirai, Ibaraki Town, Oarai, Tokai, Miho, Ami, Kawachi, Yachiyo, Goka, Sakai, Tone	36
Tochigi Prefecture	Tochigi City, Mooka, Otawara	3
Gunma Prefecture	Tatebayashi, Itakura, Ora	3
Saitama Prefecture	Saitama City, Kumagaya, Kawaguchi, Gyoda, Kazo, Kasugabe, Hanyu, Koshigaya, Toda, Hatogaya, Wako, Kuki, Yashio, Satte, Yoshikawa, Miyashiro	16
Chiba Prefecture	Chiba City, Choshi, Ichikawa, Funabashi, Kisarazu, Matsudo, Noda, Narita, Togane, Asahi, Narashino, Kashiwa, Yachiyo, Abiko, Urayasu, Sodegaura, Inzai, Minamiboso, Sosa, Katori, Sanmu, Sakae, Kozaki, Tonosho, Kujukuri	25
Tokyo Prefecture	Chuo, Minato, Sumida, Koto, Shinagawa, Ota, Kita, Itabashi, Adachi, Katsushika, Edogawa	11
Kanagawa Prefecture	Yokohama, Kawasaki	2
Total		96

(5) Overview of Damage

The following provides an overview of the damage resulting from the Great East Japan Earthquake.

1) Human Casualties and Damage to Homes

Based on figures published by the National Police Agency, the total casualties and damage as of January 16, 2013 are as follows[13]. Table 2.7 summarizes the human casualties and damage to buildings by prefecture.

① Human casualties

15,879 deaths, 2,700 missing, 6,132 injured

② Damage to buildings

128,911 completely destroyed, 268,882 partially destroyed, 733,719 with significant partial damage

19,790 flooded above floor level, 15,630 flooded below floor level

③ Fires (completely/partially burnt)

279

Table 2.7 Figures for Human Casualties and Damage to Buildings by Prefecture[13)]

(Figures published by the Emergency Disaster Countermeasures Headquarters, current as of January 16, 2013)

Prefecture Name	Human Casualties			Damage to Buildings (Damage to Homes)					
	Deaths	Missing	Injuries	Completely destroyed	Partially destroyed	Significant partial damage	Flooded above floor level	Flooded below floor level	Fires (completely/ partially burnt)
Hokkaido	1		3		4	7	329	545	
Aomori Prefecture	3	1	111	308	701	1,006			
Iwate Prefecture	4,673	1,171	208	18,370	6,501	13,000	1,761	323	15
Miyagi Prefecture	9,534	1,314	4,144	85,414	152,523	224,162	14,678	12,894	135
Akita Prefecture			11			3			
Yamagata Prefecture	2		29			21			
Fukushima Prefecture	1,606	211	182	21,096	72,390	163,007	1,061	338	80
Tokyo Prefecture	7		117	15	198	4,847			1
Ibaraki Prefecture	24	1	711	2,623	24,178	183,617	1,798	779	31
Tochigi Prefecture	4		135	261	2,109	72,400			
Gunma Prefecture	1		39		7	17,246			
Saitama Prefecture			45	24	199	1,800		1	2
Chiba Prefecture	20	2	252	800	10,033	52,124	157	728	15
Kanagawa Prefecture	4		134		39	445			
Niigata Prefecture			3			17			

Yamanashi Prefecture			2			4			
Nagano Prefecture			1						
Shizuoka Prefecture			3			13		5	
Mie Prefecture			1				2		
Tokushima Prefecture							2	9	
Kochi Prefecture			1				2	8	
Total	15,879	2,700	6,132	128,911	268,882	733,719	19,790	15,630	279

Note: The total figures as of September 28, 2012 for casualties and damage compiled by the Fire and Disaster Management Agency on the basis of reports by prefectures are as follows[14)].

(i) Human casualties: 18,131 deaths, 2,829 missing, 6,194 injured

(ii) Damage to buildings (damage to homes): 129,391 completely destroyed, 265,096 partially destroyed, 743,298 with significant partial damage, 20,580 flooded above floor level, 15,629 flooded below floor level

(iii) Fires: 330

2) Amount of Debris

The amount of debris from houses and other structures toppled by the tsunami has been estimated by the Ministry of the Environment[15)]. As shown in Table 2.8, the total amount for the three prefectures of Iwate, Miyagi, and Fukushima is estimated at 27.58 million tons (disaster waste: 18.02 million tons; tsunami deposits: 9.56 million tons) (as of August 2012). According to this, disposal of 4.42 million tons (about 25%) of the 18.02 million tons of disaster waste had been completed by the three disaster-stricken coastal municipalities as of the end of July 2012.

Table 2.8 Disposal Status of Disaster Waste, etc. in the Three Coastal Prefectures

	Estimated Amount of Disaster Waste, etc. (10,000t)	Disaster Waste				Tsunami Deposits			
		Estimated Amount (10,000t)	Amount (10,000t)	Proportion (%)	Interim Target (%)	Estimated Amount (10,000t)	Quantity (10,000t)	Proportion (%)	Interim Target (%)
Iwate Prefecture	525	395	81	21	58	130	0.3	0	50
Miyagi Prefecture	1,873	1,200	331	28	59	672	74	11	40
Fukushima Prefecture	361	207	30	15	-	153	1.6	1	-
Total	2,758	1,802	442	25	-	956	76	8	-

3) Estimated Cost of Damage

The cost of the damage to stock (buildings, lifeline facilities, social infrastructure facilities, etc.) in disaster-afflicted areas has been estimated by the Cabinet Office (disaster management section)[16)]. Table 2.9 shows the estimated cost of damage to each type of facility, with the total estimated at approximately 16.9 trillion yen. This is around 1.8 times more than the cost of damage resulting from the 1995 Great Hanshin Awaji Earthquake.

Moreover, the cost of damage to stock has also been estimated by the Cabinet Office (section in charge of economic research); two cases were assumed for the building damage rate, but the focus differs between prefectures, so a simple comparison is not possible, but the approximate total cost of damage to stock is estimated to be in the range of 16-25 trillion yen.

Table 2.9 Estimated Cost of Damage[16)]

<table>
<tr><th>Category</th><th>Cost of Damage</th><th>Reference: Great Hanshin Awaji Earthquake</th></tr>
<tr><td>Buildings, etc.
(houses, residential land, shops, offices, factories, machinery, etc.)</td><td>Approx. 10.4 trillion yen</td><td>Approx. 6.3 trillion yen</td></tr>
<tr><td>Lifeline facilities
(water supply, gas, electricity, and communications & broadcasting facilities)</td><td>Approx. 1.3 trillion yen</td><td>Approx. 0.6 trillion yen</td></tr>
<tr><td>Social infrastructure facilities
(rivers, roads, ports, sewerage systems, airports, etc.)</td><td>Approx. 2.2 trillion yen</td><td>Approx. 2.2 trillion yen</td></tr>
<tr><td>Agriculture, forestry & fisheries infrastructure
(agricultural land & facilities, forest land, fisheries facilities, etc.)</td><td>Approx. 1.9 trillion yen</td><td rowspan="2">Approx. 0.5 trillion yen</td></tr>
<tr><td>Other (education & cultural facilities, health preservation, medical care & welfare facilities, waste disposal facilities, other public facilities, etc.)</td><td>Approx. 1.1 trillion yen</td></tr>
<tr><td>Total</td><td>Approx. 16.9 trillion yen</td><td>Approx. 9.6 trillion yen</td></tr>
</table>

(Note) These figures have been compiled by the Cabinet Office (section in charge of disaster prevention) based on information provided by each prefecture and relevant government ministries and agencies concerning the cost of damage to stock (buildings, lifeline facilities, social infrastructure facilities, etc.) These figures may change in future, as the details of the damage emerge. Moreover, totals may not add up, due to rounding. Please note that these figures do not include the cost of damage associated with the nuclear power plant accident. Figures for the cost of damage resulting from the Great Hanshin Awaji Earthquake were compiled by the National Land Agency (according to estimates by Hyogo Prefecture, the total cost of damage from the earthquake was approximately 9.9 trillion yen[18)].)

4) General Overview of Damage to Facilities Within the Jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism

As the Great East Japan Earthquake was a complex disaster in which the damage was extremely extensive, due to a massive tsunami caused by a megaquake, subsidence and liquefaction, and damage caused by landslides and fires, which was compounded by the effects of an accident at a nuclear power plant, it is exceedingly difficult to gain a precise grasp of the damage. Information about damage to facilities in individual fields is provided in the subsequent chapters on each field, so this section features quotes from the FY2010 White Paper on Land, Infrastructure, Transport and Tourism in Japan, providing a general overview of damage to facilities within the jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism and the resultant impact. In addition, some figures, such as those for human casualties, have been replaced with updated figures.

Table 2.10 General Overview and Impact of Damage to Facilities Within the Jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism Resulting from the Great East Japan Earthquake (as of August 2011)[18)]

(1) Damage in Urban Areas and Human Casualties

Damage	Damage Situation, Damage-related Statistics, Impact
Damage in urban areas	・Of the total of approximately 535km^2 of land flooded in 62 municipalities in the six prefectures of Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba, approximately 119km^2 was accounted for by flooding in urban areas. ・The area of land in which most buildings were completely destroyed (including those washed away) totaled approximately 99km^2, while the area in which the majority of buildings were mostly or partially destroyed was approximately 58km^2 in total (this is a more extensive area than the approximately 35km^2 destroyed by fire as a result of the Great Kanto Earthquake). ・In Noda and Rikuzentakata in Iwate Prefecture, Minamisanriku and Higashimatsushima in Miyagi Prefecture, and Shinchi in Fukushima Prefecture, at least 80% of the urban area was damaged due to flooding.
Human casualties (including evacuees)	・15,879 deaths across 12 prefectures (see Table 2.7) (far in excess of the death toll from the Great Hanshin Awaji Earthquake, this figure constitutes the largest number of fatalities since the end of the war). ・More than 99% of the deceased and missing persons were concentrated in municipalities on the Pacific coast of the three prefectures of Iwate, Miyagi, and Fukushima. ・Of the dead, 54% were elderly people aged 65 or above (people requiring assistance to evacuate in the event of disaster). ・There were many evacuees across a wide area, due to the combined effect of the earthquake, tsunami, and nuclear power plant accident: evacuees peaked at 468,000 on the third day after the disaster (March 14) (approximately 1.5 times the peak following the Great Hanshin Awaji Earthquake). Evacuees have dispersed outside their home municipalities and further afield outside their home prefectures, and there are currently evacuees residing in each of the 47 prefectures of Japan.

(2) Damage to Housing and Infrastructure (I)

Damage	Damage Situation, Damage-related Statistics, Impact
Damage to housing and other buildings	・128,911 completely destroyed, 268,882 partially destroyed, 733,719 with significant partial damage (see Table 2.7). ・57,928 non-residential buildings were damaged, with public facilities such as local government buildings, schools, and hospitals suffering major damage. ・As well as buildings that were washed away by the tsunami or collapsed as a result of the seismic motion, buildings containing large spaces, such as gymnasiums and airports, suffered roof collapses. ・In order to prevent secondary disasters due to aftershocks, 95,381 emergency risk assessments of disaster-stricken buildings were carried out in 149 municipalities in ten prefectures (buildings deemed to be "dangerous" to enter because of the risk of collapse due to aftershocks: 11,699; buildings deemed to "require caution": 23,191).
Damage to residential land	・Due to the main quake and the frequent aftershocks, damage occurred as a result of landslides and the collapse of large tracts of land reclaimed by means of mounding. ・6,531 risk assessment surveys of disaster-stricken residential land were carried out in 56 municipalities in nine prefectures (sites deemed to be "dangerous" because of the risk of the collapse of retaining walls: 1,456; sites deemed to "require caution": 2,209). ・Liquefaction occurred over an extensive area in the Tohoku and Kanto regions, including along the coast of Tokyo Bay. Many cases of damage occurred as a result, such as the ground becoming softer, leading to

	houses being left tilted at an angle.
Damage to coasts	・Diastrophism caused extensive subsidence of the ground, including along the coast of the Sendai Plain and on other level ground. ・As well as an increase in the area of land below mean sea level, the destruction of seawalls and erosion of sand dunes along the coast led to reduced safety in regard to events such as high tides. ・With regard to the coastline in the three prefectures of Iwate, Miyagi, and Fukushima (where levee revetments run for approximately 300km along the coast), approximately 190km of embankments were completely or partially destroyed.
Damage to rivers	・Damage (including the breach or collapse of embankments) occurred at 2,115 points along rivers under the direct control of the Ministry (Kitakami River, Tone River, etc.), and at 1,360 points along rivers under the control of prefectures and municipalities. ・In terms of the mechanisms of damage, as well as deformation due to liquefaction of the foundation subgrade of the levee body, cases were also found in which deformation was presumed to have occurred due to partial liquefaction of the levee body itself.
Damage from landslides	・136 landslides occurred in 12 prefectures, including Iwate, Miyagi, and Fukushima (19 deaths). In addition, many hillside collapses were found to have occurred.

(2) Damage to Housing and Infrastructure (II)

Damage	Damage Situation, Damage-related Statistics, Impact
Transport infrastructure: damage to roads	・As a result of slope failures and road bridges being washed away, 15 expressways, 69 sections of national highways under the direct control of the Ministry, 102 sections of national highways under the control of prefectures, etc., and 540 sections of prefectural roads, etc. were closed to traffic. ・In particular, many sections of roads along the whole of the Pacific coast, primarily in the Tohoku region, became impassable due to damage resulting from the tsunami, including National Route 45, which runs along the Sanriku Coast from the city of Sendai in Miyagi Prefecture.
Transport infrastructure: damage to railways	・As well as damage to the Tohoku, Akita, and Yamagata Shinkansen high-speed train lines, lines running along the Pacific coast in particular suffered damage, with station buildings and railway tracks being washed away; as of 15:00 on March 13, 48 hours after the disaster struck, services remained suspended on 64 lines operated by 22 companies.
Transport infrastructure: damage to ports	・There was immense damage to port facilities including breakwaters, berthing facilities, and cargo handling equipment at all ports on the Pacific coast from Hachinohe in Aomori Prefecture to Ibaraki Prefecture, including 11 international hub ports and other major ports. ・Sea lanes and harbor facilities such as berths became clogged up with earth and sand, or containers, motor vehicles or debris that were washed into the harbor area by the tsunami. ・156 navigation aids such as beacons, which ensure the safe passage of marine vessels, sustained damage, including some that collapsed and others that were washed away.
Transport infrastructure: damage to airports	・Four airports (Sendai, Hanamaki, Fukushima, and Ibaraki) were affected by the disaster. ・Sendai Airport was flooded by the massive tsunami, with more than 2,000 vehicles being washed up onto the runway, taxiway, and apron; in addition, earth, sand, and debris were left strewn across a wide area and it suffered immense damage, due to power generators and other electrical equipment and machinery installed in the control tower and passenger terminal being submerged.

	・Approximately 1,400 travelers, local citizens who had evacuated there, and staff members were temporarily stranded there, and it took about two days to complete the evacuation and rescue process. ・The Sendai Airport Access Railway, which is the main means of access to Sendai Airport, suffered damage including the flooding of the airport tunnel and the submersion of traffic control equipment.
Transport infrastructure: damage to bus transport operations	・Businesses in the disaster-afflicted areas of Iwate, Miyagi, and Fukushima had a total of 219 vehicles destroyed or washed away; in addition, their staff members and company premises were also affected by the disaster. ・Many transit bus services and highway express bus services were suspended. With particular regard to transit buses, as of April 28, a month and a half after the disaster, services on 26% of routes in the coastal areas of both Iwate and Fukushima Prefectures, and on 19% of routes in the coastal areas of Miyagi Prefecture remained suspended. ・Due to fuel shortages in the immediate aftermath of the disaster, the number of services operated by bus companies in districts outside the disaster-afflicted areas were also reduced.
Damage to infrastructure for daily life: sewerage system	・Sewage treatment plants in a total of 48 locations over an extensive area, mainly on the Pacific coast of the Tohoku region, halted operations due to tsunami inundation; in addition, sewage treatment plants in 63 locations suffered damage to facilities. ・It is not possible to ascertain the status of damage at nine sewage treatment plants located in the vicinity of the TEPCO Fukushima Daiichi Nuclear Power Plant. ・Damage to sewage pipes occurred across 11 prefectures, covering a range of 550km (far in excess of the damage resulting from the Great Hanshin Awaji Earthquake, which covered a range of 162km over two prefectures).
Damage to urban parks	・The tsunami caused damage including the loss of many coastal forest areas that had been developed and maintained as urban parks.

(3) Impact on the Tokyo Metropolitan Area

Damage	Damage Situation, Damage-related Statistics, Impact
People experiencing difficulty returning home	・As the earthquake occurred in the afternoon on a weekday, there were many people who experienced difficulty in returning home, particularly from central Tokyo, because public transport services were halted so that checks and repair work could be carried out, such as the inspections and repairs required over an extensive area on all of the railway lines in the Tokyo metropolitan area.
Elevators with people trapped inside	・People were trapped inside at least 210 elevators in Tokyo and 14 other prefectures outside the Tohoku region (all were rescued by midday on March 12, the day after the disaster).
Power supply shortages	・Within the area served by Tokyo Electric Power Company, in order to avoid large-scale power cuts due to shortages in power supply, planned blackouts to curb demand were carried out in each area on a rotating basis from March 14, with the plan announced in advance; in addition, widespread calls were made for the conservation of electricity. Services were suspended and the number of services operated reduced considerably on the majority of railways in the Tokyo metropolitan area, which had a major impact on all aspects of economic and social activities, including on people's ability to get to work or school.

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2.2 Response by the National Government

(1) Initial Response by the Government

As well as establishing the Response Office at the Prime Minister's Office at 14:50 on March 11, immediately after the earthquake struck, the government convened the Emergency Response Team (the participants from MLIT were the Director-General of the River Bureau (as it was at the time), the Vice Commandant for Operations of the Japan Coast Guard, and the Deputy Director-General of the Japan Meteorological Agency).

At 15:14, as provided for in the Basic Act on Disaster Control Measures (Act No.223 of 1961), an Emergency Disaster Response Headquarters headed by the Prime Minister was established for the first time since the Act entered into force.

At 15:37, the first meeting of the Emergency Disaster Response Headquarters was held and the basic policy on emergency disaster control measures was determined.

At 06:00 on March 12, based on a Cabinet decision, the Local Headquarters for Extreme Disaster Management (Director: Senior Vice-Minister of the Cabinet Office) was established in Miyagi Prefecture. Moreover, governmental investigation teams were dispatched the same day to Iwate Prefecture and Fukushima Prefecture, and Government Local Liaison Disaster Response Offices were established in each prefectural office.

At the 12th meeting of the Emergency Disaster Response Headquarters, which was held on March 17, it was decided to establish the Headquarters for Special Measures to Assist the Lives of Disaster Victims under the auspices of the Emergency Disaster Response Headquarters, in light of the fact that providing livelihood support for those affected by the disaster would become a pressing issue in due course. By September 11, a total of 19 meetings of the Emergency Disaster Response Headquarters had been held.

(2) Reconstruction Design Council in Response to the Great East Japan Earthquake

The first meeting of the Reconstruction Design Council in response to the Great East Japan Earthquake was held on April 14, chaired by Makoto Iokibe (President of the National Defense Academy / Professor Emeritus, Kobe University) and with the participation of experts in relevant fields. The Council was established in accordance with a Cabinet decision taken on April 11, with the objective of conducting wide-ranging discussions concerning a vision for reconstruction, in order to formulate guidelines on reconstruction, In addition, to ensure that the outcomes of discussions by the Reconstruction Design Council would be reflected in guidelines on reconstruction and other areas of policy, a report entitled *Towards Reconstruction* was compiled at the 12th meeting of the Council on June 25. From then until November 10, the Council met 13 times, with meetings mainly focused on ascertaining the status of recovery efforts and initiatives aimed at reconstruction.

(3) Reconstruction Headquarters in Response to the Great East Japan Earthquake

The Reconstruction Headquarters in response to the Great East Japan Earthquake, chaired by Prime Minister Naoto Kan and composed of government ministers, was established on June 28, in accordance with the Basic Act on Reconstruction in response to the Great East Japan Earthquake (Act No.76 of 2011); the Headquarters and its three local response headquarters formed a team comprising 131 people. The Headquarters took the lead in endeavors to translate into reality the recommendations made by the Reconstruction Design Council in response to the Great East Japan Earthquake in *Towards Reconstruction*.

The basic policy on initiatives for reconstruction by the government in the aftermath of the Great East Japan Earthquake (which clarifies the overall approaches to government initiatives for reconstruction, in order to assist disaster-stricken local authorities in the compilation of their own reconstruction plans) was compiled on August 11, with plans and work schedules being published for each project.

Moreover, assistance was provided to local authorities in compiling their reconstruction plans, and legislation was introduced concerning such matters as special zones for reconstruction.

(4) Reconstruction Agency

Following the December 7 enactment of the Act on Special Zone for Reconstruction after the Great East Japan Earthquake (entered into force December 26) and the enactment of the Act on the Establishment of the Reconstruction Agency on December 9, the Reconstruction Agency was established on February 10, 2012. The systems in place hitherto, which had been focused on the Reconstruction Headquarters in response to the Great East Japan Earthquake and the three local response headquarters, were transferred to this Agency, which had been established as an organization to take decisive action in implementing reconstruction projects without being swayed by existing precedents, while maintaining close links to the disaster-afflicted areas, in order to accomplish reconstruction at the earliest possible juncture. It was decided that the Agency would be at the heart of the system for promoting the smooth, swift execution of administrative work related to reconstruction in the aftermath of the Great East Japan Earthquake, including the implementation of reconstruction measures using the Third Supplementary Budget of FY2011 and other funds.

The Reconstruction Agency implements the following administrative tasks focused on general coordination to assist the Cabinet and administrative work in relation to the implementation of individual projects.

(i) Planning and coordination of government measures relating to reconstruction

・Formulation of plans such as basic policies; general coordination and recommendations concerning each ministry's reconstruction measures

・Management and supervision of reconstruction projects; integrated submission of reconstruction budget requests; allocation of budget funds to each ministry and agency, formulation of plans concerning project implementation, etc.

(ii) Providing support and a single point of contact for local government bodies

Advice concerning the formulation of reconstruction plans by local authorities affected by the disaster; accreditation of special zones for reconstruction; allocation of reconstruction subsidies and special funds for coordinating reconstruction; implementation of national government projects, and coordination and promotion of support for prefectural and municipal government projects, etc.

Related legislation:
http://www.reconstruction.go.jp/topics/120312relevant%20legislation%23.pdf

2.3 Responses by the Ministry of Land, Infrastructure, Transport and Tourism

(1) General Actions

At 14:46, immediately after the earthquake struck, MLIT established a Major Disaster Management Headquarters; in addition, the first meeting of the Emergency Disaster Response Headquarters was held at 15:45 on March 11, and Akihiro Ohata, who was Minister of MLIT at that time, announced the following clear objectives: "First, save lives. Then secure transport routes. Do everything you can think of." In addition, meetings of the Emergency Disaster Response Headquarters were held daily until April 1, and weekly thereafter until May 30, with the 49th and final meeting taking place on August 11. Linked to the Tohoku Regional Development Bureau and the Tohoku District Transport Bureau via videoconferencing, the Ministry implemented various responses while receiving reports on the latest information from the scene.

Moreover, Parliamentary Vice-Minister Ichimura was dispatched to Miyagi Prefecture as part of the governmental investigation team at 18:42 on the day of the disaster, along with staff members from the Ministry headquarters, the Japan Meteorological Agency, the Japan Coast Guard, and the Geospatial Information Authority of Japan. This governmental investigation team was renamed the Local Headquarters for Extreme Disaster Management at 06:00 on March 12 and remained in the area to conduct further activities. Governmental investigation teams were dispatched to Iwate Prefecture at 08:52 on March 12 and to Fukushima Prefecture at 09:18 the same day, with Parliamentary Vice-Minister Tsugawa and a number of Ministry staff among the members. These governmental investigation teams conducted activities as Government Local Liaison Disaster Response Offices in both prefectures.

At the same time, at the Tohoku Regional Development Bureau, a decision was taken on March 11 to adopt a policy of opening up multiple rescue routes to the Pacific coast, a strategy which the Ministry dubbed "Operation Toothcomb", as the routes formed a pattern similar to the teeth of a comb.

On March 12, working in partnership with prefectural governments and the Self-Defense Forces, the Tohoku Regional Development Bureau swiftly moved into the implementation phase, aimed at opening up a toothcomb-shaped array of rescue routes to facilitate access from the Tohoku Expressway and National Route 4 to the Sanriku district, which had suffered immense damage due to the tsunami. The same day, after completing Step 1, which was to secure a passage along the Tohoku Expressway and National Route 4 (albeit with some detours), the Bureau moved on to Step 2, focused on opening up 11 access routes from the Tohoku Expressway and National Route 4 to major cities on the Pacific coast, a task that had been completed by March 15.

By March 18 (a week after the disaster), work was underway on Step 3, which involved clearing roads running north to south along the Pacific coast, such as National Route 45, and apart from the sector where work was suspended due to the nuclear power plant accident, 97% of roads were passable, as planned.

Members of NILIM also participated in Operation Toothcomb from the day after the disaster, providing full-scale cooperation and technical guidance concerning such matters as judgments about whether or not bridges and other structures could be used. Operation Toothcomb was able to be completed in the space of a week, thanks to the following: (i) the fact that it had been possible to prevent fatal damage such as bridge collapses, because seismic retrofit measures had already been implemented for 490 bridges within the jurisdiction of the Tohoku Regional Development Bureau, in light of the road damage that resulted from the Great Hanshin Awaji Earthquake; (ii) the fact that the intensive checks and surveys was carried out and the elimination of road obstacles was prioritized by clarifying the 16 routes (one was abandoned due to the nuclear power plant accident), representing the teeth of the comb, which were the routes from inland areas to the disaster-afflicted areas that needed to be cleared in the immediate aftermath of the disaster; and (iii) the fact that disaster agreements had been concluded with the construction industry in advance, so it was possible to gain the cooperation of the local construction industry in clearing obstacles from National Routes 6 and 45 in coastal areas (52 teams from local construction companies and companies from inland areas), as well as the fact that collaboration with the Self-Defense Forces facilitated the prompt installation of prefabricated bridges to replace those that had collapsed along National Route 45.

From April 16-17, the Minister of MLIT visited the disaster-afflicted area for the first time and met with the three prefectural governors, and the mayors of Miyako, Rikuzentakata, Kesennuma, and Ishinomaki cities; in addition, he was briefed on the damage and inspected some of the disaster-stricken areas. He subsequently visited the disaster-afflicted areas on ten occasions and promoted measures focused on repairing the damage, taking into account the actual situation on the ground there.

In light of the government's establishment of the Reconstruction Headquarters following the enactment of the Basic Act on Reconstruction in response to the Great East Japan Earthquake, MLIT established the MLIT Reconstruction Headquarters in response to the Great East Japan Earthquake, headed by the Minister of MLIT, on June 24, with the aim of facilitating the swift, smooth promotion of relevant measures. A summary of the meetings of this body is provided below[1)].

Table 2.3.1 Meetings of MLIT Reconstruction Headquarters in Response to the Great East Japan Earthquake

Date and Time	Meeting Number	Content of Meeting
June 28 15:20-	1st Meeting	Matters concerning reconstruction from the Great East Japan Earthquake
July 27 14:00-	2nd Meeting	Measures in which the Ministry is involved, related to the Basic Policy on Reconstruction from the Great East Japan Earthquake (draft)
August 25 3:15 PM-	3rd Meeting	Matters concerning the status of Ministry initiatives relating to reconstruction measures in the aftermath of the Great East Japan Earthquake
September 12 3:30 PM-	4th Meeting	The current status of repair work, and initiatives to deal with major issues
November 28 3:45 PM-	5th Meeting	Matters concerning the status of Ministry initiatives relating to reconstruction measures in the aftermath of the Great East Japan Earthquake
2012 March 8	6th Meeting	Matters concerning responses to the Great East Japan Earthquake and future initiatives in light of this disaster

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(2) Dispatch of the Technical Emergency Control Force (TEC-FORCE)

In response to the Great East Japan Earthquake, TEC-FORCE* members were immediately dispatched to the jurisdiction of the Tohoku Regional Development Bureau from Regional Development Bureaus across the country, starting on March 11, the day of the disaster; by the third day after the disaster, the number of TEC-FORCE members assembled in the Tohoku region was in excess of 500 (the total number of dispatched personnel reached the equivalent of 18,115 man-days by January 31, 2012). The dispatched TEC-FORCE provided support in promptly restoring the functions of local authorities affected by the disaster, by such means as conducting damage surveys.

In addition, the TEC-FORCE General Headquarters was established in the Tohoku Regional Development Bureau and efforts were made to integrate the chain of command, in order to facilitate swift coordination of the TEC-FORCE members mobilizing from across the country and the dispatch of the various types of machinery required for disaster countermeasures.

Disaster response helicopters belonging to each Regional Development Bureau and civilian helicopters arranged by the Hokkaido Development Bureau were used for damage surveys across an extensive area, ranging from the coast of Hokkaido to the Kanto region; part of the TEC-FORCE group from NILIM made use of these to go to the disaster-afflicted areas and gain a broad understanding of the extent of the disaster.

*TEC-FORCE: This is the abbreviated name of the Technical Emergency Control Force, which consists of units established in the Ministry headquarters, the

National Institute for Land and Infrastructure Management, the Geospatial Information Authority of Japan, Local Branch Offices, and the Japan Meteorological Agency. In the event of a large-scale disaster or the risk of such a disaster, the purpose of the TEC-FORCE is to provide technical support to disaster-stricken local government smoothly and swiftly, to aid them in promptly gaining an understanding of the extent of the disaster, preventing the occurrence or escalation of damage, achieving recovery in the disaster-afflicted areas as soon as possible, and other emergency disaster control measures.

(3) Dispatch of Disaster Information Liaison Officers

Starting immediately after the disaster, Regional Development Bureau staff were dispatched to local authorities affected by the disaster to serve as Disaster Information Liaison Officers, in order to gather information received by the local authority about the extent of the damage, convey this to the various Disaster Response Headquarters, including the one established in the Regional Development Bureau, ascertain the support needs of the local authority, and serve as a point of contact and coordination in relation to such support.

Initially, the liaison officers dispatched were mainly office staff from within the jurisdiction of the Tohoku Regional Development Bureau, but as the response period became prolonged, support staff from other Regional Development Bureaus took over and were dispatched to local authorities affected by the disaster. The liaison officers were initially dispatched to the three prefectures of Iwate, Miyagi, and Fukushima, but officers were eventually dispatched to 55 municipalities in 13 prefectures from Hokkaido to Tokyo, as well as to the Self-Defense Force (North Eastern Army Headquarters).

In terms of the number of staff dispatched, those dispatched to 31 municipalities in four prefectures (the aforementioned three prefectures within the jurisdiction of the Tohoku Regional Development Bureau, plus Aomori Prefecture) alone peaked at 96, and totaled 3,916 man-days from the time the disaster occurred until June 30.

(4) Other Forms of Support for Recovery Activities

Various disaster response vehicles, including lighting vehicles, drainage pump trucks, task force vehicles, support vehicles, sprinkler vehicles, bridge inspection vehicles, and vehicles used for gathering information, as well as prefabricated bridges were mobilized on a total of 366 occasions. In addition, a total of 247 vehicles were mobilized to the Tohoku Regional Development Bureau jurisdiction from other Regional Development Bureaus.

Moreover, in order to facilitate the flow of information and communications in the disaster-afflicted areas, a variety of communication equipments for us in disaster response were mobilized to support local authorities, with satellite communication vehicles (537 unit-days), Ku-SAT (small satellite image transmission equipment; 1,998 unit-days), simple image transmission equipment (350 unit-days), and heli-tele portable stations (2 unit-days) deployed for a total of 2,887 unit-days.

(This chapter (2.3) is an edited and revised extract from the cited Reference[1)], concerning those activities of various bodies under the auspices of MLIT that were deemed to have a close relationship with the activities of NILIM, focusing on details it was felt should be recorded for future reference.)

2.4 Response by the National Institute for Land and Infrastructure Management

(1) Initial Response by NILIM and TEC-FORCE

On the day of the disaster, at the request of the Tohoku Regional Development Bureau, NILIM dispatched six staff members in three teams (the rivers team, the bridges team, and the road disaster mitigation team), who started work early the following morning, on March 12, conducting checks of the Bureau's facilities, accompanying the teams working to clear the roads, conducting surveys of damage to the embankments along the Eai and Naruse rivers, carrying out surveys of disaster-stricken bridges on National Route 45, and providing technical support at the Bureau's Disaster Response Headquarters for the collation and compilation of information on damage to roads.

Even after the dispatch of this team, NILIM dispatched a total of 262 experts (592 man-days) in fields including sewerage systems, rivers, coastlines, roads, dams, buildings, airports, ports, and erosion control, at the request of the Tohoku and Kanto Regional Development Bureau, the various disaster-stricken prefectures, and a number of bureaus within the Ministry headquarters; after their dispatch, these personnel provided support for activities such as the repair and restoration of facilities (details of the dispatch of each team are summarized in Table Ref.1 in the reference materials at the end of this publication).

Table 2.4.1 shows the number of staff dispatched in each field.

Table 2.4.1 Number of NILIM Staff Dispatched in Each Field

Field	Total Number of Staff Dispatched	Main Activities
Sewerage system	58 people (119 man-days)	・Surveys of damage to sewage treatment plants and sewage pipes
Rivers	13 people (36 man-days)	・Surveys of the extent of earthquake and tsunami damage to facilities such as embankments
Coast	12 people (29 man-days)	・Surveys of the extent of earthquake and tsunami damage to facilities such as embankments ・Ascertaining the extent of tsunami inundation
Roads	85 people (159 man-days)	・Confirming safety during road clearance ・Diagnosis of the severity of damage to bridges and other structures, technical guidance concerning repair and reinforcement methods ・Roadside slope diagnosis and repair
Dams	3 people (8 man-days)	・Soundness checks
Buildings	44 people (116 man-days)	・Ascertaining the extent of the damage from the tsunami and earthquake, earthquake-resistance diagnosis, support for the establishment of evacuation shelters
Airports	6 people (34 man-days)	・Ascertaining the extent of the damage to airport facilities resulting from the tsunami and earthquake
Ports	24 people (66 man-days)	・Ascertaining the extent of the damage to port facilities, surveys of the coastal environment
Erosion control	17 people (25 man-days)	・Ascertaining the extent of the damage in relation to landslides and mudslides
Total	262 people (592 man-days)	—

In conjunction with the mission as part of the TEC-FORCE team, staff members conducted surveys of the extent of the damage in disaster-afflicted areas that remained independent. For example, in the field of construction, NILIM staff worked in partnership with the Building Research Institute in conducting surveys of the damage to wooden buildings, steel structure buildings, reinforced concrete buildings, residential land and ground, and nonstructural elements, and surveys of the damage resulting from the tsunami and fire.

(2) Activities as a Disaster Response Headquarters

As a result of the earthquake, NILIM's own buildings in both Tsukuba and Yokosuka sustained prolonged, severe tremors, and it was expected that damage had occurred over an extensive area as a result of this exceedingly rare megaquake. Immediately afterwards, in response to signs that catastrophic damage had occurred in various parts of the Pacific coast in the Tohoku, due to its having been engulfed by an unimaginably vast tsunami, NILIM also established a

Disaster Response Headquarters. At the Yokosuka Office, a tsunami warning was issued and staff had to respond while themselves having to evacuate the building, which exacerbated the difficulty of conducting activities. In the Tsukuba area (the Asahi and Tachihara Offices), in addition to a power cut, it was also impossible to use the emergency electric supply unit for some time at the Asahi Office, so staff were required to respond to the disaster amid a situation in which it was difficult for them to obtain information even from television and other mass media.

Moreover, with regard to confirming the safety of staff members, the overloading of telephone lines and local power cuts made it difficult to communicate via landlines, so it was not possible to confirm the safety of all staff members on the day of the disaster. It took until the 14th (Monday) to confirm the safety of all 363 staff members in the Tsukuba district (one employee sustained a contusion to the shoulder as a result of a locker falling over), and until the 15th (Tuesday) until the safety of their family members could be confirmed.

At the first Disaster Response Headquarters meeting, which was convened at 16:00 on the day of the disaster, it was decided to dispatch experts to the disaster-afflicted areas, as well as gaining a general understanding of the earthquake based on the recorded results, and reporting on progress with efforts to confirm the safety of staff and their families, The very same day, six staff members in three teams (the rivers team, the bridges team, and the road disaster mitigation team) to the stricken region.

On March 14, at the beginning of the following week, the Headquarters met twice, at 08:45 and 16:00; as well as sharing information about the extent of the damage on the ground that had become evident from the dispatch of staff members of the weekend, various logistical matters were checked in relation to the envisaged dispatch of numerous TEC-FORCE units to remote areas in due course, including liaison with the Headquarters when dispatching staff members to the disaster-afflicted areas as experts, and arrangements for emergency vehicle passes. Moreover, discussions also took place concerning the system for providing support for disaster recovery through some projects.

From March 15, meetings of the Headquarters took place at the set time of 09:30 every morning and were held each day until the 18th. After the third meeting, the next one was held on April 25; as well as listening to reports on each group's planned activities thereafter and checking on moves by relevant organizations and academic societies, the framework for liaison during the forthcoming consecutive holidays was confirmed and it was decided that information would henceforth be shared in the regular meetings within the Institute, with meetings of the Headquarters only taking place in the event that there was deemed to be a particular need for one.

Table 2.4.2 Meetings of the NILIM Disaster Response Headquarters

No.	Date	Day	Time	Main report items	Participants
1	March 11	Fri	16:00	・Overview of the earthquake ・Progress in confirming the safety of staff and their families ・Dispatch of experts to the disaster-afflicted areas	Director of Headquarters and others No detailed record
2	March 14	Mon	08:45	・Liaison with the Headquarters in the event that staff are dispatched to disaster-afflicted areas ・Acquiring emergency vehicle passes for use on the expressway ・Response by research institutes (NILIM, Public Works Research Institute, Building Research Institute) ・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, bridges, buildings, erosion control, and disaster mitigation on roads) ・Extent of the damage to the Institute's laboratory building	Director of Headquarters Deputy Directors of Headquarters (2 members) Headquarters Team (13 members)Technical Team (14 members)
3	March 14	Mon	17:00	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (sewerage system, etc.) ・Matters concerning MLIT's support system for repairing damage to the sewerage system ・Extent of damage to NILIM facilities	Director of Headquarters Deputy Director of Headquarters Headquarters Team (11 members)Technical Team (10 members)
4	March 15	Tues	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, roads, buildings, erosion control, ports, and airports) ・Extent of damage to NILIM facilities ・Interim budgetary response relating to the disaster	Director of Headquarters Deputy Director of Headquarters Headquarters Team (14 members)Technical Team (9 members)
5	March 16	Wed	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, roads, and ports) ・Extent of damage to NILIM facilities ・Status of repairs to lifelines linked to NILIM facilities ・Progress in confirming the safety of staff at MLIT and other bodies	Director of Headquarters Deputy Director of Headquarters Headquarters Team (10 members)Technical Team (8 members)
6	March 17	Thurs	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, roads, buildings, and ports) ・Status of repairs to lifelines linked to NILIM facilities ・Progress with the restoration of modes of transport, etc.	Director of Headquarters Deputy Directors of Headquarters (2 members) Headquarters Team (15 members)Technical Team (9 members)
7	March 18	Fri	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, roads, buildings, ports, and erosion control) ・Status of repairs to lifelines linked to NILIM facilities ・Progress with the restoration of modes of transport, etc. and reports on other relevant matters	Director of Headquarters Deputy Directors of Headquarters (2 members) Headquarters Team (13 members)Technical Team (8 members)
8	March 23	Wed	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, and roads)	Director of Headquarters, Deputy Director of Headquarters Headquarters Team (14 members)Technical Team (9 members)
9	March 25	Fri	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, buildings, and erosion control)	Director of Headquarters Deputy Directors of Headquarters (2 members) Headquarters Team (6 members) Technical Team (7 members)
10	March 30	Wed	09:30	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, roads, buildings, ports, and erosion control)	Director of Headquarters Deputy Directors of Headquarters (2 members) Headquarters Team (13 members) Technical Team (10 members)
11	April 25	Tues	16:45	・Reports on dispatch of TEC-FORCE, etc. to the region and surveys being conducted (including sewerage system, rivers, and buildings) ・Moves by relevant organizations and academic societies ・Opening of a website concerning the disaster	Director of Headquarters Deputy Directors of Headquarters (2 members), Headquarters Team (14 members) Technical Team (11 members)

(3) Publication of the Results of Surveys

The results of the aforementioned field surveys conducted by NILIM in collaboration with the Building Research Institute were compiled and published in May 2011 under the title *Quick Report of the Field Survey and Research on "The 2011 off the Pacific coast of Tohoku Earthquake" (the Great East Japan Earthquake)*, Technical Note of National Institute for Land and Infrastructure Management No.636. Moreover, the final report was compiled and published in March 2012, under the title *Report on Field Surveys and Subsequent Investigations of Building Damage Following the 2011 off the Pacific coast of Tohoku Earthquake*, Technical Note of National Institute for Land and Infrastructure Management No.674. With regard to the field surveys conducted in collaboration with the Public Works Research Institute, focused on coastal, sewerage, river, dam, and road infrastructure, primarily on the Pacific coast of Hokkaido and the Tohoku and Kanto regions, the results were compiled and published in July, under the title *Quick Report on Damage to Infrastructures by the 2011 off the Pacific coast of Tohoku Earthquake*, Technical Note of National Institute for Land and Infrastructure Management No.646.

In conjunction with the publication of various materials, on April 26, 2011, NILIM, the Public Works Research Institute, and the Building Research Institute held the *Briefing on Surveys Conducted After the Great East Japan Earthquake* at the Hitotsubashi Memorial Hall in Tokyo; this briefing featured reports on the characteristics of the seismic motion and tsunami, and the extent of the damage to various facilities and infrastructure, focusing on sewerage, river, coastal, road, building, port, and airport facilities and infrastructure (see Table 2.4.3).

In addition, on June 10 the same year, in collaboration with organizations including the Building Research Institute, NILIM held the *Presentation of Surveys Conducted After the Great East Japan Earthquake*, which featured reports on the results of surveys focused on damage to wooden, reinforced concrete, and steel-frame buildings due to seismic motion and the tsunami (see Table 2.4.4).

Furthermore, in 2012, on March 13 (Nissho Hall, Tokyo) and March 21 (I-Osaka, Osaka), a seminar entitled *NILIM and PWRI Great East Japan Earthquake Seminar - What We See Now, One Year after the Disaster* was held. This seminar features a wide range of reports on initiatives undertaken to date and prospects for the future, including appraisals of the usability of infrastructure such as roads and ports, which are crucial to lifesaving endeavors and recovery activities, and technical guidance concerning emergency repair work, as well as research into such matters as the revision of technical standards including new disaster prevention measures relating to excess external force and complex natural disasters, in light of the lessons learned from major disasters (see Table 2.4.5).

Table 2.4.3 Program for the Seminar on Surveys Conducted After the Great East Japan Earthquake

(April 26, 2011, Hitotsubashi Memorial Hall, National Center of Sciences Building)

Organizers: National Institute for Land and Infrastructure Management, Public Works Research Institute, Building Research Institute

Topic	Coordinating Research Department(s)	Presenter
Opening Remarks		Kazuhiro Nishikawa (Director-General, NILIM)
[Seismic motion] Attributes of the seismic motion	Research Center for Disaster Management, NILIM International Institute of Seismology and Earthquake Engineering, Building Research Institute	Shojiro Kataoka (Research Center for Disaster Management, NILIM)
[Tsunami] Attributes of the tsunami	Coastal and Marine Department, NILIM International Institute of Seismology and Earthquake Engineering, Building Research Institute	Kentaro Kumagai (Coastal Disaster Prevention Division, NILIM)
[Ports] Extent of the damage to ports from the earthquake and tsunami, and support for their repair	Port and Harbor Department, NILIM	Takashi Nagao (Port Facilities Division, NILIM)
[Coast] Attributes of the damage to coastal structures and the hinterland due to the tsunami	River Department, NILIM	Yoshio Suwa (Coast Division, NILIM)
[Rivers] Extent of the damage to river embankments due to the seismic motion and tsunami	River Department, NILIM Geology and Geotechnical Engineering Research Group, Public Works Research Institute	Atsushi Hattori (River Department, NILIM)
[Sewerage system] Extent of the damage to the sewerage system due to the tsunami and liquefaction, and support for emergency repair	Water Quality Control Department, NILIM Materials and Resources Research Group, Public Works Research Institute	Toshihiro Yokota (Wastewater System Division, NILIM)
[Roads (bridges)] Extent of the damage to road bridges and the characteristics thereof	Road Department, NILIM Center for Advanced Engineering Structural Assessment and Research, Public Works Research Institute	Jun-ichi Hoshikuma (Center for Advanced Engineering Structural Assessment and Research, Public Works Research Institute)
[Dams] Overview of the results of interim checks of dams and extent of the main damage	River Department, NILIM Hydraulic Engineering Research Group, Public Works Research Institute	Yoshikazu Yamaguchi (Dam and Appurtenant Structures Research Team, Public Works Research Institute)
[Damage from landslides] Extent of landslide damage and status of erosion control infrastructure	Research Center for Disaster Management, NILIM Erosion and Sediment Control Research Group, Public Works Research Institute	Nobutomo Osanai (Erosion and Sediment Control Division, NILIM)
[Buildings (seismic motion)] Overview of the damage to buildings due to seismic motion	Building Department, NILIM Department of Structural Engineering, Building Research Institute	Takahiro Tsuchimoto (Evaluation System Division, NILIM)
[Buildings (tsunami)] Overview of the damage to buildings due to the tsunami	Building Department, NILIM Department of Structural Engineering, Building Research Institute	Yasuo Okuda (Department of Structural Engineering, Building Research Institute)
[Airports] Overview of surveys of basic infrastructure at Sendai Airport	Airport Department, NILIM	Junichi Mizukami (Airport Facilities Division, NILIM)
Closing Remarks		Taketo Uomoto (Chief Executive, Public Works Research Institute)

Table 2.4.4 Program for the *Seminar on Surveys Conducted After the Great East Japan Earthquake*

(June 10, 2011, Sumai-ru Hall)

Organizers: National Institute for Land and Infrastructure Management, Building Research Institute

Co-organizer: Japan Housing Finance Agency

Topic	Presenter
Opening Remarks	Hiroshi Ito Deputy Chief Executive, Building Research Institute
Activities by MLIT	Shinji Takami Planning Officer, Housing Bureau
Activities by the Japan Housing Finance Agency	Takashi Kawada, Technical Information Group Leader CS Promotion Department, Japan Housing Finance Agency
Characteristics of the earthquake and tsunami	Yushiro Fujii, Senior Research Scientist International Institute of Seismology and Earthquake Engineering, Building Research Institute
Characteristics of the seismic motion	Toshihide Kashima, Senior Research Engineer International Institute of Seismology and Earthquake Engineering, Building Research Institute
Characteristics of damage due to seismic motion (wooden buildings)	Takahiro Tsuchimoto, Senior Researcher, Evaluation System Division Research Center for Land and Construction Management, NILIM
Characteristics of damage due to seismic motion (reinforced concrete buildings)	Hiroshi Fukuyama, Director Department of Structural Engineering, Building Research Institute
Characteristics of damage due to seismic motion (steel-frame buildings)	Takashi Hasegawa, Senior Research Engineer Department of Structural Engineering, Building Research Institute
Characteristics of damage due to seismic motion (residential land and ground)	Hiroshi Arai, Senior Researcher Building Department, NILIM
Characteristics of damage due to seismic motion (nonstructural elements)	Yoshio Wakiyama, Senior Research Engineer Department of Production Engineering, Building Research Institute
Characteristics of damage due to the tsunami (wooden buildings)	Yasuhiro Araki, Research Engineer Department of Structural Engineering, Building Research Institute
Characteristics of damage due to the tsunami (reinforced concrete buildings)	Hiroto Kato, Senior Research Engineer Department of Structural Engineering, Building Research Institute
Characteristics of damage due to the tsunami (steel-frame buildings)	Tadashi Ishihara, Senior Research Engineer International Institute of Seismology and Earthquake Engineering, Building Research Institute
Characteristics of damage due to fire	Tatsuya Iwami, Senior Researcher Research Center for Land and Construction Management, NILIM
Closing Remarks	Juntaro Tsuru Deputy Director-General, NILIM

Table 2.4.5 Program for *NILIM and PWRI Great East Japan Earthquake Seminar - What We See Now, One Year after the Disaster*

(March 13, 2012, Japan Firefighters Association Hall (Nissho Hall))

(March 21, 2012, I-Osaka, (Osaka Labor Center))

Organizers: National Institute for Land and Infrastructure Management, Public Works Research Institute

Topic	Coordinating Research Department(s)	Presenter
Opening Remarks		Kazuhiro Nishikawa (Director-General, NILIM)
[Seismic motion / liquefaction] Methods of evaluating design ground motion and liquefaction in light of an M9 earthquake	Research Center for Disaster Management, NILIM Geology and Geotechnical Engineering Research Group, Public Works Research Institute	Shojiro Kataoka (Research Center for Disaster Management, NILIM)
[Ports] The impact on logistics of damage to ports, and earthquake and tsunami countermeasures	Coastal and Marine Department, NILIM Port and Harbor Department, NILIM	Shinichi Urabe (Deputy Director-General, NILIM)
[Coasts / prevention of tsunami-related disasters] Seawall design techniques and technologies for supporting the development of tsunami-resistant communities	River Department, NILIM	Yoshio Suwa, Fuminori Kato (Coast Division, NILIM)
[Rivers] Extent of the erosion of river embankments due to tsunami runup flow and overflow	River Department, NILIM	Atsushi Hattori (River Department, NILIM)
[Rivers] Verification of the effects of measures to counter the liquefaction of river embankments and related challenges	Geology and Geotechnical Engineering Research Group, Public Works Research Institute	Tetsuya Sasaki (Soil Mechanics and Dynamics Research Team, Public Works Research Institute)
[Sewerage systems] Effectiveness of earthquake-proofing techniques for sewerage pipe infrastructure	Water Quality Control Department, NILIM	Wataru Fukatani (Wastewater System Division, NILIM)
[Sewerage systems] Phased recovery of sewage treatment plant functions and measures to deal with radioactive material	Water Quality Control Department, NILIM Materials and Resources Research Group, PWRI	Masashi Ogoshi (Wastewater and Sludge Management Division, NILIM) Mamoru Suwa (Recycling Research Team, Public Works Research Institute)
[Roads] Technical standards for road structures with consideration for securing traffic functions in the event of an earthquake	Road Department, NILIM Center for Advanced Engineering Structural Assessment and Research, Public Works Research Institute Geology and Geotechnical Engineering Research Group, Public Works Research Institute	Takashi Tamakoshi (Bridge and Structures Division, NILIM) Jun-ichi Hoshikuma (Center for Advanced Engineering Structural Assessment and Research, Public Works Research Institute) Hidetoshi Kohashi (Construction Technology Research Team, Public Works Research Institute)
[Roads] Road network issues identified from probe data	Road Department, NILIM	Yukihiro Tsukada, Katsumi Uesaka (Traffic Engineering Division / Road Department, NILIM)
[Erosion control] Prediction of sites where earthquakes are likely to cause landslides and extensive satellite-based survey of landslide scars	Research Center for Disaster Management, NILIM Erosion and Sediment Control Research Group, PWRI	Masaki Mizuno (Erosion and Sediment Control Division, NILIM) Toshiya Takeshi (Landslide Research Team, Public Works Research Institute)
[Buildings and housing] Technical standards for tsunami evacuation buildings and other buildings	Building Department, NILIM	Atsuo Fukai (Standards and Accreditation System Division, NILIM)
[Buildings and housing] Technical support for housing reconstruction that takes into account regional characteristics and the local community	Housing Department, NILIM	Masashi Mori (Housing Planning Division, NILIM)
[Future development of research] Risk and crisis management for excessive and multiple disasters	Research Center for Disaster Management, NILIM River Department, NILIM	Shigeki Unjoh (Research Center for Disaster Management, NILIM)
Closing Remarks		Taketo Uomoto (Chief Executive, Public Works Research Institute)

(4) Collaborative Endeavors Involving Research in Various Fields (Including the *Great East Japan Earthquake Recovery and Reconstruction Seminars*)

NILIM launched a collaborative initiative involving research in various fields, entitled NILIM Workshops on Earthquake and Tsunami Countermeasures: Thinking Outside the Box; the first workshop was held on April 14, 2011 (see Table 2.4.6).

Table 2.4.6 Workshops on Earthquake and Tsunami Countermeasures

Work-shop No.	Date	Theme, etc.	Main Content
1st	April 14 (Thurs) 14:00 ～	Sharing information about the extent of the damage to structures and approaches to disaster response	・ Introduction to the situation in terms of seismic motion, the tsunami, sewerage systems, rivers, landslides, roads, buildings, the coast, ports, and airports
2nd	April 18 (Mon) 3:00 PM～	Exchange of opinions concerning issues (brainstorming) Theme: Tsunami (earthquake) countermeasures (1)	・ Introduction to the situation from the perspective of remaining airports and dams ・Effects of the tsunami that should be taken into consideration in future disaster prevention measures
3rd	April 20 (Wed) 14:00 ～	Theme: Tsunami (earthquake) countermeasures (2) Theme: Measures to deal with complex, extensive disasters; liquefaction countermeasures	・Responses to complex, extensive disasters ・ Liquefaction countermeasures throughout the region ・Provision of information concerning urban development and extensive disasters
4th	April 27 (Wed) 14:00 ～	Theme: Challenges faced in working toward recovery and reconstruction (building earthquake- and tsunami-resistant towns and a country that can withstand such disasters (hard & soft measures))	・ Introduction to comprehensive tsunami-related disaster prevention measures ・Issues that NILIM should tackle (short- and long-term issues)
5th Workshop	May 10 (Tues) 14:00 ～	Summary	・Outline of damage to major facilities and structures, and progress in dealing with this (general overview) ・ Support for the reconstruction of houses in the tsunami-afflicted area of Banda Aceh

The objective of this series of workshops was to share information about what happened during the recent earthquake and approaches to disaster response in each field at present, based on participation by all those who wished to do, in order to ensure that a wide range of opinions could be heard. After exchanging opinions regarding the extent of the damage to various structures and approaches to disaster response during the first workshop, content was solicited from those who wished to engage in the free exchange of opinions during the second and subsequent workshops, including the opinions of individuals; the secretariat then coordinated the dates of the workshops and all those who wished to participate gave presentations concerning their views during the next four sessions. A total of 73 people participated in the workshops, including members of each department and division who wished to take part, as well as NILIM's executive officers.

The discussions began with an effort to ascertain what was meant by the term "beyond expectations", which had also aroused considerable debate among the public. The main topics discussed at the workshops are as follows.

(i) Characteristics that differed from conventional disasters and matters that could serve as lessons for the future

(ii) Conventional measures that were effective, those that were not effective, and new discoveries

(iii) Responses to the phenomenon of a multistage disaster that involves extreme events: regional characteristics and the question of what must be protected, and to what extent

(iv) Approaches to rehabilitating the disaster-stricken region and repairing various structures

(v) The reality of information sharing in the field in an emergency

(vi) Disaster responses that were implemented effectively and things that exacerbated the difficulties

(vii) Dealing with hazardous areas

(viii) Lifeline malfunctions due to liquefaction and the impact of this on the lives of local citizens and business continuity of local industry

(ix) Hard and soft measures to alleviate such malfunctions and restore lifelines promptly

(x) Outline of the damage to each type of structure and establishment of investigative committees, etc.

(xi) Status of emergency measures, emergency repairs, proper repairs, and reconstruction plans in regard to each type of structure

(xii) Current standards regarding infrastructure and facilities, and approaches to their revision (in particular, tsunami levels and target performance levels)

Along with these topics, the workshop participants summarized the issues regarding which NILIM should make a contribution and the Institute's research objectives, with reference to surveys and studies aimed at recovery and reconstruction.

Moreover, on May 13, after brainstorming issues that became evident from the Great East Japan Earthquake and proposals for solutions to such issues, in light of the discussions and proposals at these workshops, the various departments and research centers at NILIM engaged in an exchange of opinions. In addition, issues relating to such matters as common logistical and back-up systems (including TEC-FORCE) were summarized and proposals for solutions submitted (see Tables 2.4.7 and 2.4.8).

Table 2.4.7 Issues That Became Evident from the Great East Japan Earthquake and Proposals for Solutions
(Common Issues Relating to Logistical and Back-up Systems)

No.	Category	Issue & Proposed Solution
1	The TEC-FORCE system	The mobilization standby time should be minimized, so that the unit can be dispatched without delay.
2		A system is required that takes into account the broader perspective in planning and coordinating the dispatch of the limited personnel available for dispatch in the event of a large-scale disaster over an extensive area.
3	Smoother dispatch of experts	Only limited numbers of vehicles and mobile phones for disaster prevention purposes are available to staff members, posing an obstacle to the dispatch of experts. The introduction of satellite phones is also required.
4		Vehicles (minibuses, etc.) for use by staff members, which can accommodate not only the necessary personnel, but also the food, clothing, and equipment that they need, is required.
5		Strengthening of NILIM's information support system, in order to prevent the dispatched experts from being cut off from information once at their destination.
6		Maintaining a permanent stock of the latest maps for the whole country, in order to ensure that activities in disaster-afflicted areas can be carried out smoothly.
7		NILIM should designate its emergency vehicles in advance and ensure that it has passes for emergency routes at all times.
8		The number of servers and telecommunication lines, which are the key to the volume of information that can be transmitted via the disaster prevention LAN, should be increased. Then it should be enabled to give technical guidance and to ascertain the status of the Disaster Response Headquarters in the disaster-afflicted area by means of videoconferencing, and to grasp the situation in the disaster-stricken areas through the use of CCTV.
9		Using emergency negotiated contracts to outsource tasks such as those required in order to carry out recovery and reconstruction without delay.
10	Team structure and framework for the dispatch of experts	It is necessary to cultivate experts who can provide technical guidance in the event of disaster, and to implement personnel-related initiatives to secure such experts on an ongoing basis
11		When a large-scale disaster occurs, in the event of requests for technical support through the dispatch of experts focused on an extremely large number of types of infrastructure in various fields, such as roads and rivers, the Institute should coordinate with other relevant organizations in relation to the expansion of staffing and organizations to meet those requests.
12		A mechanism for gathering information from Ministry headquarters, etc. concerning the technical support required by the Regional Development Bureau in the disaster-afflicted area, and conveying this information to NILIM (e.g. dispatch of a liaison officer).
13	Upgrading of office buildings to ensure the continuity of operations	Putting in place emergency electric supply unit that can be used in the event of a disaster, even when lifeline functions have been lost.
14		Installation of a well that can provide a source of water in the event of emergency

*) Summary as drawn up on May 13, 2011

Table 2.4.8 Research Projects That NILIM Should Tackle in Light of the Great East Japan Earthquake

No.	Category		Issue
1	Expectations of damage and evaluating the impact of damage		Research concerning expectations of flood damage due to tsunami and subsidence, and measures to deal with this
2			Re-checking areas where there is a danger of landslide and revising the evaluation criteria
3			Analysis of damage to the road network due to the disaster and the economic impact thereof
4	Plans for creating national land and communities that are resistant to disaster, and land use in accordance with this	Planning	Research into measures to develop a disaster prevention structure in coastal areas of cities that is tailored to the degree of risk of damage in the event of an earthquake
5			Prior measures to ensure rapid reconstruction and approaches to plans for recovery and reconstruction
6			Approaches to disaster response management
7			Evaluation of the impact on service levels resulting from the severing of the road network, and consideration of efficient measures to improve functions
8		Acquisition of data essential to plan formulation	Support for the formulation of disaster prevention plans using flow data
9	Revision of technical standards, etc.		Surveys of the extent of the damage to the road structure
10			Consideration of seismic design methods for road bridges in relation to megaquakes
11			Surveys of performance requirements for bridges likely to be affected by tsunami
12			Technical review of the requirements for tsunami evacuation buildings
13			Review of guidelines for preventing roof collapses
14			Responses to long-period ground motion in relation to tall buildings
15	Responses to the impact of the disaster on environmental pollution and energy	Environmental pollution	Responses to radioactivity at sewage treatment facilities
16			Deliberations regarding emergency exemptions and relaxation of environmental quality standards when conducting disaster recovery
17			Research concerning downstream and processing function recovery measures to minimize the risk from raw sewage overflow
18			Disaster response at sewage treatment facilities
19		Energy shortages	Deliberations concerning energy supply and energy conservation on the road network
20	Systems in the field to support rapid recovery, and securing the requisite workforce		Ensuring the soundness of quantity surveying systems used in emergency repair work in the event of a major disaster, and of the local businesses undertaking the work
21	Consensus building and risk communication aimed at recovery and reconstruction	The era of population decline, an aging population, and a declining birthrate	Development of models for sustainable dwelling styles in the region in the era of population decline, an aging population, and a declining birthrate
22		Risk communication and other issues	Deliberations and surveys concerning risk communication during the reconstruction phase
23			Creation of 3D data showing the landscape before the disaster
24	Rapid collection and dissemination of disaster information	Ascertaining the extent of the disaster	Developing landslide observation systems that use remote sensing
25			Research concerning seismic motion and damage
26			Using traffic probe data to identify sectors that are passable and travel times through them
27		Provision of disaster information	Provision of warnings to vehicles in areas where there is a risk of disaster

*) Summary as drawn up on May 13, 2011 (does not correspond to the actual research theme titles subsequently adopted)

External experts and others were invited to participate in investigative committees established in each specialist field, with deliberations focusing on technical considerations.

As deliberations in each specialist field progressed, concerns arose that it would become difficult to formulate and implement rational, consistent measures; for example, there were worries that if deliberations in each field were entrusted wholly to these committees, a situation might arise in which the measures formulated in those fields would be inconsistent with the given natural and external force conditions. In order to avoid such a situation, as well as ensuring that there was a consistent common awareness in each field, when gaining an understanding of such matters as the extent of the damage and the scale of the tsunami and other external forces that caused it, it was deemed vital to share information when formulating recovery and reconstruction measures. Accordingly, with the objective of sharing information about the matters discussed by each investigative committee, those in the Tsukuba district launched the *Great East Japan Earthquake Recovery and Reconstruction Seminars* (abbreviated title; at the time of the launch, the seminar was entitled *The Liaison Conference for Sharing Information About the Great East Japan Earthquake*) on July 11, 2011; these seminars were chaired by the Executive Director for Research Affairs. Subsequently, the seminars were held at around one-month intervals and have taken place 14 times since then. Table 2.4.9 provides a summary of the seminar program, the information shared, and the main points discussed.

Table 2.4.9 Content of Deliberations at the *Great East Japan Earthquake Recovery and Reconstruction Seminars*

Seminar Number	Date Held	Main Points Verified	Reports on Main Activities by the Committees
1st Seminar	July 11	・Reports from each field, moves by the government ・*Method of Setting Design Tsunami Water Level, etc.* ・Guidelines on tsunami inundation simulations	Investigative Committee on Measures to Deal with Radioactive Material in the Sewerage System
2nd Seminar	August 2	・Reports from each field, moves by the government ・Liquefaction damage to sewerage infrastructure and river embankments, and construction methods to deal with this	Technical Review Committee on Earthquake and Tsunami Countermeasures Pertaining to Sewerage Systems
3rd Seminar	August 26	・Reports from each field, moves by the government ・Handling of external force from tsunami in river management; embankment structure ・Advantages, disadvantages, and disparities between tsunami envisaged in each field and required tsunami resilience performance ・Usefulness of the FL method of evaluating liquefaction	*Emergency Recommendations concerning River Tsunami Countermeasures* Technical Review Committee on Liquefaction Countermeasures
4th Seminar	September 29	・Reports from each field, moves by the government ・Approaches to the design of tsunami evacuation buildings	Emergency Investigative Committee on Earthquake Resistance Measures for River Embankments Building Structure Standards Committee
5th Seminar	October 19	・Reports from each field, moves by the government ・Methods of determining wave power (velocity) in the design of tsunami evacuation buildings, application of reduction rules (2/1.5 times the height)	Building Structure Standards Committee Bridges Committee (Japan Road Association)
6th Seminar	November 9	・Reports from each field, moves by the government Content of and approaches to the technical standards in the Act on Regional Development for Tsunami Disaster Mitigation ・Revision of technical standards concerning roads, including guidelines regarding earthworks, and relevant measures	Technical Review Committee on the Creation of Tsunami-resistant Communities Emergency Investigative Committee on Earthquake Resistance Measures for River Embankments Earthworks Committee (Japan Road Association)
7th Seminar	December 7	・Reports from each field, moves by the government ・Seawalls, methods of setting the design-basis tsunami and crest height, and robust, effective seawall structures	Investigative Committee on Tsunami Countermeasures in Coast Areas Investigative Committee on Landscapes in the Restoration and Repair of River and Coastal Structures
8th Seminar	2012 January 24	・Reports from each field, moves by the government ・Approaches to methods of setting the standard tsunami, development activity, and draft technical standards for tsunami defense facilities ・Approaches to buildings, etc. designated as restricted areas and special restricted areas ・Use of rubble in the development of parks and other social capital	Steel Structure Committee / Special Committee on Surveys of Steel Structures Following the Great East Japan Earthquake (Japan Society of Civil Engineers) Investigative Committee on the Development of Parks and Green Areas in Relation to Reconstruction in the Aftermath of the Great East Japan Earthquake
9th Seminar	March 8	・Matters concerning the content of reports at the Disaster Seminar	
10th Seminar	March 27	・Reports from each field, moves by the government ・Deliberations concerning robust seawall structures, seawall experiments ・Surveys concerning public housing for disaster victims ・Shake table experiments concerning the effect of measures to counter liquefaction using drain pipes	Committee on the Promotion of Measures to Counter the Liquefaction of Residential Land Investigative Committee on Reconstruction Measures in Disaster-afflicted Urban Areas That Suffered Liquefaction Due to the Great East Japan Earthquake
11th Seminar	May 9	・Reports from each field, moves by the government ・Technical bulletin: *A Study on Resilient Structures for Coastal Dikes* ・Regional block meetings to exchange opinions concerning tsunami inundation assumptions ・Earthquake resistance of sewerage systems, tsunami resistance performance, progress with repairs ・Publication of technical guidelines on the development of parks and green spaces in relation to reconstruction in the aftermath of the Great East Japan Earthquake	Disaster Mitigation and Management Committee (Japan Society of Civil Engineers)
12th Seminar	June 1	・Reports from each field, moves by the government ・Deliberations concerning measures to counter liquefaction on residential land and roads, measurement of the the effects of measures to counter liquefaction using drain pipes, and other topics	Working Group on Measures to Counter a Nankai Trough Megaquake
13th Seminar	July 13	・Reports from each field, moves by the government ・Summary of reports by NILIM, and other topics	
14th Seminar	October 4	・Reports from each field, moves by the government ・Coordination of drafts by the NILIM departments submitting reports, and other topics	

The following provides an outline of the main details that emerged from the discussions at these seminars.

① Setting standards for assumptions about the height of the "frequently-occurring tsunami" and the "largest-possible tsunami"

In almost all fields, an approach was adopted that focused on dividing assumptions about tsunami into two levels, wherein it was assumed that the frequently-occurring tsunami would not give rise to damage, while resilient structures should be built to withstand the largest-possible tsunami, with priority being given to protecting human life. In terms of the size of this, although there were some differences, such as in the mode of expression, the approach indicated in the Interim Summary by the Central Disaster Management Council's Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunami Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake" was followed (see Figure 2.4.1).

② Differences between fields in their approach to considering tsunami

In the case of sewerage facilities, the basic premise was that other disaster prevention infrastructure such as seawalls would prevent frequently-occurring tsunami, apart from in areas where there would be a risk of their being directly exposed to tsunami damage, such as some sluice sections, so a structure that would withstand all external forces is not required in these facilities. In relation to the largest-possible tsunami, deliberations focused primarily on identifying which areas should be prioritized, such as maintaining functions, and which parts should be protected in order to make the restoration of functions easier. On the other hand, in the case of disaster prevention infrastructure such as seawalls, breakwaters, and river embankments, it is necessary for the facilities themselves to have the ability to withstand frequently-occurring tsunami, and it emerged that there are utterly different approaches concerning the functions required of such infrastructure. As a result, a more profound mutual understanding developed regarding each party's design assumptions, such as the fact that the conditions assumed regarding external forces differ greatly, and the points that should be borne in mind when setting external force conditions in each field became clear.

③ Revised design tsunami height in coastal areas and reflection of this in designs

Bringing together information from each field made it possible to promote analysis of the extent of the damage in the disaster-stricken coastal regions, the

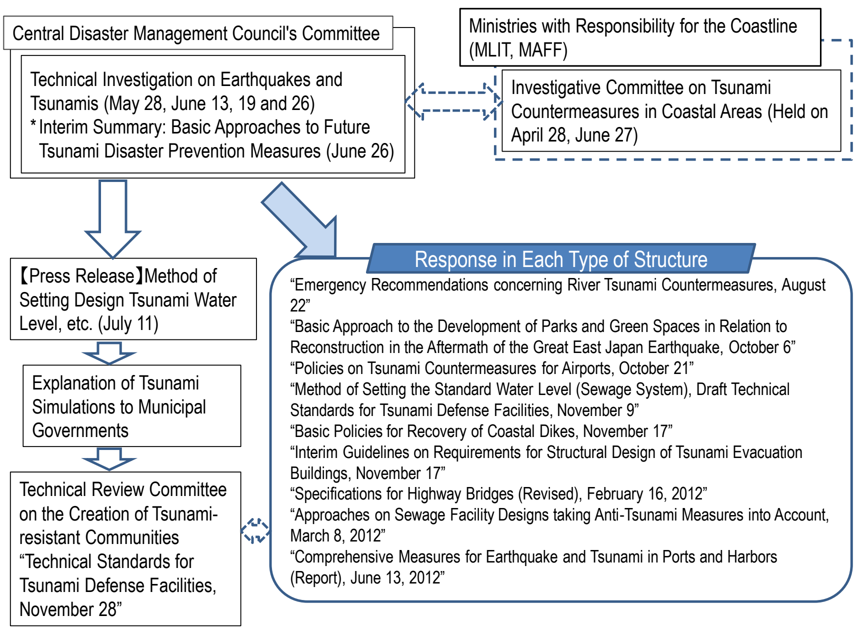


Figure 2.4.1 Consideration of New Assumptions About Level I and Level II Tsunami and Their Reflection in Each Field (Schematic Chart)

actual size of the tsunami at each point, and estimates of the scale of the external forces acting on those points. Moreover, close collaboration facilitated the process of rethinking approaches to the design conditions regarding external forces that are required for tsunami evacuation buildings.

At the ninth seminar, a question and answer session was held regarding the content of reports to be given at the *NILIM and PWRI Great East Japan Earthquake Seminar - What We See Now, One Year after the Disaster*, which was subsequently held on March 13 and 21, 2012.

The 13th seminar featured reports concerning the latest activities relating to research in each field, as well as reports on the implementation status of relevant research activities. It was decided to compile this information as a research report that could s erve as a point of reference in the event of any similar disasters in future, and opinions were exchanged concerning the content of this.

The seminars featured updates on deliberations by the Building Structure Standards Committee established by NILIM (Chairman: Tetsuo Kubo, Professor, Graduate School of Engineering, University of Tokyo, with other members including NILIM Deputy Director Juntaro Tsuru and Building Department Director Isao Nishiyama; the Committee's tasks included compiling the original draft of the *Interim Guidelines on Requirements for Structural Design of Tsunami Evacuation Buildings*, Notice Published November 17, 2011). In addition, there were regular briefings on the content of discussions by external committees in which staff members were participating, as shown in Table 2.4.10, as well as other moves by the government as a whole in relation to reconstruction.

Table 2.4.10(1) NILIM Staff Involvement in External Committees and Their Recommendations

Name of Committee, etc.	Organizer	Relationship to NILIM	Main Objectives or Recommendations	Date
Ministry of Land, Infrastructure, Transport and Tourism, etc.				
Technical Review Committee on Liquefaction Countermeasures	Engineering Affairs Division, Minister's Secretariat; Technology Policy Division, Policy Bureau	Shigeki Unjoh, Research Coordinator for Earthquake Disaster Prevention; Toshiro Yokota, Head, Wastewater System Division	Outcomes of deliberations by the Technical Review Committee on Liquefaction Countermeasures (August 31, 2011)	2011 May 11, July 12, August 19
River Tsunami Countermeasures Committee	Water and Disaster Management Bureau Chairman: Professor Shoji Fukuoka, Research and Development Initiative, Chuo University	(Secretariat)	*Emergency Recommendations concerning River Tsunami Countermeasures* (August 22, 2011)	2011 July 7, July 28, August 5
Emergency Investigative Committee on Earthquake Resistance Measures for River Embankments	Japan Institute of Construction Engineering Chairman: Professor Ikuo Towhata, Graduate School of Engineering, University of Tokyo	Koichi Fujita, Head, River Department; Atsushi Hattori, Head, River Division	*Toward Earthquake-resistance Measures for River Embankments* (interim summary; August 12, 2011) *Report on Future Earthquake-resistance Measures for River Embankments in Light of the Great East Japan Earthquake* (September 27, 2011)	2011 May 11, June 21, August 12, September 27
Technical Review Committee on Estuary Barrages and Floodgates in Light of the Great East Japan Earthquake	Water and Disaster Management Bureau Chairman: Professor Tadashi Yamada, Chuo University	Koichi Fujita, Head, River Department; Atsushi Hattori, Head, River Division; Keiichi Tamura, Research Coordinator for Earthquake Engineering(PWRI); Iwao Sasaki, Senior Researcher (PWRI)	Compilation of the final report of the technical review committee (September 14, 2011)	2011 April 26, May 27, June 22, August 8, September 14
Investigative Committee on Tsunami Countermeasures in Coast Areas	Ministries and agencies with responsibility for the coastline Chairman: Professor Masahiko Isobe, Graduate School of Frontier Science, University of Tokyo	Yoshio Suwa, Head, Coast Division	*The Basic Policies for Recovery of Coastal Dikes Damaged by the 2011 Great East Japan Earthquake and Tsunami*	2011 April 28, June 17, November 15
Technical Review Committee on the Creation of Tsunami-resistant Communities	Water and Disaster Management Bureau; City Bureau; River Department, NILIM Chairman: Shoji Fukuoka, Professor, Research and Development Initiative, Chuo University	Secretariat: Yoshio Suwa, Head, Coast Division	Technical Review Committee on the Creation of Tsunami-resistant Communities (January 27, 2012) ・ Method of setting the standard water level ・ Technical standards for specified development activities ・ Technical standards for tsunami protection facilities	2011 November 8, November 28, December 9 2012 January 11
Investigative Committee on Landscapes in the Restoration and Repair of River	Water and Disaster Management Bureau	Yoshio Suwa, Head, Coast Division Kunihiko Amano, Head, River Environment Division	*Landscape Consideration Manual for the Recovery of River and Coastal Protection Facilities Damaged in the Great East*	2011 September 1, September 21, October 14, November 11

and Coastal Structures			*Japan Earthquake* (November 11, 2011)	
Technical Review Committee on Earthquake and Tsunami Countermeasures Pertaining to Sewerage Systems	Sewerage and Wastewater Management Department Chairman: Professor Masanori Hamada, Waseda University	Nobuyuki Horie, Head, Water Quality Control Department	Emergency proposals (April 12, 2011); second set of proposals (May 24); third set of proposals (August 15); fourth set of proposals (March 8, 2012), Committee Report	2011 April 12, May 22-24 July 19, October 17, December 15 2012 February 24, March 22
Investigative Committee on Measures to Deal with Radioactive Material in the Sewerage System	Sewerage and Wastewater Management Department, Japan Sewage Works Association Chairman: Professor Tetsuya Kusuda, University of Kitakyushu	Nobuyuki Horie, Head, Water Quality Control Department (extraordinary member); Wastewater and Sludge Management Division (Secretariat), Yutaka Suzuki, Team Leader, Materials and Resources Research Group (PWRI) (member)	*Interim Summary by the Investigative Committee on Measures to Deal with Radioactive Material in the Sewerage System* (November 25, 2011)	2011 June 17, July 25, August 29, October 4, November 16 2012 May 28
Bridges Committee (Permanent)	Japan Road Association	Kazuhiro Nishikawa, Director-General; Shigeki Unjoh, Research Coordinator for Earthquake Disaster Prevention; Takashi Tamakoshi, Head, Bridge and Structures Division	*Specifications for Highway Bridges* (Revised) (February 16, 2012 (entered into force April 1, 2012))	2011 May 12, July 27, October 13, December 14 2012 February 8
Earthworks Committee (Permanent)	Japan Road Association	Shigeki Unjoh, Research Coordinator for Earthquake Disaster Prevention; Takashi Tamakoshi, Head, Bridge and Structures Division	Publication of FY2012 editions of *Highway Earthworks: Guidelines on Measures to Deal with Soft Ground* and *Guidelines on Retaining Walls*	2011 October 27, November 11 December 14 2012 January 19
Liaison Committee on Community-centered Housing in Post-disaster Reconstruction	Iwate, Miyagi and Fukushima Prefectures (and the Housing Bureau)	Akio Mizutani, Research Coordinator for Disaster Mitigation of Building; Masashi Mori, Head, Housing Planning Division; Hiroshi Hasegawa, Head, Residential Environment Planning Division; Ken Nunota, Housing Production Division	Designs and Production System Guidelines for Community-centered Housing in Post-disaster Reconstruction (from February 2012, for each prefecture)	2011 September 8, October 4, December 14
Prefectural Working Groups on the Inspection of Emergency Temporary Housing	Housing Bureau		*Interim Summary of the Manual on the Construction of Emergency Temporary Housing* (May 21, 2012)	2011 November 28 2012 March 26
Joint Liaison Committee on Surveys of Public Housing for Disaster Victims	Housing Bureau		*Seminar on Surveys of Public Housing for Disaster Victims* (March 2012), *Guidelines on the Focus of Projects to Develop Public Housing for Disaster Victims* (entered into force March 31, 2012)	2011 December 9. 14-16 2012 January 24-30, February 10 February 6-14, March 7-22
Committee on the Promotion of Measures to	City Bureau Chairman: Professor Ikuo Towhata,	Tatsuo Akashi, Head, Urban Planning Division; Masamiki Ohashi, Senior	Deliberations concerning technical standards to curb liquefaction damage to	2011 September 27, November 9

Counter the Liquefaction of Residential Land	University of Tokyo	Researcher, Urban Planning Division; Hiroshi Arai, Senior Researcher Structural Standards Division; Namihiko Inoue, Senior Researcher, Standards and Accreditation System Division	residential land	2012 January 30, February 27, July 9 September 11, October 22
Investigative Committee on Reconstruction Measures in Disaster-afflicted Urban Areas That Suffered Liquefaction Due to the Great East Japan Earthquake	City Bureau Chairman: Professor Susumu Yasuda, Tokyo Denki University		*Deliberations and Surveys Aimed at the Reconstruction of Disaster-afflicted Urban Areas That Suffered Liquefaction Due to the Great East Japan Earthquake* (Guidance (Draft)) (April 2012; City Bureau and National Institute for Land and Infrastructure Management)	2011 September 27, November 9 2012 January 30, February 27, March 27, July 23, October 30
Deliberations and surveys concerning techniques for the reconstruction of disaster-stricken urban areas affected by the tsunami	City Bureau	(Conducting surveys in each field, cooperation as committee members, etc.)	*Deliberations and Surveys Concerning Techniques for the Reconstruction of Disaster-stricken Urban Areas Affected by the Tsunami in the Aftermath of the Great East Japan Earthquake* (Summary; April 24, 2012)	
Investigative Committee on the Development of Parks and Green Spaces in Relation to Reconstruction in the Aftermath of the Great East Japan Earthquake	City Bureau	Masahiko Matsue, Head, Landscape and Ecology Division	*Basic Approach to the Development of Parks and Green Spaces in Relation to Reconstruction in the Aftermath of the Great East Japan Earthquake* (interim report) (October 6, 2011); *Technical Guidelines Concerning the Development of Parks and Green Spaces in Relation to Reconstruction in the Aftermath of the Great East Japan Earthquake* (published March 27, 2012)	2011 August 11, September 15 November 16 2012 February 21
Council on Tsunami Simulations for Airports	Civil Aviation Bureau	Junichi Mizukami, Head, Airport Facilities Division	Deliberations concerning matters including the tsunami inundation range that is to serve as basic data when formulating a plan for the prompt restoration of airport functions after an airport is affected by a tsunami	2012 October 2, March 22 August 10, September 24
Investigative Committee on Tsunami Design Guidelines for Breakwaters and Seawalls in Ports	Ports and Harbours Bureau, NILIM Chairman: Professor Masahiko Isobe, Graduate School of Frontier Science, University of Tokyo	Shinichi Urabe, Deputy Director-General; Takeshi Suzuki, Head, Coastal, Marine and Disaster Prevention Department (Takashi Koizuka, Head, Coastal and Marine Department); Takashi Nagao, Head, Port and Harbor Department (concurrently Head, Port Facilities Division); Takashi Negi, Head, Coastal Disaster Prevention Division	Deliberations on guidelines for tsunami design	2011 December 12 2012 January 31, March 9

Table 2.4.10(2) NILIM Staff Involvement in External Committees and Their Recommendations

Name of Committee, etc.	Convening Body	Relationship to NILIM	Main Objectives or Recommendations	Background to Convening
Dealing with recovery and reconstruction in the disaster-afflicted areas, earthquake countermeasures, etc.				
Investigative Committee on Technology for the Repair of Embankments Along the Kitakami and Other Rivers	Tohoku Regional Development Bureau	Atsushi Hattori, Head, River Division	Deliberations concerning the mechanisms of damage to embankments and construction methods for their repair; verification of river embankment structures in relation to tsunami; deliberations concerning checks of disaster-stricken embankments and flood forecasting standards, etc. (May 30, 2011: interim report (draft); December 2011: report)	2011 April 14, May 6, May 30, July 29, October 7 November 16
Investigative Committee on the Environment in Repairs to Estuarine and Coastal Infrastructure on the Coast of Miyagi Prefecture	Tohoku Regional Development Bureau	Yoshio Suwa, Head, Coast Division	*Guide to Consideration for the Environment in Repairs to Estuarine and Coastal Infrastructure on the Coast of Miyagi Prefecture* (March)	2011 November 25 2012 February 9, March 7
Investigative Committee on Water Quality Preservation Measures Relating to the Repair of the Breakwater at the Mouth of Ofunato Port	Sendai Research and Engineering Office for Port and Airport, Tohoku Regional Development Bureau	Tomonari Okada, Head, Marine and Coast Division	Deliberations concerning the repair of the breakwater at the mouth of Ofunato Port and the impact thereof on the environment within the port	2012 February 13 - March 16
Investigative Committee on Technology for the Repair of River Embankments	Kanto Regional Development Bureau	Atsushi Hattori, Head, River Division	Verification of the extent of the damage to river management infrastructure such as embankments; deliberations concerning repair methods appropriate to the extent of the damage, river management as flood season approaches, and effective approaches to flood prevention (September 14, 2011; summary of deliberations concerning earthquake countermeasures in relation to river embankments)	2011 April 27, June 1, September 14
Committee for Follow-up Deliberations on River Embankment Rebuilding Techniques	Kanto Regional Development Bureau	Atsushi Hattori, Head, River Division	Use of integrated geophysical exploration for evaluation of embankments after repair; deliberations concerning the standard water level for gauging stations	2012 May 24, July 5
Investigative Committee on Earthquake Countermeasures Along Directly-controlled Areas of the Kochi Coast	Shikoku Regional Development Bureau	Yoshio Suwa, Head, Coast Division	Deliberations concerning earthquake-resistance measures relating to seawalls in areas under the Bureau's direct control	2011 December 9
Tokyo Metropolitan Government Investigative Committee on Measures to Counter	Tokyo Metropolitan Government, City Bureau	Juntaro Tsuru, Deputy Director-General	Deliberations concerning measures to counter liquefaction focused on buildings such as wood-frame houses (May 21, 2012; interim summary)	2011 July 27, October 18, December 20 2012 February 10, April 20, July 30

Liquefaction of Buildings				
Iwate Prefecture Expert Committee on Tsunami and Disaster Prevention Technology	Iwate Prefecture	Yoshio Suwa, Head, Coast Division	Presenting proactive fundamental approaches to tsunami-resilient urban and community development when making proposals concerning the vision for reconstruction	2011 April 22, May 8, May 23, July 4, August 9, September 5, October 15 2012 January 23, October 26
Iwate Prefecture Investigative Committee on the Environment and Landscapes in the Restoration and Repair, etc. of River and Coastal Structures	Iwate Prefecture	Yoshio Suwa, Head, Coast Division	Basic Approaches Aimed at Consideration for the Environment and Landscapes in the Restoration and Repair, etc. of River and Coastal Structures in Iwate Prefecture (draft) Interim Summary (March 27, 2012)	2011 November 17, December 19 2012 January 27, February 23, September 14
Investigative Committee on Coastal Tsunami Countermeasures in Ibaraki	Ibaraki Prefecture	Yoshio Suwa, Head, Coast Division	・Water level of design tsunami and target embankment height (August 24, 2012) ・ Assumptions concerning tsunami inundation (August 24, 2012)	2011 December 26 2012 February 15, March 30, August 24
Project Team on Damage from Tsunami Inundation and Seismic Motion	Tokushima Prefecture	Yoshio Suwa, Head, Coast Division	・ Assumptions concerning tsunami inundation (October 31, 2012) ・ Deliberations concerning the water level of design tsunami	2011 December 17 2012 April 8, September 2, October 29
Technical Review Committee on the Design of Tsunami Evacuation Facilities (on roads)	Shizuoka Prefecture	Kazuhiko Mizutani, Research Coordinator for Road Structures	Deliberations concerning plans for the installation of tsunami evacuation towers (standard specifications and design standards for the tsunami evacuation towers to be installed on roads on September 2012)	2012 July 30, August 29, September 27
Kochi Prefecture Investigative Committee on Earthquake and Tsunami Countermeasures Pertaining to Sewerage Systems	Kochi Prefecture	Hiroaki Morita, Research Coordinator for Water Quality Control	Assumptions concerning damage to sewerage facilities, in preparation for a Nankai Trough megaquake; promotion of earthquake and tsunami countermeasures (earthquake and tsunami guidelines concerning the sewerage system are due to be formulated at the end of FY2012)	2012 October 5
Investigative Committee on Post-disaster Repair of the Sendai-Tobu Road Tobu Viaduct	NEXCO East	Shigeki Unjoh, Research Coordinator for Earthquake Disaster Prevention	Damage analysis and estimates; deliberations concerning repair methods	2011 May 11, August 25, December 2
Technical Review Committee on Tsunami and Earthquake Countermeasures at Tohoku Ports	Coastal Development Institute of Technology	Shinichi Urabe, Deputy Director-General; Seiji Matsumoto, Deputy Director-General	Technical review of policies for the repair of port facilities affected by the disaster (September 2011, *Technical Review Policy on Repair of Breakwaters and Wharves*)	2011 April 30, June 9, September 26

Investigative Committee on the Basic Plan for Tsunami Countermeasures for Sewage Treatment Plants in Yokosuka	Japan Institute of Wastewater Engineering Technology (Yokosuka)	Toshiro Yokota, Head, Wastewater System Division	Numerical analysis simulation techniques for forecasting tsunami damage to sewage treatment plants; deliberations concerning tsunami countermeasures for sewage treatment plants in the city of Yokosuka	2012 January 19. April 26, July 19
Specialist Investigative Committee on the Revision of Policies on Earthquake-resistance Measures for Sewerage Facilities	Japan Sewage Works Association	Nobuyuki Horie, Head, Water Quality Control Department; Hiroaki Morita, Research Coordinator for Water Quality Control; Toshiro Yokota, Head, Wastewater System Division; Ichiro Harada, Head, Wastewater and Sludge Management Division	Deliberations concerning the revision of relevant existing manuals and guidelines in response to the report compiled by the Technical Review Committee on Earthquake and Tsunami Countermeasures Pertaining to Sewerage Systems	2012 June 26

Table 2.4.10(3) NILIM Staff Involvement in External Committees and Their Recommendations

Name of Committee, etc.	Convening Body	Relationship to NILIM	Main Objectives or Recommendations	Background to Convening
Academic Society, etc.				
Investigative Committee on Evaluation of Wave Force Inflicted on Bridges by Tsunami	Japan Society of Civil Engineers Chairman: Professor Kyuichi Maruyama, Nagaoka University of Technology	Takashi Tamakoshi, Head, Bridge and Structures Division	Investigative Committee on Evaluation of Wave Force Inflicted on Bridges by Tsunami: Interim Report (June 26, 2012)	2011 August 9, November 4 2012 February 14, May 18
Steel Structure Committee / Special Committee on Surveys of Steel Structures Following the Great East Japan Earthquake	Japan Society of Civil Engineers Chairman: Atsuo Ogawa, West Nippon Expressway Engineering Kansai Co., Ltd.	Takashi Tamakoshi, Head, Bridge and Structures Division	*Extent of the Damage to Steel-frame Structures and the Analysis Thereof: Report of the Special Committee on Surveys of Steel Structures Following the Great East Japan Earthquake*	2011 November 25 2012 January 27
Disaster Mitigation and Management Committee	Japan Society of Civil Engineers	Nozomu Mori, Research Coordinator for Construction Management	Interim Briefing (2011 December 14) Symposium: *Strengthening Disaster Response Management Ability: What Was Learned from the Great East Japan Earthquake* (scheduled for November 2012)	2011 December 21, 22 2012 January: Interviews
Urayasu City Technical Review Committee on Measures to Counter Liquefaction	Japan Society of Civil Engineers; Urayasu Cityt	Hiroshi Arai, Senior Researcher Structural Standards Division; Toshiro Yokota, Head, Wastewater System Division	*Citizens' Briefing on the Technical Review of Measures to Counter Liquefaction* (December 18, 2011); March 2012: publication of the *Report on the Technical Review of Measures to Counter Liquefaction in Urayasu City*	2011 July 22, September 12 October 17, November 28
Technical Review Committee on the Feasibility of Measures to Counter Liquefaction	Japan Society of Civil Engineers; Urayasu Cityt	Hiroshi Arai, Senior Researcher Structural Standards Division	Dewatering methods and lattice-shaped ground improvement; evaluation of the liquefaction prevention and reduction effects of individual methods and the business risks thereof, and deliberations concerning the feasibility of an integrated program of measures to counter liquefaction in urban areas, focused on residential land, roads, and other public facilities	2012 June 25, August 24
Subcommittee on Research into Performance-based Seismic Design Techniques for Bridges; Working Group on Analysis of Damage to Bridges Due to the Great East Japan Earthquake	Earthquake Engineering Committee, Japan Society of Civil Engineers	Shojiro Kataoka, Senior Researcher, Earthquake Disaster Prevention Division	Activity Report of the Working Group on Analysis of Damage to Bridges Due to the Great East Japan Earthquake (July 26, 2012); Report of the Working Group on Analysis of Damage to Bridges Due to the Great East Japan Earthquake	2011 November 28, September 29, December 8 2012 January 25, March 16, April 25
Great East Japan Earthquake Damage Survey Committee	Japan Society of Erosion Control Engineering	Nobutomo Osanai, Head, Erosion and Sediment Control Division Atsushi Okamoto, Head, Erosion and Sediment Control	Deliberations concerning surveys and measures aimed at the reduction of landslides due to earthquakes in future, based on fact-finding surveys	2011 December 2 2012 January 17 Special symposium

		Division		
Committee on Surveys of Prestressed Concrete Structures Following the Great East Japan Earthquake; Earthquake Survey Working Group	Japan Prestressed Concrete Engineering Association	Shojiro Kataoka, Senior Researcher, Earthquake Disaster Prevention Division	*Report of the Committee on Surveys of Prestressed Concrete Structures Following the Great East Japan Earthquake* (December 21, 2011); *Report on Damage Surveys of Prestressed Concrete Structures Following the Great East Japan Earthquake*	(discussions via e-mail)
Special Committee on the Great East Japan Earthquake Subcommittee on Materials Production and Use	Japan Concrete Institute	Hiroyuki Tanano, Research Coordinator for Quality Control of Building	Interim Report by the Special Committee on the Great East Japan Earthquake (July 5, 2012; JCI Annual Convention 2012 (Hiroshima))	
Special Committee on the Great East Japan Earthquake Subcommittee on Structural Design	Japan Concrete Institute	Yusuke Fukunaga, Senior Researcher, Port Facilities Division; Toshikazu Kabeyasawa, Researcher, Standards and Accreditation System Division	Interim Report by the Special Committee on the Great East Japan Earthquake (July 5, 2012; JCI Annual Convention 2012 (Hiroshima))	
Committee on Verification and Evaluation of Academic Society Proposals	Japanese Geotechnical Society	Toshiro Yokota, Head, Wastewater System Division	*Issues and Measures Concerning Ground Damage Due to Earthquakes (Lessons and Recommendations from the Great East Japan Earthquake)* (June 2011)	2011 April 22, May 6, May 13, May 31, June 13, June 26, July 12, October 12, November 30
Committee on Research into Tsunami Countermeasures and Guidelines for These	Japan Association for Earthquake Engineering	Yasuo Okuda, Research Coordinator for Advanced Building Technology; Masahiro Kaneko, Head, Earthquake Disaster Prevention Division	Seminar: *Lessons from Tsunami Damage Due to the Great East Japan Earthquake* (October 21, 2011)	2011 August 24, December 27 2012 March 16, August 29

2.5 Other Relevant Developments

Table 2.5.1 and 2.5.2 provide a summary of various government-oriented conferences and committees established under the auspices of academic societies and organizations other than the aforementioned activities by the government, MLIT, and NILIM; in addition, these tables summarize the recommendations concerning recovery and reconstruction that emerged as the outcomes thereof. A number of the activities shown in Table 2.5.2 that were conducted under the auspices of academic societies were implemented with participation and cooperation from NILIM as well.

Table 2.5.1 Conferences Established by the Government and Their Recommendations Concerning Recovery and Reconstruction

Name	Main Members	Start of Deliberations and Number of Meetings	Date	Recommendations, etc.
Emergency Disaster Response Headquarters for the 2011 Great East Japan Earthquake http://www.bousai.go.jp/1info/higashinihon_taisaku/index.html		March 11 - September 11, 2011; 19 meetings	March 11 (3 times), March 12 (3 times), March 13 (twice) March 14, March 15, March 16 March 17, March 21, March 31 April 11, May 6, May 20, August 26, September 11	
Central Disaster Management Council	Chairman: Prime Minister	January 26, 2001 onwards; 31 meetings	April 27, October 11, December 27 2012 March 29, September 6	Interim Policy on Initiatives Aimed at Enhancing and Strengthening Disaster Prevention Measures; March 29, 2012 http://www.bousai.go.jp/chubou/30/30_siryo2.pdf
Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunami Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake" http://www.bousai.go.jp/jishin/chubou/higashinihon/index_higashi.html	Chairman: Yoshiaki Kawata; Vice-chairman: Katsuyuki Abe; members including Masahiko Isobe, Fumihiko Imamura, Makoto Okamura, Kunihiko Shimazaki, Shigeo Takahashi (PARI)	May 28 - September 28, 2011; 12 meetings	May 28, June 13, June 19, June 26, July 10, July 31, August 16, August 25, September 10, September 17, September 24, September 28	Basic Approaches to Future Tsunami Disaster Prevention Measures (Interim Summary; June 26, 2011) http://www.bousai.go.jp/jishin/chubou/higashinihon/tyuukan.pdf Recommendations Arising from the Interim Summary: Basic Approaches to Future Tsunami Disaster Prevention Measures (June 26, 2011) http://www.bousai.go.jp/jishin/chubou/higashinihon/teigen.pdf Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunami Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake" (September 28, 2011) http://www.bousai.go.jp/jishin/chubou/higashinihon/houkoku.pdf
Council on Disaster Countermeasures Promotion http://www.bousai.go.jp/chubou/suishinkaigi/index.html		October 28, 2011 - June 28, 2011; 13 meetings	October 28, November 28, December 7 2012 February 1, February 16, March 7, April 18, April 26, May 17, June 7, June 28, July 19, July 31	Interim Report of the Council on Disaster Countermeasures Promotion, March 7, 2012 http://www.bousai.go.jp/chubou/suishinkaigi/chukan_hontai.pdf; Final Report of the Council on Disaster Countermeasures Promotion, July 31, 2012 http://www.bousai.go.jp/chubou/suishinkaigi/saishuu_hontai.pdf
Council on Disaster Countermeasures Promotion: Working Group on Measures to Deal with a Nankai Trough Megaquake http://www.bousai.go.jp/jishin/chubou/taisaku_nankaitrough/index.html	Chairman: Yoshiaki Kawata; Vice-chairman: Atsushi Tanaka; members including Katsuyuki Abe, Fumihiko Imamura, Nobuo Fukuwa	From April 20, 2012; 8 meetings	2012 April 20, May 28, June 8, June 27, July 17, August 8, August 22, September 4, October 10	*Interim Report Concerning Measures to Deal with a Nankai Trough Megaquake*, July 19, 2012 http://www.bousai.go.jp/jishin/chubou/taisaku_nankaitrough/pdf/20120719_chuukan.pdf Working Group on Measures to Deal with a Nankai Trough Megaquake (First Report), August 29, 2012 http://www.bousai.go.jp/jishin/chubou/taisaku_nankaitrough/pdf/20120829_higai.pdf

Committee for Modeling a Nankai Trough Megaquake http://www.bousai.go.jp/jishin/chubou/nankai_trough/nankai_trough_top.html	Chairman: Katsuyuki Abe; members including Fumihiko Imamura, Makoto Okamura, Yukinobu Okamura	2011 From August 28; 26 meetings to date	August 28, October 3, October 25, November 15, November 24, December 12, December 27 2012 January 17, January 30, February 13, February 20, March 1, March 19, March 27, March 31, April 27, May 17, May 31, June 19, July 2, July 17, August 1, August 9, August 17, September 24, October 11	Committee for Modeling a Nankai Trough Megaquake Interim Summary, December 27, 2011 http://www.bousai.go.jp/jishin/chubou/nankai_trough/chukan_matome.pdf Committee for Modeling a Nankai Trough Megaquake (Second Report), August 29, 2012 http://www.bousai.go.jp/jishin/chubou/nankai_trough/pdf/20120829_2nd_report01.pdf
Working Group on Measures to Deal with an Earthquake Directly under the Capital City http://www.bousai.go.jp/jishin/chubou/taisaku_shutochokka/index.html	Chairman: Hiroya Masuda; Vice-chairman: Hiroaki Yoshii; members: Katsuyuki Abe, Miho Ohara; Itsuki Nakabayashi; Haruo Hayashi; Yoshiaki Hisada	2012 From April 25; 8 meetings to date	2012 April 25, May 25, June 6, June 18, July 10, August 6, September 6, October 16	Interim Report on Measures to Deal with an Earthquake Directly under the Capital City, July 19, 2012 http://www.bousai.go.jp/jishin/chubou/taisaku_shutochokka/pdf/20120719_chuukan.pdf
Committee for Modeling an Earthquake Directly under the Capital City http://www.bousai.go.jp/jishin/chubou/shuto_chokka/index.html	Chairman: Katsuyuki Abe; members including Fumihiko Imamura, Tomotaka Iwata, Nobuo Fukuwa, Takashi Furumura	2012 From May 11; 8 meetings to date	2012 May 11, June 8, June 29, July 9, July 24, August 7, September 20, October 3	(The objective was to consider the model of an earthquake directly under the capital city as envisaged in 2005 by the Central Disaster Management Council, and examine the distribution of seismic intensity and tsunami height using a model for the largest-possible megaquake occurring along the Sagami Trough, taking into account all possibilities based on the latest scientific knowledge available at present)
Working Group on Tsunami Evacuation Measures (Working Group on Tsunami Disaster Prevention) http://www.bousai.go.jp/jishin/chubou/taisaku_tsunami/index.html	Chairman: Atsushi Tanaka; members including Katsuyuki Abe, Masahiko Isobe, Fumihiko Imamura, Toshitaka Katada	From December 24, 2010; 9 meetings to date	2010 December 24 2012 January 23, February 29, March 26, April 26, May 23, June 7, June 13, June 28	Working Group on Tsunami Evacuation Measures, July 18, 2012 http://www.bousai.go.jp/jishin/chubou/taisaku_tsunami/wg_20120718/report.pdf
Council on Measures to Counter a Nankai Trough Megaquake	Masaharu Nakagawa, Minister of State for Disaster Management; Yasuo Harada, Director-General for Policy Planning; Katsuki Sasaki, Deputy Director General for Disaster Management, Minister's Secretariat, Cabinet Office; representatives of 136 organizations, including government ministries and agencies, Local Branch Offices, and designated public institutions (2nd meeting: 119 organizations)	2012 From June 4; 2 meetings	24 June 4, August 10	(Consisting of representatives of various government ministries and agencies, Local Branch Offices, relevant local government bodies, and designated public institutions, this Council was convened due to the recognition that the establishment of a forum to bring together a wide range of bodies from both the public and private sectors and the building of relationships that will endure in both times of peace and in emergencies were pressing issues)

Table 2.5.2 Committees Established by Academic Societies and Their Recommendations

Name of Committee, etc.	Main Objectives or Recommendations
Science Council of Japan	
Committee on Measures in Response to the Great East Japan Earthquake 1st meeting (March 24, 2011) - 24th Meeting (September 14, 2011) Science Council of Japan Subcommittee on a Grand Design for the Reconstruction of the Disaster-afflicted Areas 1st meeting - 7th meeting (April 20, May 9, May 30 June 20, July 28, August 6, September 14)	March 25, 2011 *First Emergency Recommendation in Response to the Great East Japan Earthquake*
	April 4 Second Emergency Recommendation: *Regarding the necessity of the investigation of radiation levels after the accident of the Fukushima Daiichi Nuclear Power Plant*
	April 5 Third Emergency Recommendation: *For the relief of victims of the Great East Japan Earthquake and the recovery of the disaster-stricken areas*
	April 5 Fourth Emergency Recommendation: *Urgent proposal related to measures for earthquake disaster waste and prevention of environmental impact*
	April 13 Fifth Emergency Recommendation: *Utilization of robot technology for the accident of the Fukushima Daiichi Nuclear Power Plant*
	April 15 Sixth Emergency Recommendation: *Perspective of gender equality with regard to relief, support, and restoration*
	April 20 Establishment of the Subcommittee on a Grand Design for the Reconstruction of the Disaster-afflicted Areas, 1st meeting (Subcommittee on Energy Policy Options and joint session)
	June 8 Recommendation: *Reconstruction of the disaster-stricken areas of the Great East Japan Earthquake – Reconstruction goals and seven principles -*
	August 3 Seventh Emergency Recommendation: *Scientific Survey and Analysis of Movement of Radioactive Substances over a Wide Area*
	September 21 Recommendation: *Employment support and industrial regeneration support in reconstruction from the Great East Japan Earthquake*
	September 27 Recommendation: *Protecting children from the Great East Japan Earthquake and the subsequent nuclear power plant accident*
	September 30 Recommendation: *Reconstruction of a new generation fisheries industry after the Great East Japan Earthquake*
	September 30 Recommendation: *Reconstruction of the disaster-stricken areas of the Great East Japan Earthquake - Reconstruction goals and seven principles (2nd recommendations) –*
Committee on Supporting Reconstruction after the Great East Japan Earthquake 1st meeting (October 28, 2011) onwards (2012 February 20, March 16, April 3 onwards (ongoing)) Committee on Supporting Reconstruction after the Great East Japan Earthquake Sub-Committee on Building Disaster-Resilient Communities 1st meeting (December 2, 2011) onwards (2012 January 13, February 3, March 2, October 5 onwards (ongoing)) among others	April 9, 2012 Recommendation by the Committee on Supporting Reconstruction after the Great East Japan Earthquake: *Recommendations from Science Council of Japan (SCJ) - with Confident Steps towards Reconstruction -*
	April 9 Recommendation by the Sub-Committee on Building Disaster-Resilient Communities, Committee on Supporting Reconstruction after the Great East Japan Earthquake: *Building Tsunami-proof Communities – Showing How Tohoku Reconstruction Makes Use of Nature –*
	April 9 Recommendation by the Sub-Committee on the Promotion of Industry and Employment, Committee on Supporting Reconstruction after the Great East Japan Earthquake: *Supporting Job-Seekers and Establishing Reconstruction Non-profits in Disaster-Stricken Areas- Towards the Promotion of Industry and Employment to Support Victims in Disaster-Stricken Areas -*
	April 9 Recommendation by the Sub-Committee on Counter-measures for Radiation, Committee on Supporting Reconstruction after the Great East Japan Earthquake: Toward Making a New Step Forward in Radiation Measures - Taking Actions based on Fact-based Scientific Research -
	June 22 Establishment of the Sub-Committee on Building Resilience to Disasters
	June 22 Establishment of the Sub-Committee on Supporting Reconstruction in Fukushima
	June 22 Establishment of the Sub-Committee on Energy Supply Problems
Collaborative Endeavors by Academic Societies	
Society of Heating, Air-Conditioning and ***Sanitary*** Engineers of Japan, Japanese Geotechnical Society, Japan Society of Civil Engineers, Architectural Institute of Japan, Japan Concrete Institute, Japanese Institute of Landscape Architecture, City Planning Institute of Japan	April 26, 2011 Joint recommendation by the presidents of the seven academic societies concerning reconstruction in the aftermath of the Great East Japan Earthquake
Science Council of Japan, Japan Society of Civil Engineers, and 20 other academic societies	May 27, 2011 Basic Policy for Protecting the Lives of the People and National Land from Megaquakes and Massive Tsunami
Liaison Council of Academic Societies and Associations for a Comprehensive Response to the Great East Japan Earthquake; initiative involving 30 academic societies	May 10, 2012 Joint statement by the 30 academic societies: *Toward the Rethinking of Policies on National Land and Disaster Prevention and Mitigation - Protecting the Lives of the People and National Land from Major Disasters*

Name of Committee, etc.	Main Objectives or Recommendations
Japan Society of Civil Engineers	
Great East Japan Earthquake Special Committee	Organization of sessions for the dissemination of proposals on specific themes: Regional Disaster Preparedness and Response Planning Committee; Tsunami Disaster Management Committee; Soil Liquefaction Committee; Civil Engineering Technology for Nuclear Safety Committee; Post-Earthquake Recovery & Reconstruction Committee; Reconstruction EngineeringTechnology Committee; Creative & Innovative Reconstruction-PI System Committee; Disaster Mitigation and Management Committee; Committee on ICT-Based Natural Disaster Risk Management and Resilience Development; Radioactive Waste Countermeasure Civil Engineering Committee Special activities: Social Safety Committee, Tsunami Damage Estimation and Risk Reduction Committee, JSCE Regional Chapter Group on Reconstruction Design for a Disaster Resilient, Safe Land Structure
	June 2012 Report of the Tsunami Damage Estimation and Risk Reduction Committee
	July 20 Interim Summary of the Social Safety Committee: *Restoring Trust in Engineers*
	August 8 Creative & Innovative Reconstruction-PI System Committee: *Final Report on Guidelines for Creative and Innovative Reconstruction*
Architectural Institute of Japan	
Headquarters for Supporting Surveys and Reconstruction Following the Great East Japan Earthquake: Research and Proposals Subcommittee	September 26, 2011 *Returning to the Basic Purpose of Architecture: Regeneration and Innovation of a Place for Living - in Light of the Great East Japan Earthquake* (First Recommendations)
Japanese Geotechnical Society	
FY2011 Committee on Verification and Evaluation of Academic Society Proposals	August 8, 2011 Issues Relating to Ground Damage in the Event of an Earthquake and Relevant Countermeasures Lessons and Proposals in the Aftermath of the 2011 Great East Japan Earthquake (First) (Toshiro Yokota, Head, Wastewater System Division worked in partnership with the committee) August 3, 2012 Issues Relating to Ground Damage in the Event of an Earthquake and Relevant Countermeasures Lessons and Proposals in the Aftermath of the 2011 Great East Japan Earthquake (Second)
Japan Association for Earthquake Engineering	
Symposium of 6 academic societies	March 1-4, 2012 International Symposium on Engineering Lessons Learned from the Giant Earthquake - One Year After the 2011 Great East Japan Earthquake - Sponsors: Ministry of Land, Infrastructure, Transport and Tourism, NILIM (Shigeki Unjoh, Research Coordinator for Earthquake Disaster Prevention, participated in the organizing committee for the symposium)
Special Research Committee on Responses to Extensive System Damage	May 24, 2012 *Proposals for Earthquake Damage Mitigation and Reconstruction: In Light of the Great East Japan Earthquake*
Japanese Institute of Landscape Architecture	
Investigative Committee on Supporting Reconstruction after the Great East Japan Earthquake	May 21, 2011 Recommendations for Reconstruction Support in the Aftermath of the Great East Japan Earthquake: *Post-disaster Reconstruction Through Landscape Regeneration* May 15, 2012 Publication of *Scenes of Reconstruction: A Concept Book for Supporting Reconstruction Through Landscape Generation*

3. Initiatives Focused on Recovery and Reconstruction Following the Great East Japan Earthquake

3.1 Initiatives by the National Institute for Land and Infrastructure Management Focused on Recovery and Reconstruction

As a member of bodies including TEC-FORCE, NILIM has conducted emergency damage studies and damage analysis focused on facilities within NILIM's jurisdiction, working in partnership with various relevant organizations, starting in the immediate aftermath of the Great East Japan Earthquake in March 2011. In addition, as befits its role as a research institute affiliated to MLIT, it has conducted deliberations and made proposals concerning emergency response measures, as well as providing technical support in relation to legislation and the revision of technical standards, and technical support at sites where construction and repair were taking place.

This chapter provides a summary of the support measures implemented in relation to post-earthquake recovery and reconstruction measures in various fields including erosion control, sewerage systems, rivers, water resources, coastlines, roads, ports, airports, buildings, houses, cities, parks and other green areas, IT and information, and environmental technology.

In addition, with regard to technical support for MLIT headquarters, its Regional Development Bureaus, and local authorities, it includes matters relating to the support provided as part of the external committees in which NILIM members participated and the proposals that they made, which are summarized in Table 2.4.10.

3.2. Evaluation and Analysis of Seismic Force and Action

3.2.1. Ground Motion

The 2011 off the Pacific coast of Tohoku Earthquake(hereinafter referred to as the Tohoku Earthquake) of which source region, is approximately 450 km long and 200 km wide, ruptured from off Sanriku to off Ibaraki Prefecture and became an event with the largest moment magnitude, Mw 9.0[1], in Japan's observation history. Figure-3.2.1.1[1] shows the spacal and temporal distribution of the slip caused by the main shock estimated from the teleseismic body-wave by the Japan Meteorological Agency. It suggests that three large ruptures, denoted by numbers 1, 2, and 3 in the figure, occurred; the first two in off Miyagi Prefecture and then the third in off Ibaraki Prefecture and the second rupture was significantly large. As a result, a very large slip over 30 m was likely to have occurred in off Miyagi Prefecture. In the following sections, section 3.2.2.1 shows the characteristics of the ground motions generated during the rupture-sequence in the source region and section 3.2.2.2 presents analytic studies on the design ground motion for interplate earthquake using strong motion records. For the analyses of the ground motion observed at dams and buildings, refer to the subsections 3.3.4 (4) and 3.3.9.2 (1), respectively.

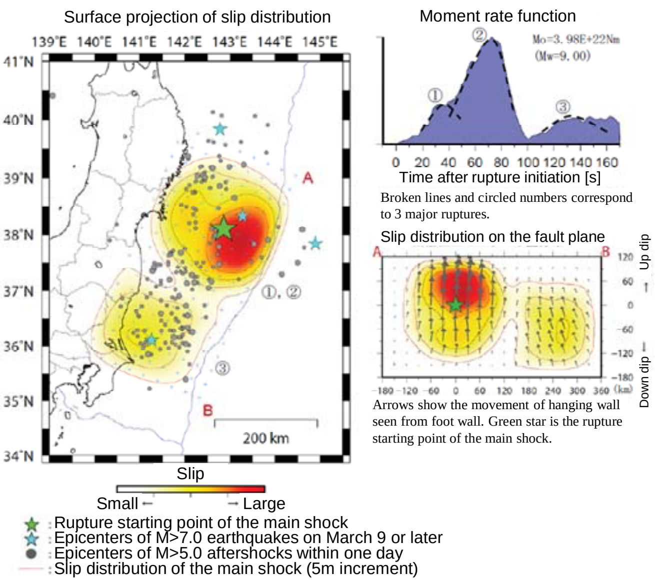


Figure-3. 2. 1. 1: Slip Distribution Released by the JMA[1]

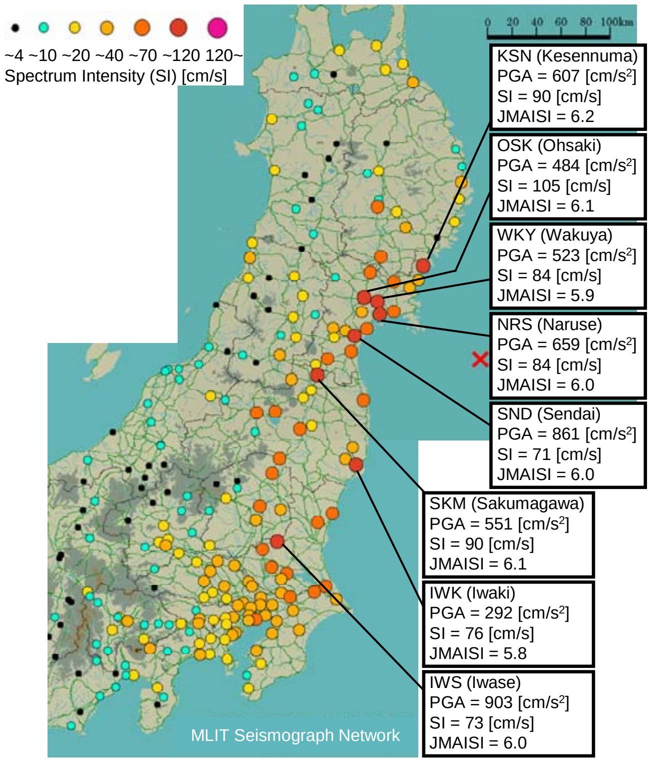
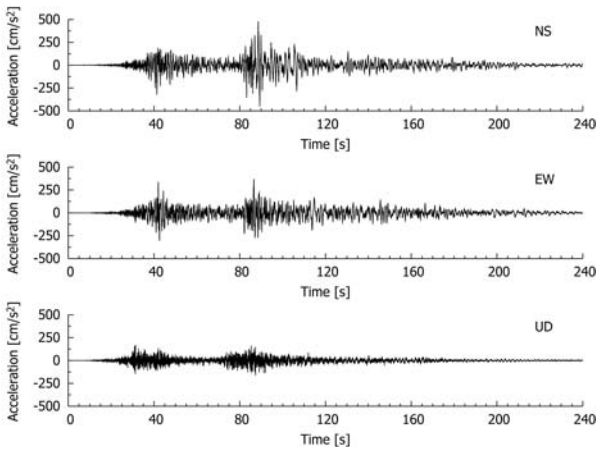
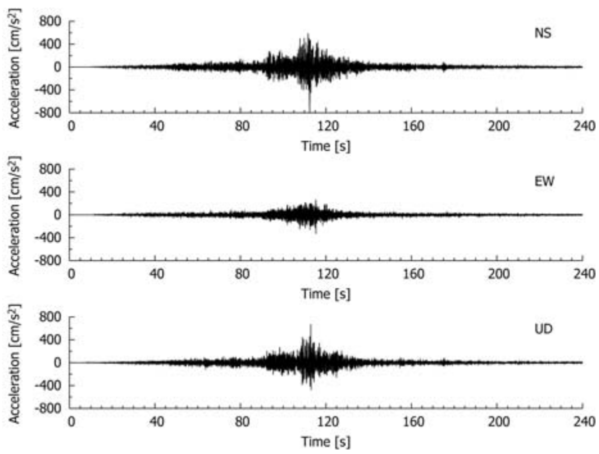


Figure-3. 2. 1. 2 Observations by MLIT Seismograph Network[2)]



(a) Osaki Branch-Office



(b) Iwase National Highway Branch-Office

Figure-3.2.1.3: Acceleration Waveforms

3.2.1.1. Characteristics of the observed ground motions

(1) Ground motion intensity-map and acceleration waveforms

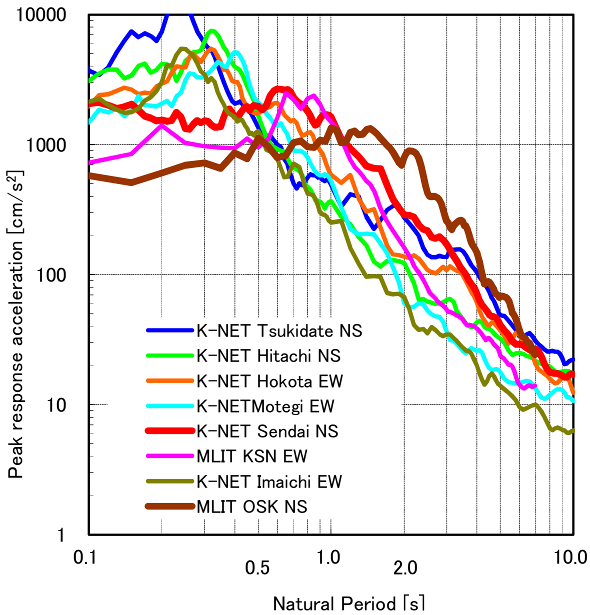
Figure 3.2.1.2 shows the map of SI values (spectrum intensity: an index for ground motion intensity, representing the scale of shaking of an ordinary structure) and the observations at the observation stations having experienced SI values over 70 cm/s. (corresponds to 6 upper of the Japanese seismic intensity scale). PGA denotes peak ground acceleration in the figure. The figure suggests that strong ground motions were observed in a wide-range of areas from the northern part of Miyagi Prefecture to the southern part of Ibaraki Prefecture because the source region was very large.

Figure 3.2.1.3 shows the acceleration waveforms observed during the main shock at the Osaki Branch-Office (Osaki City, Miyagi Prefecture) and the Iwase National Highway Branch-Office (Sakuragawa City, Ibaraki Prefecture) stations. In the waveform observed at the Osaki Branch-Office station, we found two wave-phases having significantly large amplitude. Those phases were caused by the two ruptures near the hypocenter as shown in Figure-3.2.1.1.

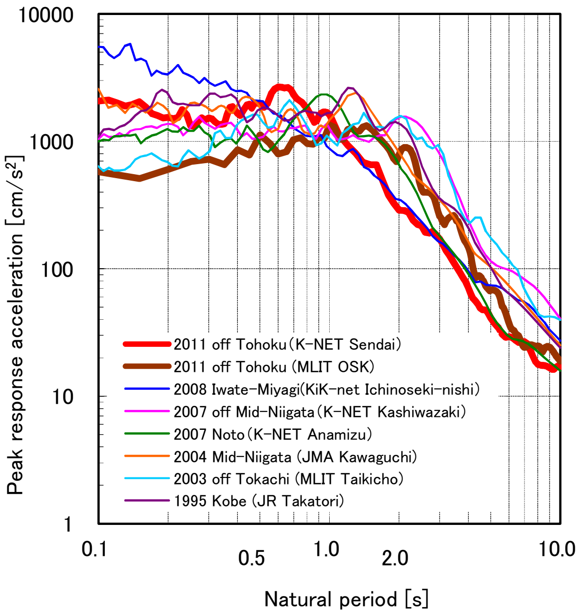
On the other hand, we found no such multiple-phases in the observations at the Iwase National Highway Branch-Office station; the seismic wave caused by the rupture in off Ibaraki Prefecture was dominant over those caused by the first two ruptures near the hypocenter having attenuated their amplitude while propagating.

(2) Acceleration Response Spectrum

Figure-3.2.1.4 (a) shows the eight acceleration response spectra (damping ratio: 0.05) of strong motion records with large instrumental seismic intensity obtained by K-NET[3] of the National Research Institute for Earth Science and Disaster Prevention and the MLIT Seismograph Network during the Tohoku Earthquake. Two of them are compared with acceleration response spectra of strong motion records obtained during recent major earthquakes since the 1995 Hyogo-ken Nanbu Earthquake in Figure-3.2.1.4 (b).



(a) Observations in the Tohoku Earthquake



(b) Comparison with Past Major Earthquakes

Figure-3.2.1.4: Acceleration Response Spectra (Damping ratio: 0.05)

We have obtained numerous records during the Tohoku Earthquake with various predominant periods, short (periods of less than 0.5 s), middle (periods from 0.5 to 1 s) and long (periods of longer than 1 s), corresponding to distance from the source region and soil conditions. When we look into the figure focusing on the natural periods of 1 to 2 s, which have significant effectson structures such as bridges and low/middle rise buildings, we find that the spectra

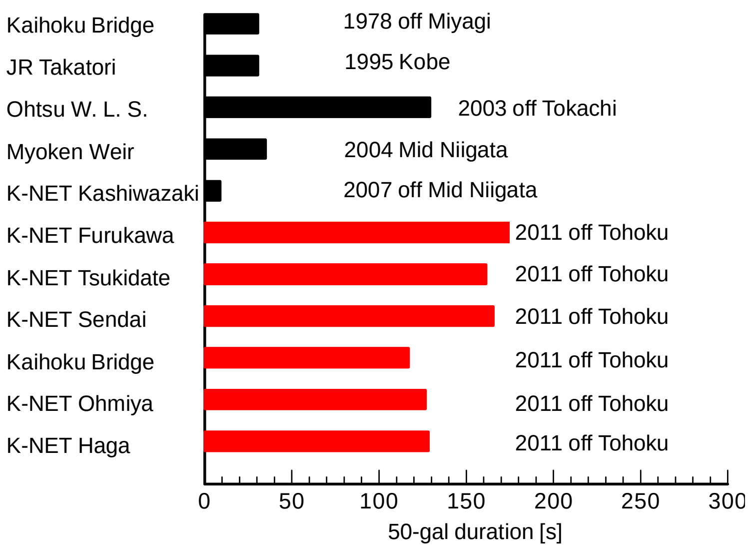


Figure-3. 2. 1. 5: Comparison of 50-gal Duration

obtained in the Tohoku Earthquake are smaller than or the same as those of the devastating 1995 Hyogo-ken Nanbu Earthquake (Takatori Station).

Note that, with regard to the observation by K-NET Tsukidate, which was the only observed record having an intensity 7 according to the JMA announcement, various investigations including amplification characteristic of surface soils by aftershock observations have been conducted. Some of the reports have suggested that the observation record, with predominant periods in the spectrum with a period of 0.2 to 0.3 s, has been influenced by the local geographical conditions and is unlikely to be a typical observation for the surrounding neighborhood[4].

(3) Duration of the ground motions

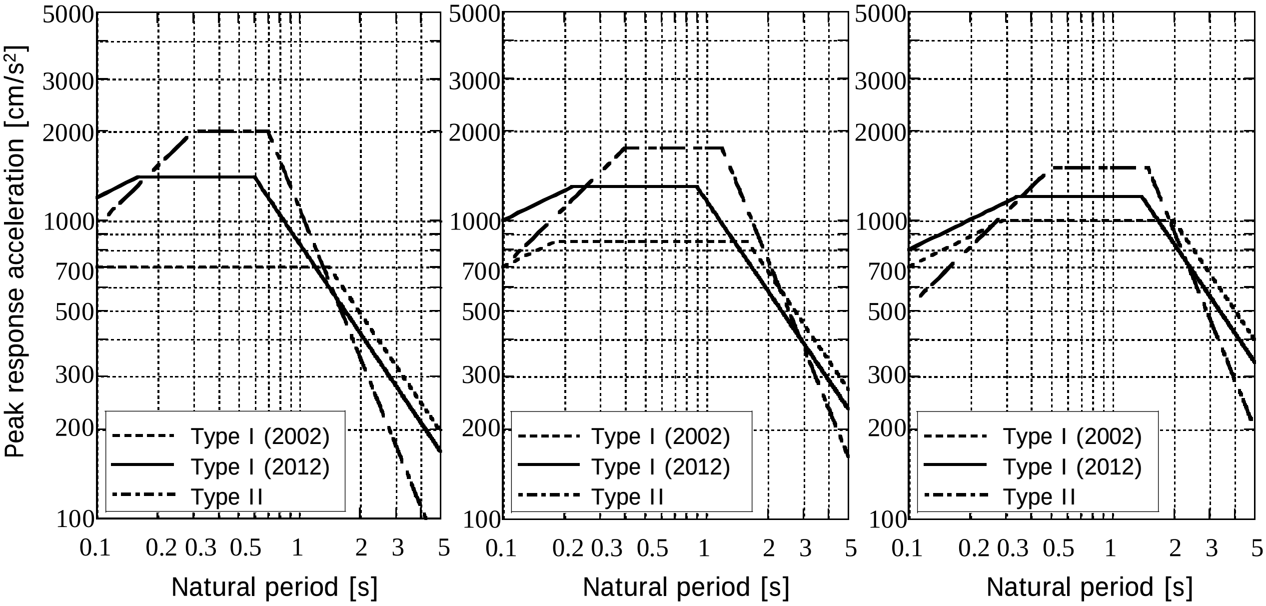
One of the outstanding aspects of the ground motions caused by the Tohoku Earthquake is a long duration of ground motion resulting from the long-lasting rupture sequence occurring in the source region. Figure-3.2.1.5[5] shows the comparison of the duration observed during the Tohoku Earthquake to those recorded in the major earthquakes in the past. The duration here is defined as the time between first and last moments that the ground motion amplitude (synthesized two horizontal components) exceeds 50 gals while there are different ways of calculating the duration.

Beside K-NET Furukawa having observed a long duration of 178 s, other observation stations in the Tohoku and Kanto regions observed durations longer than 120 s; generally, the durations observed during the Tohoku Earthquake are longer than those observed during the 2003 off Tokachi Earthquake, 130s.

3.2.1.2. Research on Design Earthquake Motion for an Interplate Earthquake

Since the 1995 Hyogo-ken Nanbu Earthquake (JMA magnitude M_J 7.3), the two-step design method–using Level 1 earthquake motion and Level 2 earthquake motion–has generally been applied to the seismic design of civil engineering structures. In designing a highway bridge, for example, two types of Level 2 earthquake motions are applied; one is for a large-scale interplate earthquake (Type I earthquake motion) and the other is for an inland shallow earthquake (Type II earthquake motion).

The Tohoku Earthquake provided, for the first time, abundant records of Mw 9.0 class strong motions, which would help in promoting the analysis of ground motion characteristics in a giant earthquake which had been underdeveloped so far because of the very low frequency of the occurrence of such giant earthquakes. Taking account of the prediction that the Tokai, Tonankai, and Nankai Earthquakes, which are all interplate earthquakes like the Tohoku Earthquake,will occur in the near future[6], we revised



(a) Type 1 Soil (b) Type 2 Soil (c) Type 3 Soil

Figure-3.2.1.6: Comparison of Standard Acceleration Response Spectra

the Level 2 earthquake motion (Type I) presented in the Specifications for Highway Bridges based on the results of the analyses on the strong motion records obtained during the Tohoku Earthquake.

The research conducted for the above-described revision of Level 2 earthquake motion (Type I), presented in the "Specifications for Highway Bridges V-Seismic Design"[7], is introduced in the following as an example of analyses for the characteristics of the ground motion from the giant interplate earthquake.

(1) Revising the standard acceleration response spectra

The design earthquake motion specified in the Specifications for Highway Bridges is set by multiplying a correction factor due to damping and a zone factor to the standard acceleration response spectrum specified for each ground type as shown in Figure-3.2.1.6. The standard acceleration spectra for Level 2 earthquake motion (Type I) are formulated based on, with engineering judgments, the ground motion in Tokyo are during the 1923 Kanto Earthquake (Mw 7.9) extimated by enhanced attenuation relationships[8) and 9)] developed using recent strong motion records and an improved regression analysis method.

Figure-3.2.1.6 illustrates the previous standard acceleration response spectra for Type I earthquake motion and the revised standard acceleration response spectra for Type I and Type II earhtquake motions. The revised spectra for Type I earthquake motion have peaks higher than those of the previous spectra for Type I earthquake motion and larger than Type II earthquake motion in long period range.

The previous spectra for Type I earthquake motion had larger peaks for ground type III (weak ground among alluvial soil layers) is higher than that for ground type I (sound diluvial soil or rock), while the relationship is reversed for the revised spectra. This is a result of the adoption of a trend found in the estimated acceleration response spectra that the spectrum peak becomes lower in the order of ground type I, type II, and type III; the trend was found through formulating acceleration response spectra by applying the ground type factor for each ground type obtained by selectively using the strong ground motion records with a larger amplitude.

(2) Revising the zone factor

as Along with revising the standard acceleration response spectra, we formulated, besides the conventional factors, new zone factor to be applied to Level 2 earthquake motions (Type I) (Figure-3.2.1.7) on the basis of the information on the source

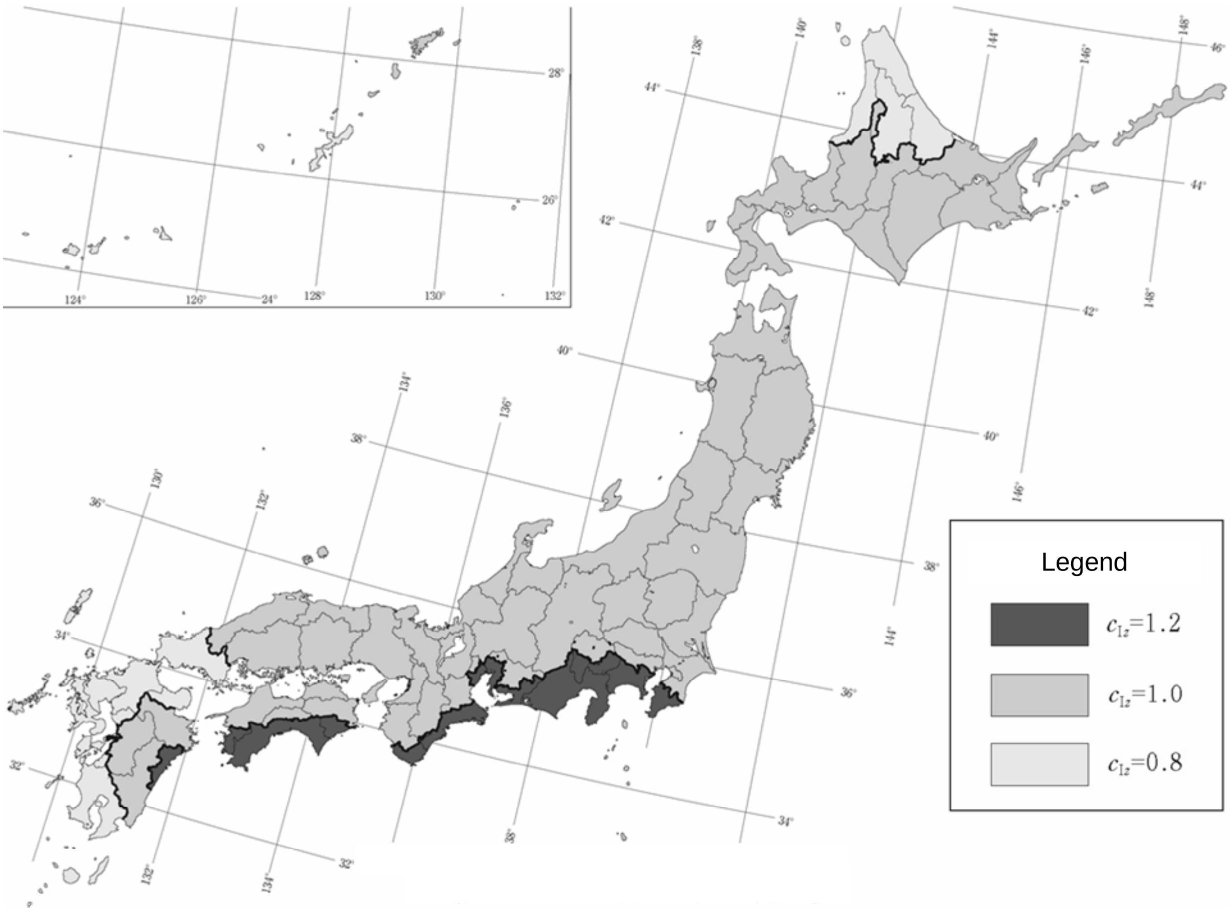


Figure-3. 2. 1. 7: Zone factors for Level 2 Earthquake Motion (Type I), C_{Iz}

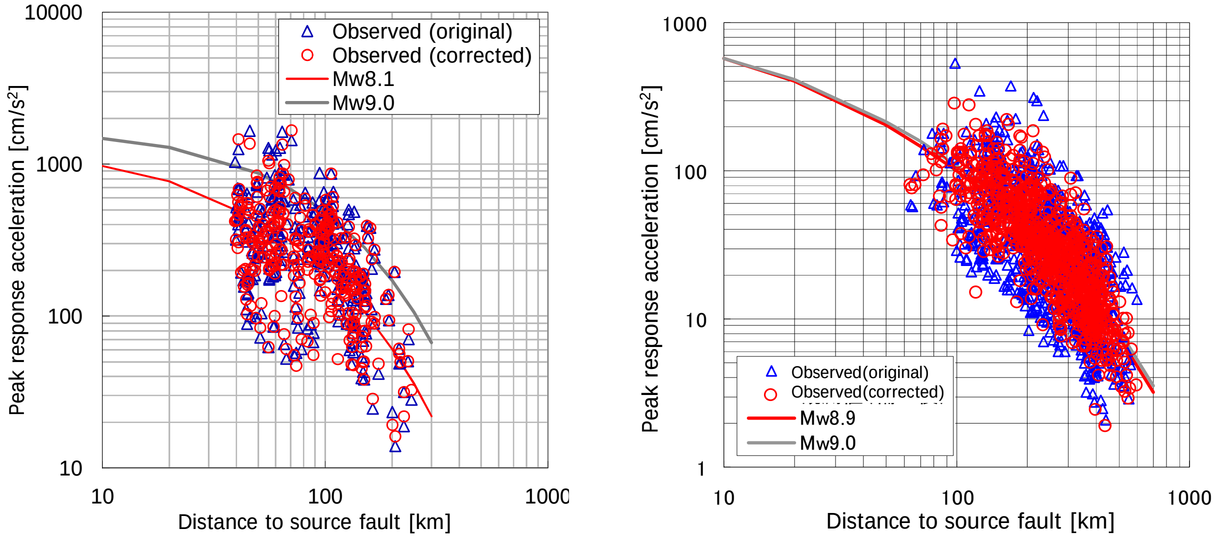
regions[10) and 11)] having been used for designating the Areas for Intensified/Promoted Earthquake Disaster Prevention Measures in 2002 and 2003.The zone factor of 1.2 was set for the areas predicted to have stronger ground motions than those experienced in the Tokyo area during the 1923 Kanto Earthquake taking into account the coupling of earthquakes such as the Off the Pacific Coast of Tohoku Earthquake, Off the Pacific Coast of Hokkaido Earthquake, and the Tokai-Tonankai -Nankai-Hyuganada Earthquake[12) and 13)].

Note that the attenuation relationship for short period ground motion were found to have the least misfit (square-sum of the residual-errors) with the observations during the Tohoku Earthquake at Mw of 8.1 to 8.3[14)] as shown in Figure-3.2.1.(a) as an example of the acceleration response spectrum with natural period of 1 s. Thus, we set the upper limit of Mw 8.3 for calculating ground motion intensity by the attenuation relationship for short period[8)], and, in contrast, we set Mw 9.0 as the upper limit for long period motions, because the misfit becomes the least at the Mw of 8.7 to 8.9 as shown in Figure-3.2.1.8 (b) as an example of the acceleration response spectrum with natural period of 3 s.

(3) Acceleration Waveforms for Dynamic Analysis

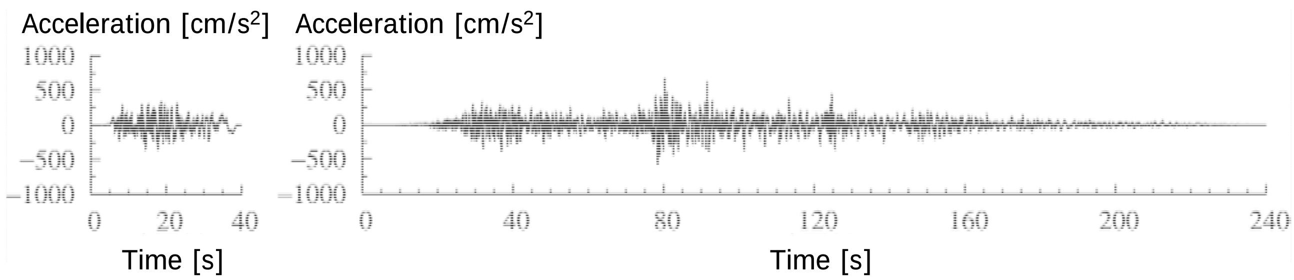
Acceleration waveforms for seismic design through dynamic analyses were produced by a spectral fitting technique. Three waveforms were prepared for each ground type using strong motion records from the 2003 off Tokachi and the Tohoku Earthquakes as original waveforms.

Figure-3.2.1.9 shows, as an example for comparison, the original acceleration waveform for one of three waveforms for ground type II and the revised waveform; the original waveform (a) and the revised waveform (b) were obtained by spectral fitting from the strong motion records observed respectively on the soil near Itajima-bashi Bridge, Uwajima City,



(a) Peak Response Acceleration (Natural period: 1 s) (b) Peak Response Acceleration (Natural period: 3 s)

Figure-3.2.1.8: Comparison of Estimated Acceleration Response Spectra by Attenuation Relationships to Observations during the Tohoku Earthquake[8)]



(a) Original Waveform (b) Revised Waveform

Figure-3. 2. 1. 9: Example of Acceleration Waveform of Level 2 Earthquake Motion (Type I) for Dynamic Analysis (one of three waveforms for ground type II)

Ehime Prefecture during the 1968 Hyuganada Earthquake (M_J 7.5), and on the soil in the premises of Sendai River and National Highway Office during the Tohoku Earthquake. It is obvious that one of the remarkable aspects of the ground motions observed during the Tohoku Earthquake is that their duration is long; we decided to apply such a long ground motion waveform to practical analyses because drastic performance improvements in computers have made it practical to conduct dynamic analysis using an input motion with a long duration.

Acknowledgements

The observation records obtained by the Japan Meteorological Agency, the National Research Institute for Earth Science and Disaster Prevention, West Japan Railway Company, and the Ministry of Land, Infrastructure, Transportation and Tourism were used in this study. We would like to express our appreciation to these organizations.

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3.2.2 Tsunami

3.2.2.1 Coastline

(1) Tsunami Inundation Survey

1) Definition of Height

Figure 3.2.2.1 shows the relationship between tsunami height and inundation depth, inundation height and run-up height.

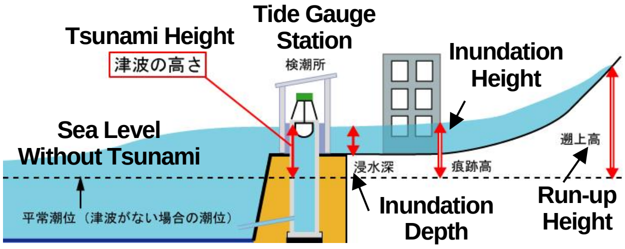

Figure 3.2.2.1 Relationship between Tsunami Height and Inundation Depth, Inundation Height, and Run-up Height at a Tide Gauge Station (from the Meteorological Agency website)

2) Survey Method and Survey Items

The survey method, survey items and criteria for determining the reliability of the traces have been taken from the website of the 2011 Tohoku Earthquake Tsunami Joint Survey Group.

The measurement of tsunami height (including run-up height, inundation height, and rises in the sea level in ports) in field surveys is usually carried out by means of the following method.

(i) Finding traces of the tsunami height (e.g. seawater marks, debris, and verbal evidence).

(ii) Photographing the traces and surrounding area.

(iii) Using GPS to confirm the position.

(iv)Measuring the height of the traces above the shoreline and their distance from it. (Recording the time at which the shoreline was measured.)

Table 3.2.2.1 shows an example of the data sheet used in the field survey.

Table 3.2.2.1 Example of data sheet

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Survey Locations	Latitude & Longitude (GPS)	Survey Time	Measured Value	Reliability	Horizontal Distance	Inundation Height / Run-up Height Distinction	Topography Incline	Height of Tide Level or Benchmark	Tsunami Height After Correction
		hours minutes	m units	A-D	m units		°	m units	m units

The following shows the judgment criteria concerning the reliability of the traces.

A: High reliability. Clear traces, with the smallest margin of error in measurement.

B: Moderate reliability. Traces unclear, so interviews were conducted that made it possible to establish the water level with some reliability, based on the surrounding situation. Low margin of error in measurement.

C: Low reliability. Other factors suggesting waves came up to an extreme degree, or traces where the observation point is located some distance from the shore and there is a large margin of error in the measurement.

D: Minimal reliability. Unclear traces due to overlapping by high tides, typhoons, etc.

3) Timing of Survey and Involved Groups

The most important factor in field surveys concerning tsunami is the timing of the visit to the disaster-afflicted area. If the start of the survey is delayed, the traces of the tsunami disappear and the recollections of eyewitnesses become vague. However, if it begins too early, there is an increased risk that it could hamper search and rescue operations. Moreover, if each researcher conducts independent field surveys, there is a tendency for them to be concentrated in areas in which there was immense damage and areas in which the pattern of damage had particular characteristics. Accordingly, in order to obtain survey results effectively, while minimizing the burden on the disaster-afflicted areas, the 2011 Tohoku Earthquake Tsunami Joint Survey Group was formed and carried out field surveys while also coordinating such matters as the areas to be surveyed, the timing of this, and the number of staff to be involved. Other participants in the 2011 Tohoku Earthquake Tsunami Joint Survey Group included staff from universities and research institutes, as well as from private sector companies and government bodies. Moreover, a wide range of academic societies was involved, including the Japan Society of Civil Engineers and the Japan Geoscience Union, so field surveys were carried out with the cooperation of specialists in a variety of fields, and the survey data were then consolidated. These data include the survey results measured by

NILIM.

4) Survey Results

The data concerning inundation height and run-up height consolidated by the 2011 Tohoku Earthquake Tsunami Joint Survey Group have been plotted on Figure 3.2.2.2.

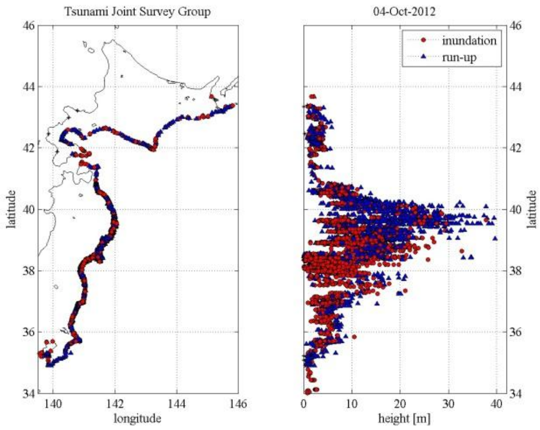

Figure 3.2.2.2 Coastal Distribution of Traces (Results of Survey by the 2011 Tohoku Earthquake Tsunami Joint Survey Group [October 4, 2012])

From Figure 3.2.2.2, we can see that the inundation height and the run-up height exceeded 10m on Miyagi Prefecture and Fukushima Prefecture. There were many places in this sector that suffered immense damage.

Based on the results above and the trace survey measurements taken by NILIM, distribution of the trace heights along the tsunami run-up direction was investigated on the southern Sendai Plain, the Ishinomaki Plain, Rikuzentakata, and the Taro district of Miyako City, in which areas the topography of the tsunami run-up zone differed. Then the characteristics of the tsunami inundation flow were estimated from these distribution results. In terms of trends in the run-up, it was ascertained that the tsunami traces diminished along the run-up direction on the plains, where there was an extensive run-up zone. In contrast, the tsunami traces did not diminish, but actually rose in some cases on areas where the run-up zone was confined to a narrower area (Rikuzentakata and the Taro district of Miyako City). The details are shown below.

(i) Southern Sendai Plain

Figure 3.2.2.3 shows the tsunami trace height survey lines on the southern Sendai Plain. Moreover, Figures 3.2.2.4 - 3.2.2.19 show the trace height distribution for each of these survey lines. From Figure 3.2.2.4 - 3.2.2.15, we can see that the trace height diminishes along the tsunami run-up direction. Moreover, in figure 3.2.2.16 - 3.2.2.19, the trace heights did not diminish along the tsunami run-up direction. This is thought to be because the plain becomes narrower from the Kasano Coast to Isohama Fishing Port and the hilly terrain impeded tsunami run-up.

Figure 3.2.2.3 Tsunami Trace Height Survey Lines (Southern Sendai Plain)
(L1: Behind Sendai Shinko Port, L2: Left Bank of the Nanakita River, L3: Sendai Coast, L4: Arahama Coast, L5: Left Bank of the Natori River, L6: Right Bank of the Natori River, L7: Hiroura, L8: Kabasaki Coast, L9: Left Bank of the Abukuma River, L10: Right Bank of the Abukuma River, L11: Torinoumi Brackish Lake, L12: Yoshidahama Beach, L13: Kasano Coast, L14: Sakamoto River, L15: Nakahama Coast, L16: Isohama Fishing Port)

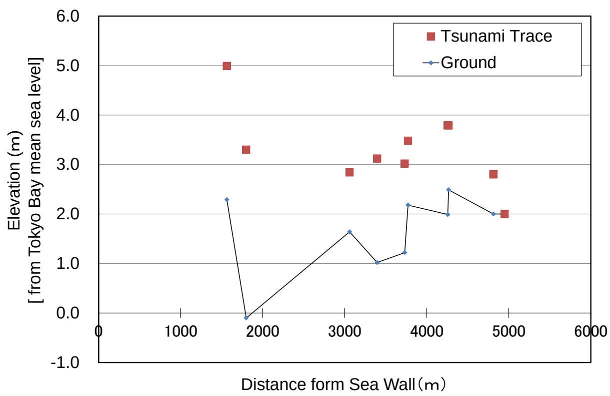

Figure 3.2.2.4 Trace Height Distribution (Behind Sendai Shinko Port)

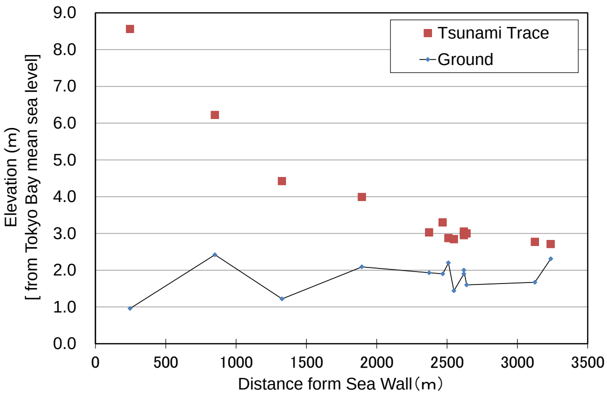

Figure 3.2.2.5 Trace Height Distribution (Left Bank of the Nanakita River)

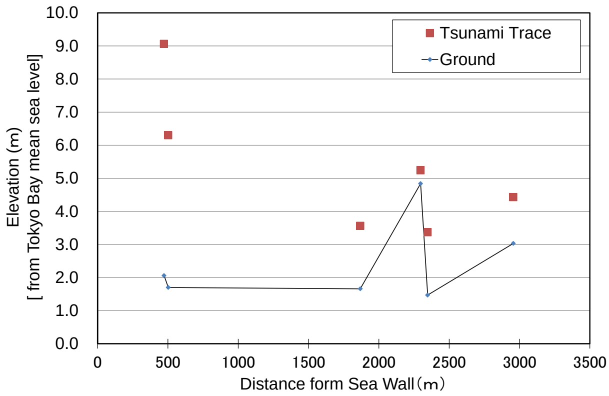

Figure 3.2.2.8 Trace Height Distribution (Left Bank of the Natori River)

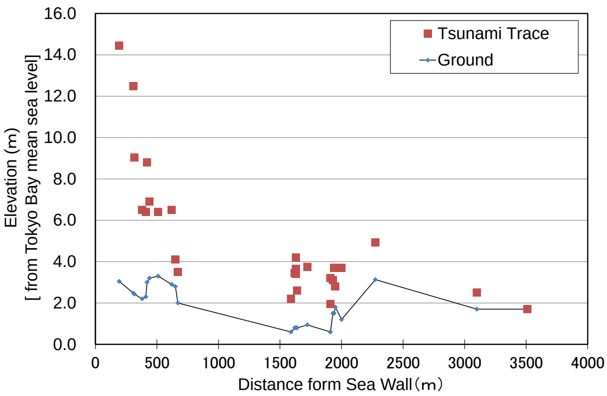

Figure 3.2.2.6 Trace Height Distribution (Sendai Coast)

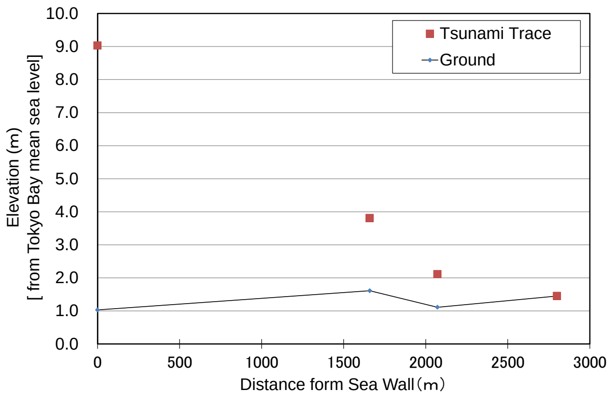

Figure 3.2.2.9 Trace Height Distribution (Right Bank of the Natori River)

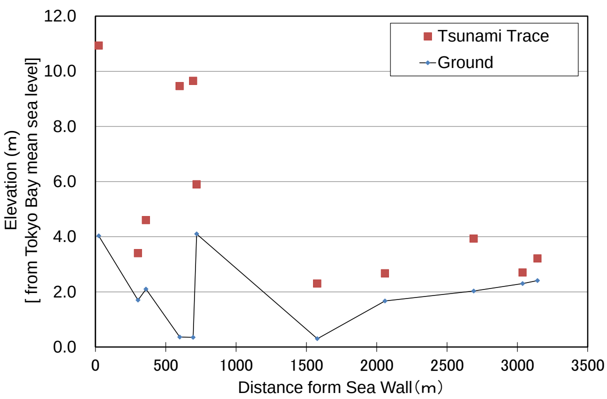

Figure 3.2.2.7 Trace Height Distribution (Arahama Coast)

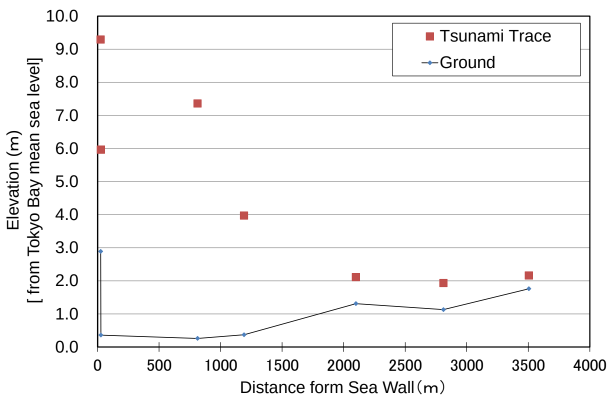

Figure 3.2.2.10 Trace Height Distribution (Hiroura)

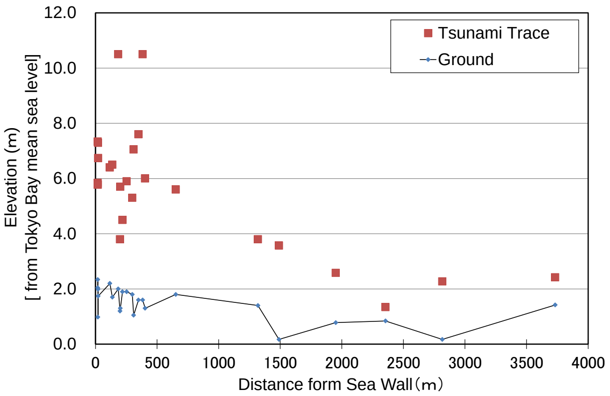

Figure 3.2.2.11 Trace Height Distribution (Kabasaki Coast)

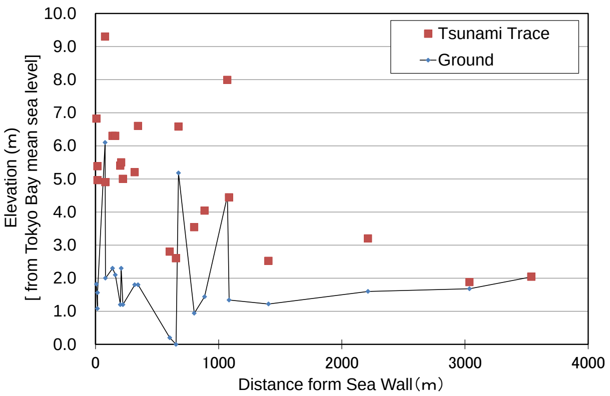

Figure 3.2.2.12 Trace Height Distribution (Left Bank of the Abukuma River)

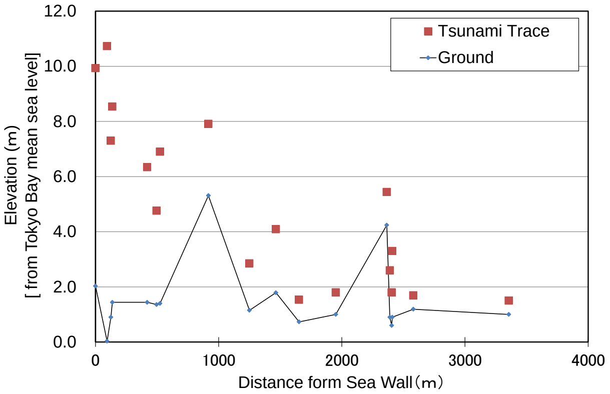

Figure 3.2.2.13 Trace Height Distribution (Right Bank of the Abukuma River)

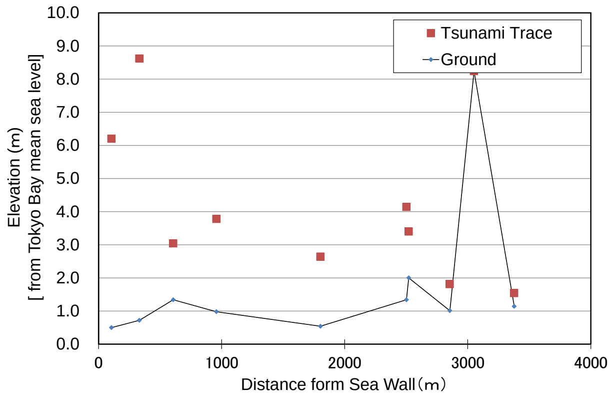

Figure 3.2.2.14 Trace Height Distribution (Torinoumi Brackish Lake)

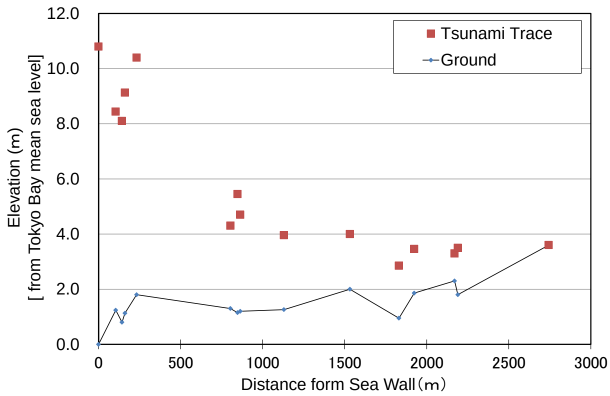

Figure 3.2.2.15 Trace Height Distribution (Yoshidahama Beach)

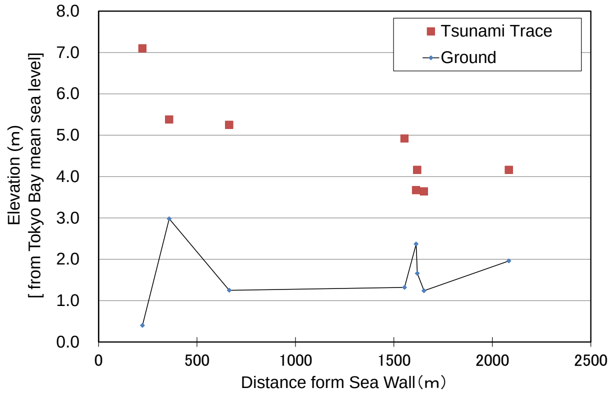

Figure 3.2.2.16 Trace Height Distribution (Kasano Coast)

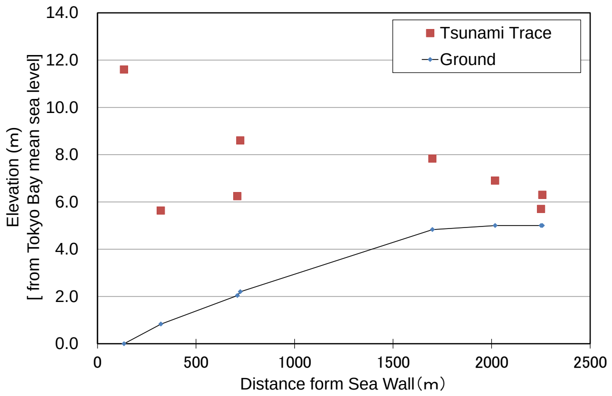

Figure 3.2.2.17 Trace Height Distribution (Sakamoto River)

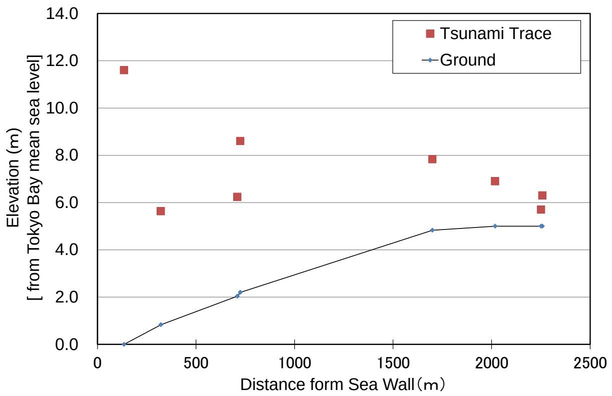

Figure 3.2.2.18 Trace Height Distribution (Nakahama Coast)

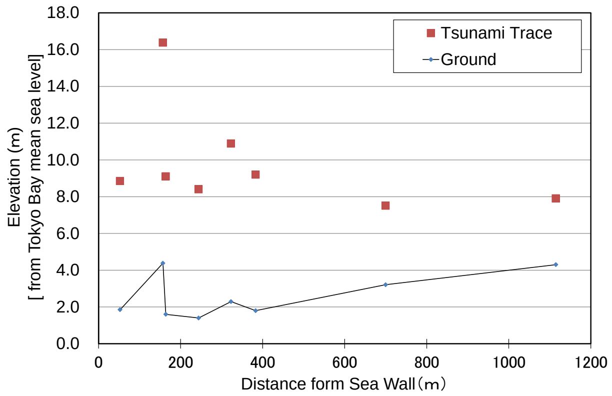

Figure 3.2.2.19 Trace Height Distribution (Isohama Fishing Port)

(ii) Ishinomaki Plain

Figure 3.2.2.20 shows the tsunami trace height survey lines on the Ishinomaki Plain. Moreover, Figures 3.2.2.21 and 22 show the trace height distribution for each of these survey lines. From Figure 3.2.2.21 and Figure 3.2.2.22, we can see that the trace height diminishes along the tsunami run-up direction, in the same way as on the Sendai Plain.

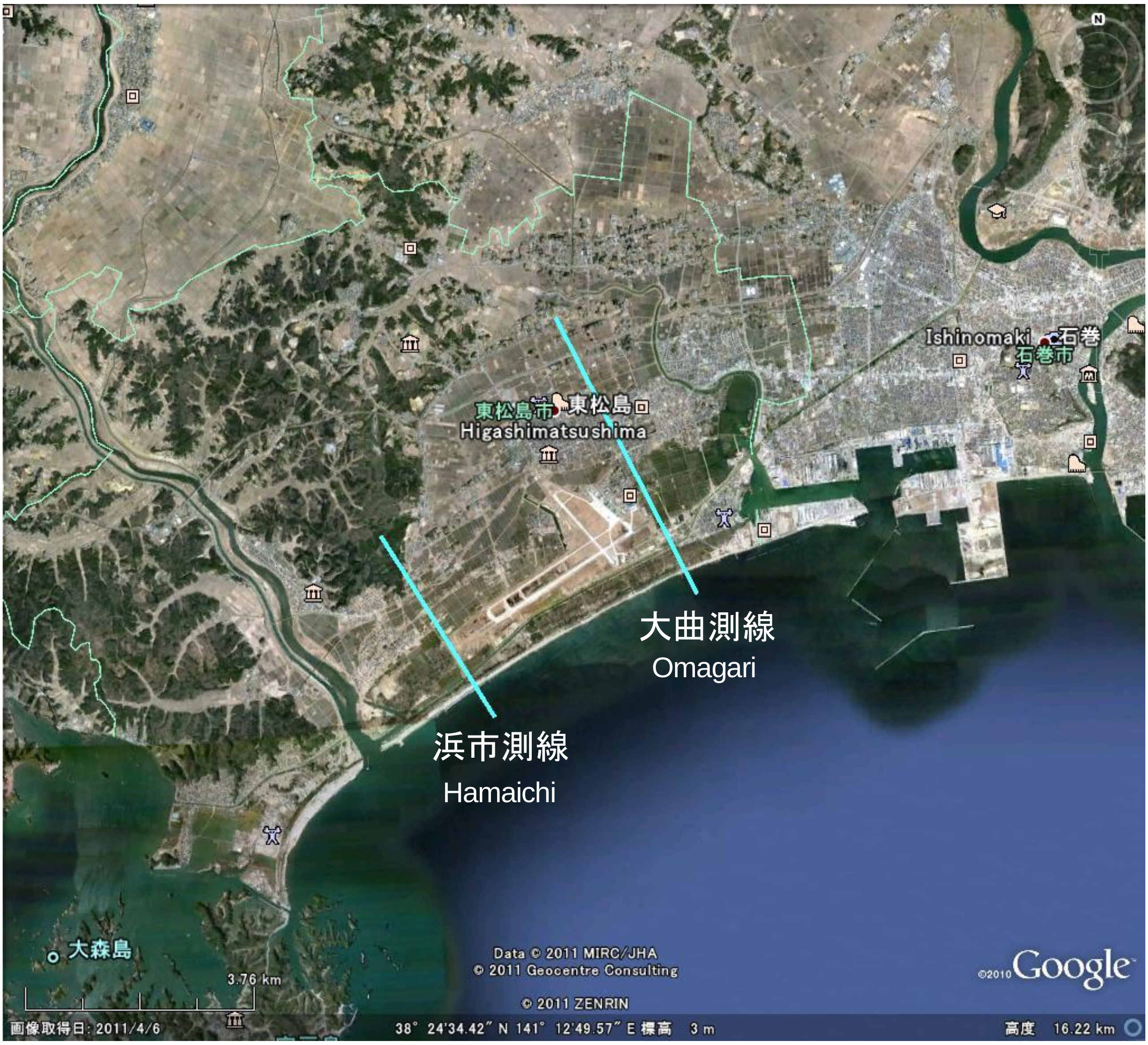

Figure 3.2.2.20 Tsunami Trace Height Survey Lines (Ishinomaki Plain)

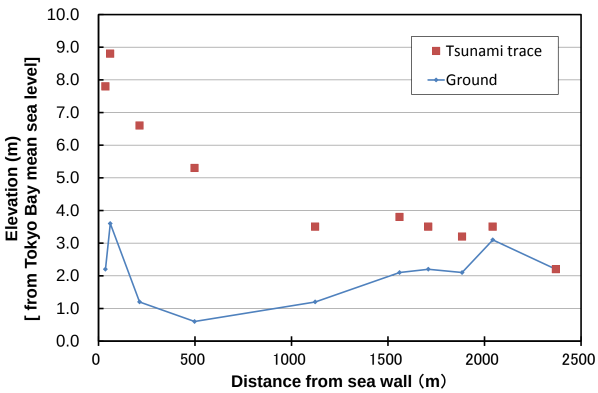

Figure 3.2.2.21 Trace Height Distribution (Hamaichi)

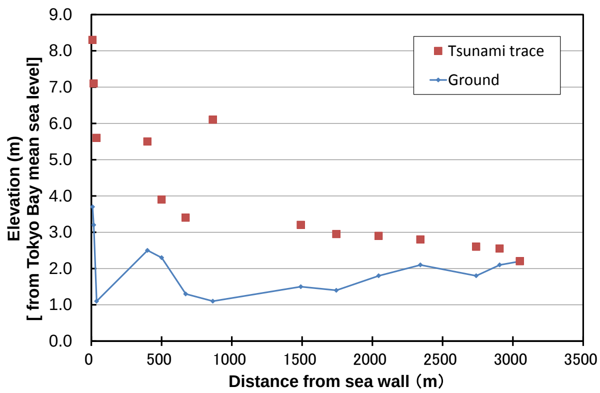

Figure 3.2.2.22 Trace Height Distribution (Omagari)

(iii) Rikuzentakata

Figure 3.2.2.23 shows the tsunami trace height survey lines in Rikuzentakata. Moreover, Figure 3.2.2.24 shows the trace height distribution for each of these survey lines. In terms of characteristics identified from the results of survey lines 1-3 in Figure 3.2.2.24, we cannot see any attenuation in trace height along the tsunami run-up direction, and the trace height continues to be parallel as same as observed on the southern Sendai Plain. This is thought to be because the plain is narrow and the hilly terrain impeded tsunami run-up.

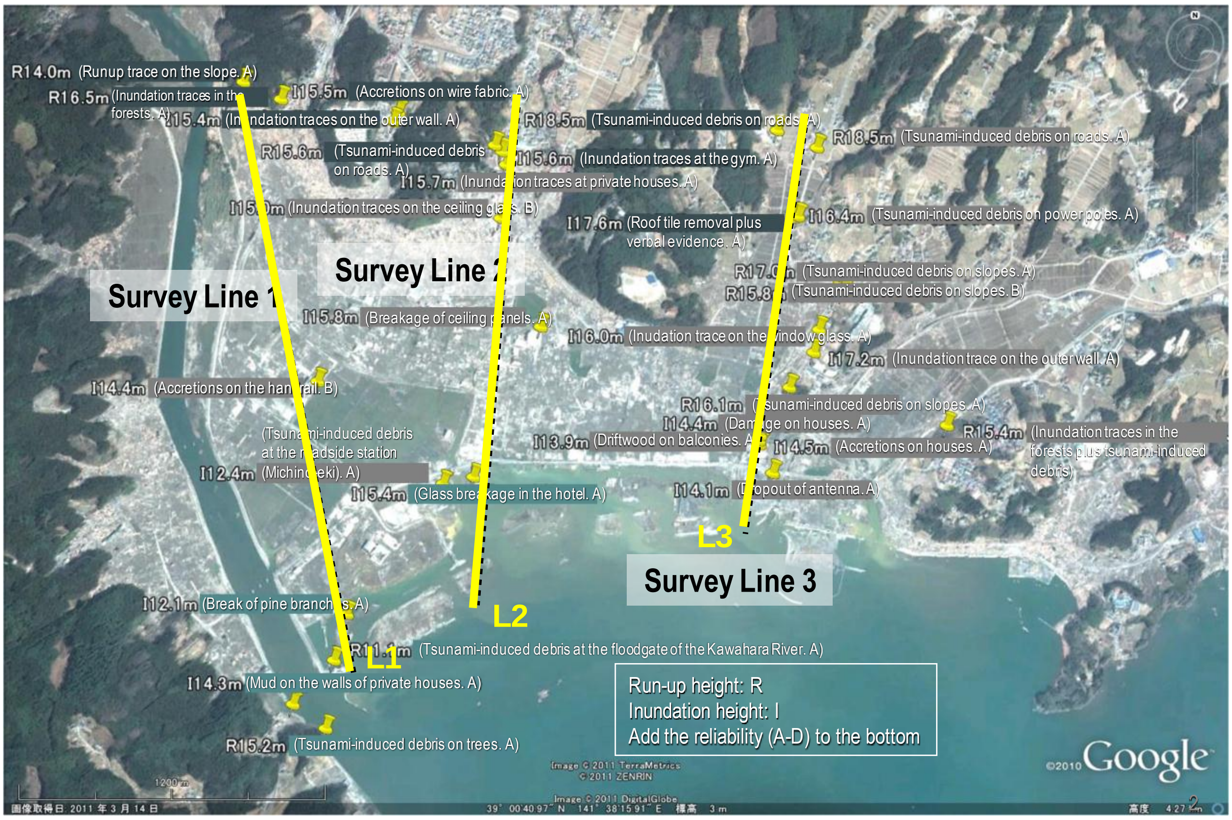

Figure 3.2.2.23 Tsunami Trace Height Survey Lines (Rikuzentakata)

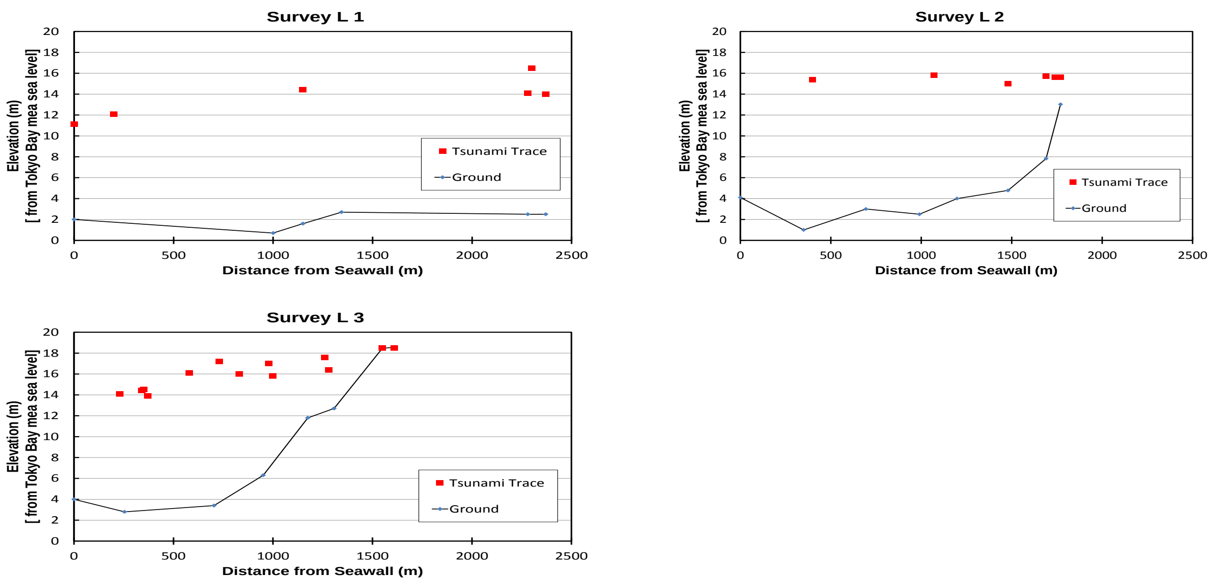

Figure 3.2.2.24 Trace Height Distribution (Rikuzentakata)

Diagrams plot the results of surveys by the 2011 Tohoku Earthquake Tsunami Joint Survey Group, Tohoku Regional Development Bureau of MLIT, and NILIM.

(iv) Taro District of Miyako City

Figure 3.2.2.25 shows the tsunami trace height survey lines in the Taro district of Miyako City. Moreover, Figure 3.2.2.26 shows the trace height distribution for each of these survey lines. In terms of characteristics identified from the results of survey lines 1-2 in Figure 3.2.2.26 , one cannot see any attenuation in trace height in the tsunami run-up direction, and the trace height continues to be parallel, in the same way as the survey lines on the southern Sendai Plain and in Rikuzentakata, or rises. This is thought to be because the plain is narrow and the hilly terrain impeded tsunami run-up as in Rikuzentakata.

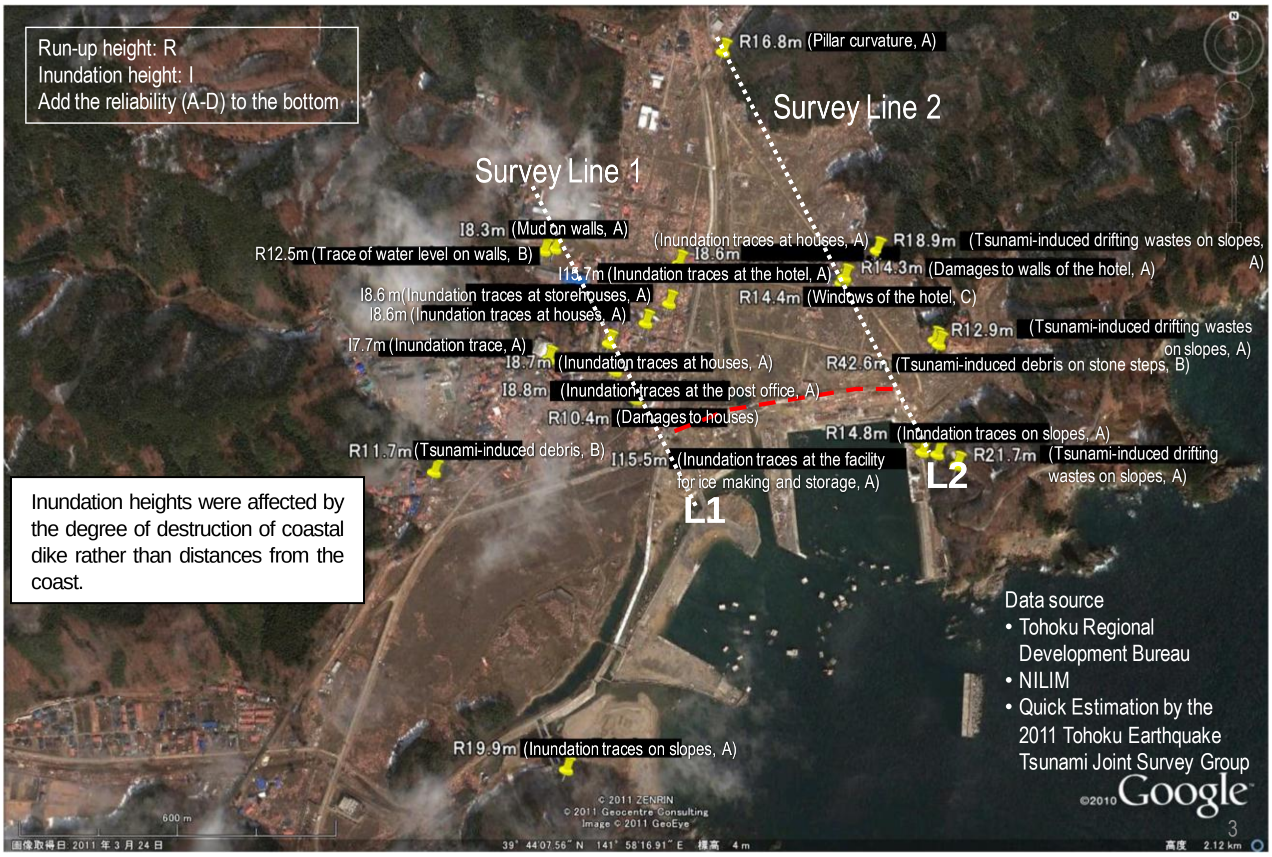

Figure 3.2.2.25 Tsunami Trace Height Survey Lines (Taro District of Miyako City)

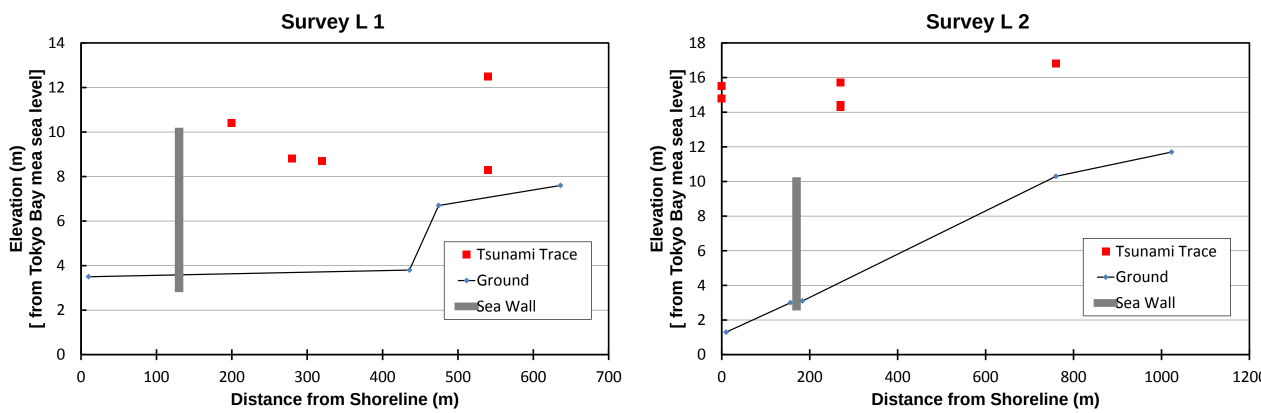

Figure 3.2.2.26 Trace Height Distribution (Taro District of Miyako City)

Diagrams plot the results of surveys by the 2011 Tohoku Earthquake Tsunami Joint Survey Group, Tohoku Regional Development Bureau of MLIT, and NILIM.

5) Summary

Based on the foregoing data, the following facts were suggested.

(i) On the plains, where there was a broad run-up zone, the tsunami trace height diminished along the direction of tsunami run-up.

(ii) In places where the run-up zone was confined to a narrower area, in contrast to the plains, the tsunami trace height did not diminish along the direction of tsunami run-up, but actually rose in some cases (this appears to be because the hilly terrain impeded tsunami run-up before it was attenuated by friction with the land surface and buildings, so the kinetic energy of the flow was changed into potential energy).

(2) Numerical simulation of Tsunami Inundation

1) Method of Analysis

In order to understand the attributes of the tsunami that ran up on shore, the tsunami inundation was calculated in cases where there was no seawall and where there was a seawall, on the southern Sendai Plain, in Rikuzentakata, and in the Taro district of Miyako City, and the inundation depths and flow velocities were compared.

Using the Fujii and Satake model ver.4.0[1], which is one of the fault plane models for the Great East Japan Earthquake, the movement of the sea bottom was calculated using a technique following Okada (1992)[2], and with this as the initial profile, the tsunami inundation was calculated by means of a two-dimensional shallow water model based on a nonlinear long-wave equation. However, of the parameters in the fault model, the slippage was adjusted to increase the fitness of the inundation situation in each sector. Moreover, in the Great East Japan Earthquake, diastrophism caused pronounced ground deformation, so based on the data measured by the Geospatial Information Authority of Japan, land subsidence was set uniformly at 0.5m from the pre-disaster altitude data in the southern Sendai Plain, 0.7m in Rikuzentakata, and 0.5m in the Taro district of Miyako City.

2) The simulation on the Southern Sendai Plain

Table 3.2.2.2 shows the computational conditions for calculating tsunami inundation. The grid spacing for the calculations was set at 1,350m, 450m, 150m, 50m, and 10m from the offshore area including the source area of the tsunami, so that it became smaller the closer it came to the area concerned.

Table 3.2.2.2 Computational Conditions (Southern Sendai Plain)

Item	Content
Grid spacing for calculations	(Wave source - coast) 1,350m, 450m, 150m, 50m, 10m
Calculation time	3 hour
Calculation time interval	0.1 seconds
Tide level condition	High water (T.P. +0.76m)
Cutoff depth of wave front during runup on land	10^{-5}m
Roughness coefficient	0.025
Overflow boundary (breakwater, embankment, etc.)	Overflow calculated using the Honma formula.

Moreover, the tide level at the time the tsunami struck (T.P. -0.42m) and tsunami inundation assuming that the seawalls were not destroyed were calculated separately and, as a result of using inundation data from 177 points to calculate the geometric mean K and the geometric standard deviation κ proposed by Aida (1977)[3], it was ascertained that generally good fitness (K=0.87, κ=1.34) could be obtained by setting the slip at 1.2 times the level used in the Fujii and Satake model ver.4.0.

The structural conditions of the seawall and other coastal structures were set on the basis of the three cases shown in Figure 3.2.2.27. In Case 1, it was assumed that there was no seawall, etc. In Case 2, it was assumed that the seawall, etc. was the same height as before the Great East Japan Earthquake, specifically 3.0-7.2m. In Case 3, it was assumed that the seawall, etc. had a height of T.P. +4.0m, equivalent to the highest water level reached in the area concerned, which was obtained via calculations of tsunami inundation using the fault model for the 1933 Sanriku Earthquake developed by Aida (1977).

Figure 3.2.2.28 shows changes in the water level over time at the point where the depth of the water was 10m, in front of the structure (the seaward side of the seawall), and behind the structure (the landward side of the seawall), on a cross-shore transect at Sendai. The maximum water level occurred immediately after the arrival of the first wave and increased in the order Case 2, Case 3, and Case 1 at the 10m depth point and in front of the structure, with the order being reversed behind the structure. While the water level on the seaward side rises due to the seawall, it appears to fall on the landward side.

Figure 3.2.2.29 shows the planar distribution of the maximum inundation depth in each case. With regard to the inundation range, the differences between cases are not clear, but the maximum inundation depth declined in the order Case 2, Case 3, and Case 1, so a tendency for the maximum inundation depth to decrease as the seawall height increases can be seen. In addition, a little to the west of the center of the inundation zone, the places where the maximum inundation depth change substantially meander from north to south, but this is due to the effects of the embankments built for the Sendai-Tobu Road and the Joban Expressway.

Figure 3.2.2.30 shows the planar distribution of the maximum flow velocity in each case. Compared with Case 1, one can see a tendency for the maximum flow velocity to decline in Cases 2 and 3, as the wave approaches the Sendai-Tobu Road and the Joban Expressway.

The diagrams in Figure 3.2.2.31 show the relationship between inundation depth h and flow velocity v at five-second intervals at three set points within the inundation zone in Cases 1 and 2. The diagrams also show relational expressions of inundation depth and flow velocity when the Froude number is 0.5, 1, and 2. At Point (1) that is the point closest to the sea on the seaward side, the flow velocity become high immediately after the tip of the tsunami arrives there and the inundation depth increases while the flow velocity remains broadly the same; the inundation depth then reaches a maximum when the Froude number is less than 1, after which both inundation depth and flow velocity decline. This kind of counterclockwise change over time can also be seen at Point (2), but at Point (1), it is not clear, due to the effect of the embankment of the Sendai-Tobu Road. In addition, at all three points, the inundation depth and flow velocity are smaller in Case 2 than in Case 1, demonstrating the effect of a seawall in reducing inundation depth and flow velocity.

Figure 3.2.2.32 shows the cumulative addition of the area of inundation, starting with the area with deeper inundation levels. Although the size of the total area of inundation increases in the order Case 1, Case 3, and Case 2, the difference is comparatively small, while the area with an inundation depth of at least 5m in Case 1 is approximately double that in Case 2. Accordingly, it would appear that, in this region, a seawall has the effect of reducing the area in which the inundation depth is comparatively high.

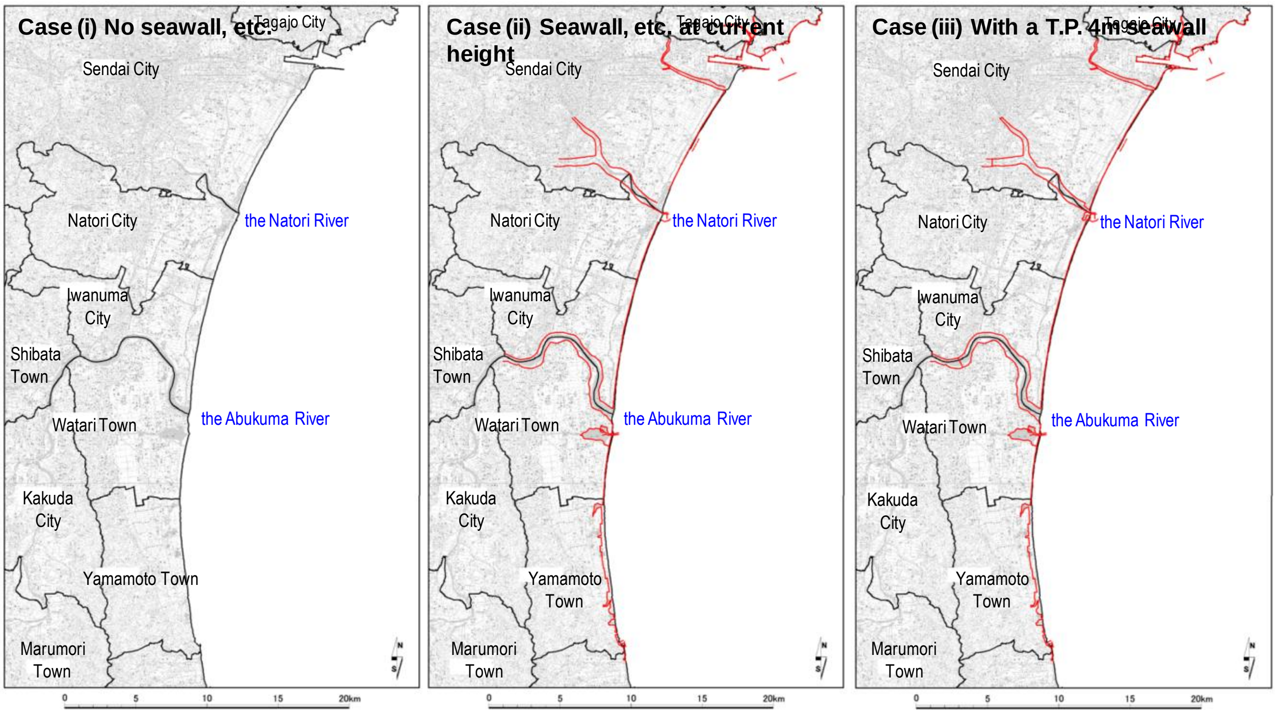

Figure 3.2.2.27 Structure Deployment in Each Case (indicated by red line)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

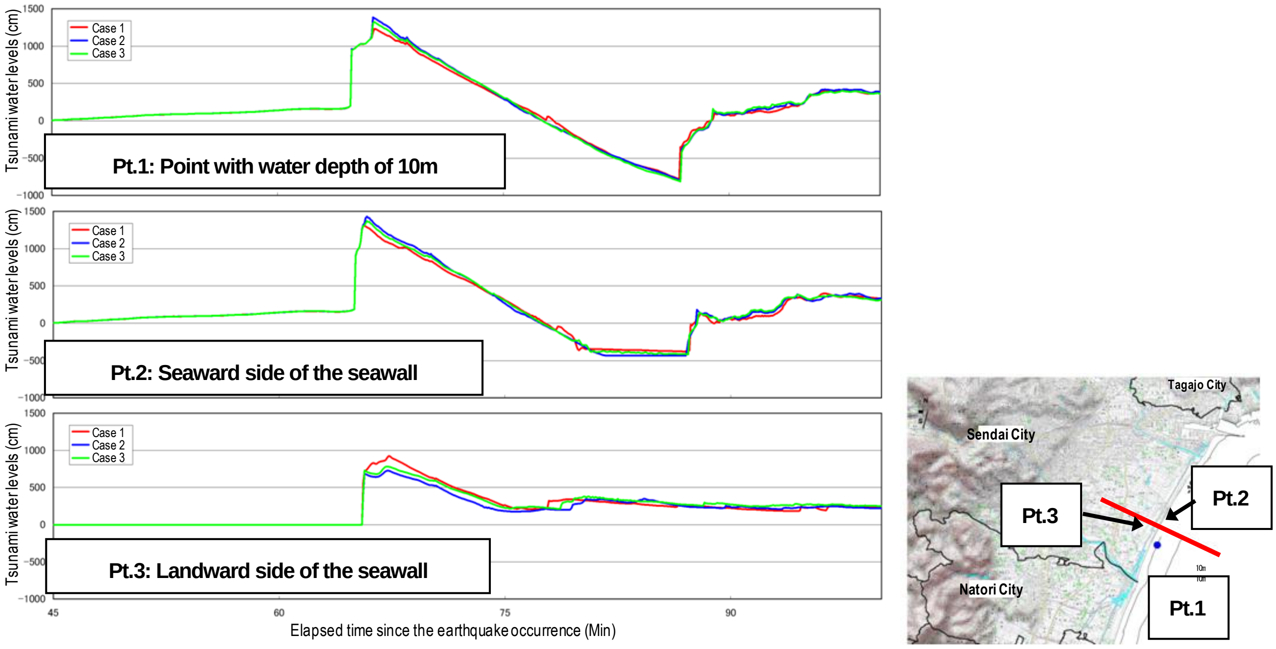

Figure 3.2.2.28 Time-series Data on Tsunami Water Levels (Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

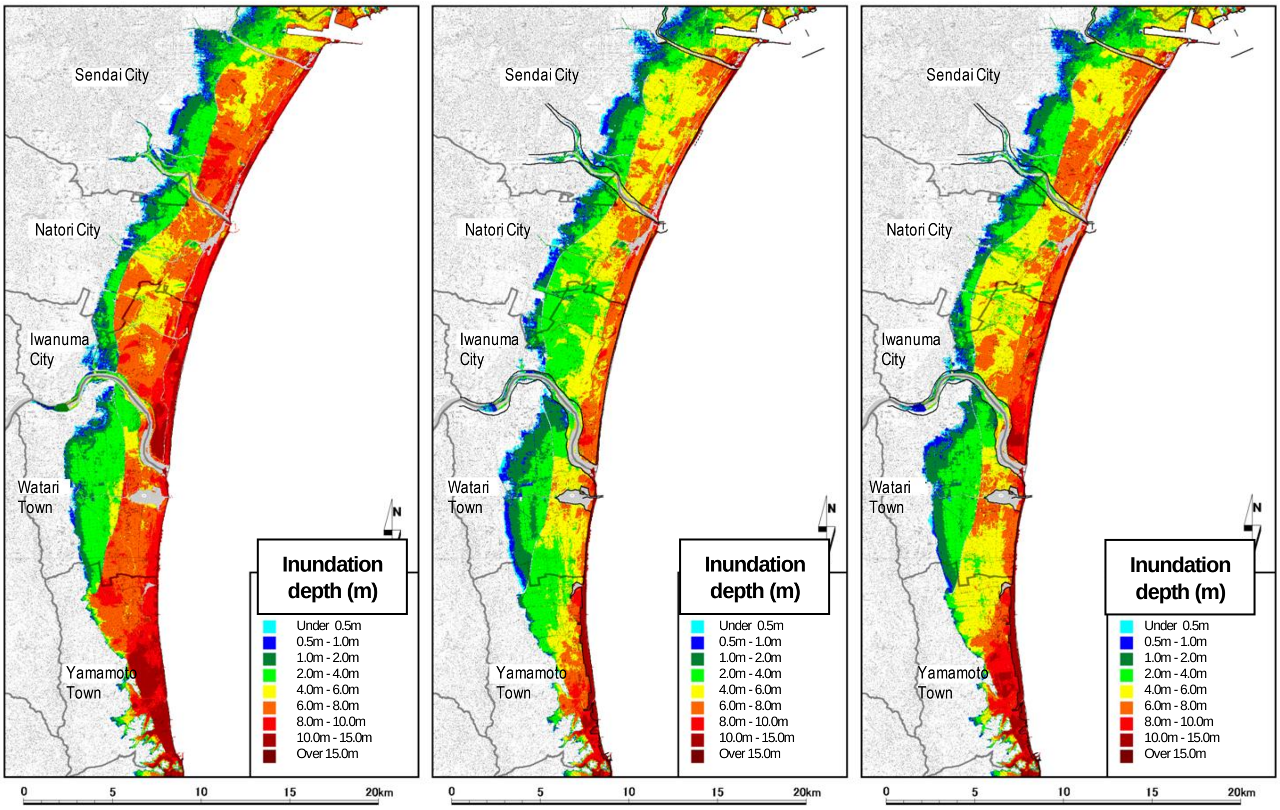

Figure 3.2.2.29 Maximum Inundation Depth (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

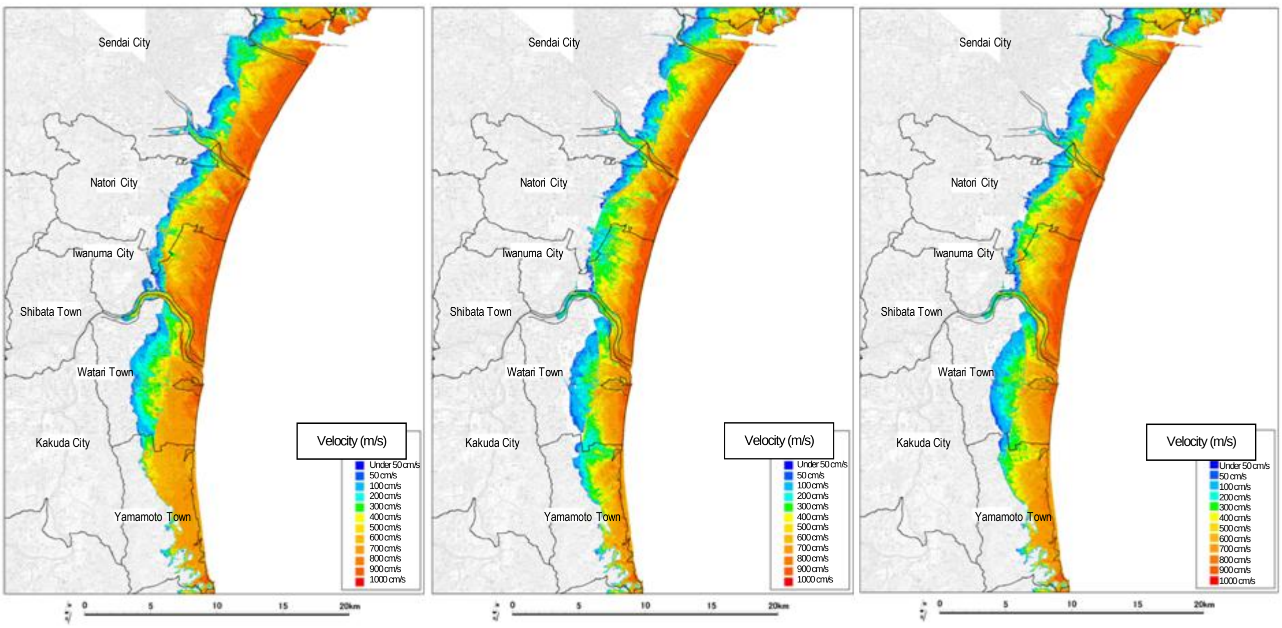

Figure 3.2.2.30 Maximum Flow Velocity (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

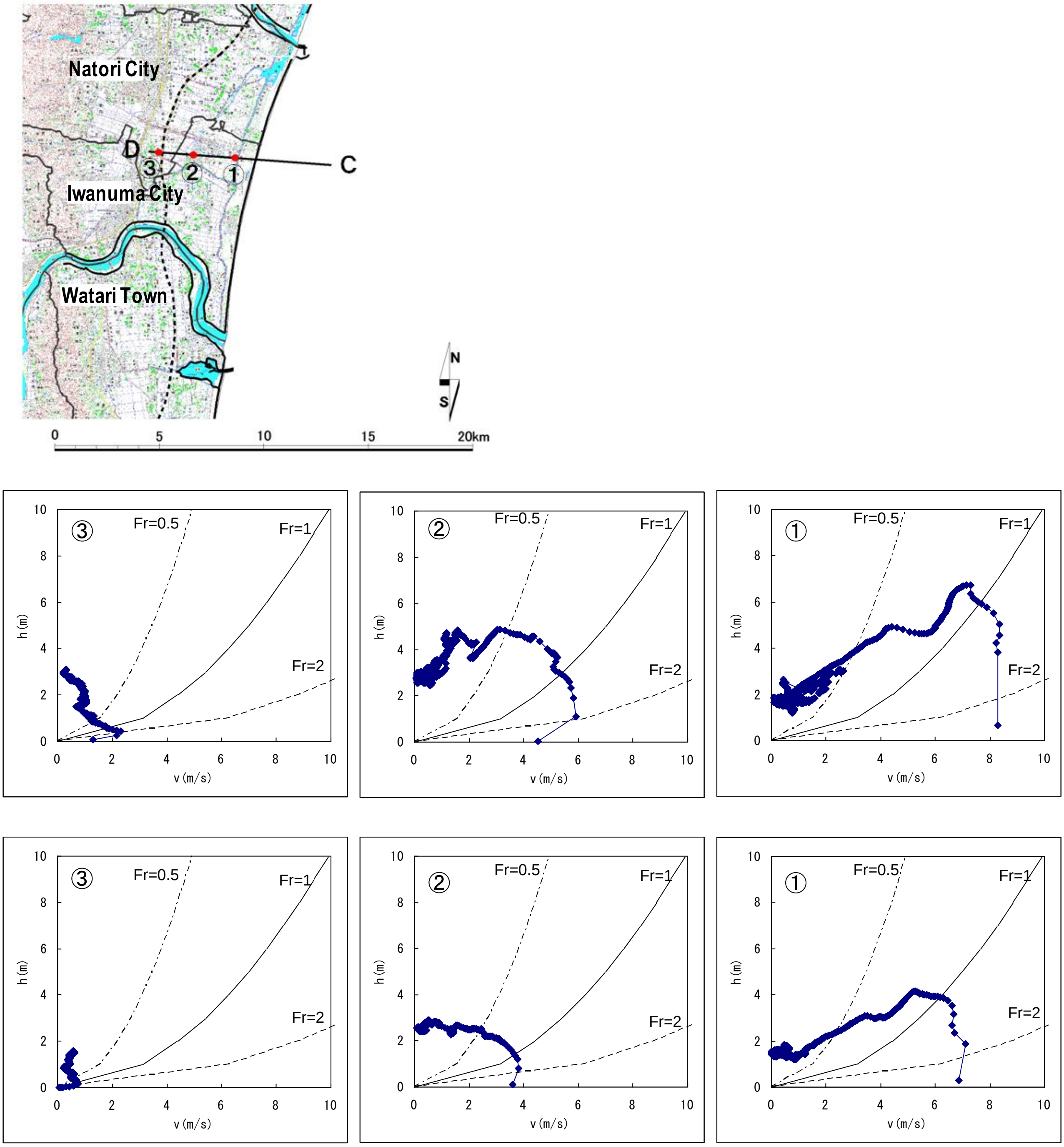

Figure 3.2.2.31 Relationship Between Inundation Depth and Flow Velocity (Top: Case 1; Bottom: Case 2)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

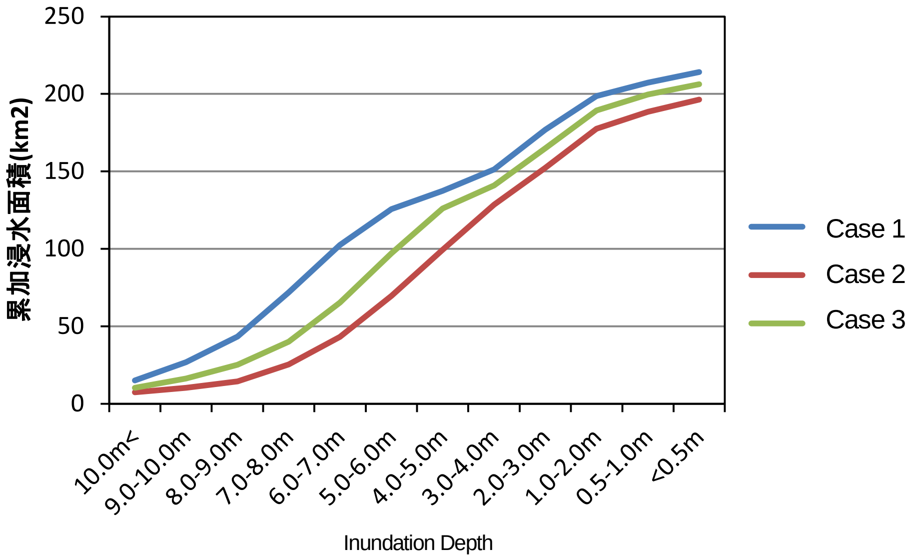

Figure 3.2.2.32 Cumulative Inundation Area by Inundation Depth Zone

3) The simulation on Rikuzentakata

Table 3.2.2.3 shows the computational conditions for calculating tsunami inundation. The grid spacing for the calculations was set at 3,240m, 1,080m, 360m, 120m, 40m, and 10m from the offshore area including the source area of the tsunami, so that it became smaller the closer it came to the area concerned.

Table 3.2.2.3 Computational Conditions (Rikuzentakata)

Item	Content
Grid spacing for calculations	(Wave source - coast) 3,240m, 1,080m, 360m, 120m, 40m, 10m
Calculation time	3 hours
Calculation time interval	0.2 seconds
Tide level condition	High water (T.P. +0.65m)
Truncation depth of wave front during runup on land	10^{-5}m
Roughness coefficient	0.025
Overflow boundary (breakwater, embankment, etc.)	Overflow calculated using the Honma formula.

Moreover, based on the results of simulations carried out by the Iwate Prefecture Expert Committee on Tsunami and Disaster Prevention Technology, the slip in the fault model was set at 1.3 times that in the Fujii and Satake model ver.4.0, in order to increase the reproducibility of the tsunami in the areas concerned.

The structural conditions of the seawall, etc. were set on the basis of the three cases shown in figure 3.2.2.33. In Case 1, it was assumed that there was no seawall, etc. In Case 2, it was assumed that the seawall, etc. kept the height it was at the time of the Great East Japan Earthquake, with a height of 4.95-6.15m. In Case 3, it was assumed that the seawall, etc. had a height of T.P. +5.2m, equivalent to the highest water level reached in the area concerned, which was obtained via calculations of tsunami inundation using the fault model for the 1933 Sanriku Earthquake developed by Aida (1977).

Figure 3.2.2.34 shows time-series data for the water level at three points where the water depth was 10m. After declining from the time of the earthquake until 30 minutes later, the water level sharply rises to T.P. +13-15m. Moreover, unlike the southern Sendai Plain, hardly any difference could be seen between cases in terms of the water level at the point where the water reached a depth of 10m.

Figure 3.2.2.35 shows the planar distribution of the maximum inundation depth in each case. The maximum inundation depth is in excess of 10m over an extensive area, but the differences between cases are not clear in relation to the inundation range. Moreover, as in Figure 3.2.2.36, which shows the difference in maximum inundation depth between Case 1 and Case 2, a tendency can be seen for the maximum inundation depth to be lower on the landward side of the seawall in case 2, while in Case 1 there is a tendency for it to be lower on the seaward side.

As shown in Figure 3.2.2.37, the maximum flow velocity is around 5m/s over an extensive area. When the cases were compared in terms of maximum flow velocity (Figure 3.2.2.38), in the same way as for maximum inundation depth, while the velocity was higher on the landward side of the seawall in cases with a seawall, it was lower on the seaward side of the seawall.

The diagrams in Figure 3.2.2.39 show the relationship between inundation depth h and flow velocity v at five-second intervals at three set points within the inundation zone in Cases 1 and 2. At Point (4), sandwiched between the primary and secondary seawalls, the flow velocity during the wash and backwash of the first wave becomes enormous, and in Case 2, with an seawall, the inundation depth rises quickly. At Points (5) and (6), located on the landward side of the seawall, the same counterclockwise change over time can be seen as on the southern Sendai Plain, but the flow velocity is quite a bit lower at the point where the inundation depth is at its highest. This indicates that the tsunami that ran up on shore was a standing wave, which is consistent with the fact that the trace heights in Rikuzentakata did not diminish in the inland direction. It is surmised that the same phenomenon occurred in sectors where the plain is comparatively narrow, as on the Sanriku Coast.

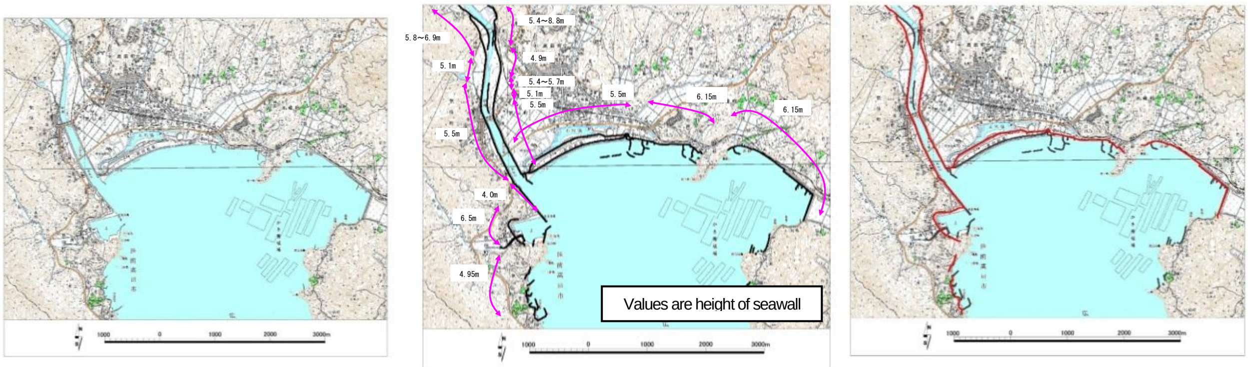

Figure 3.2.2.33 Structure Deployment in Each Case (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

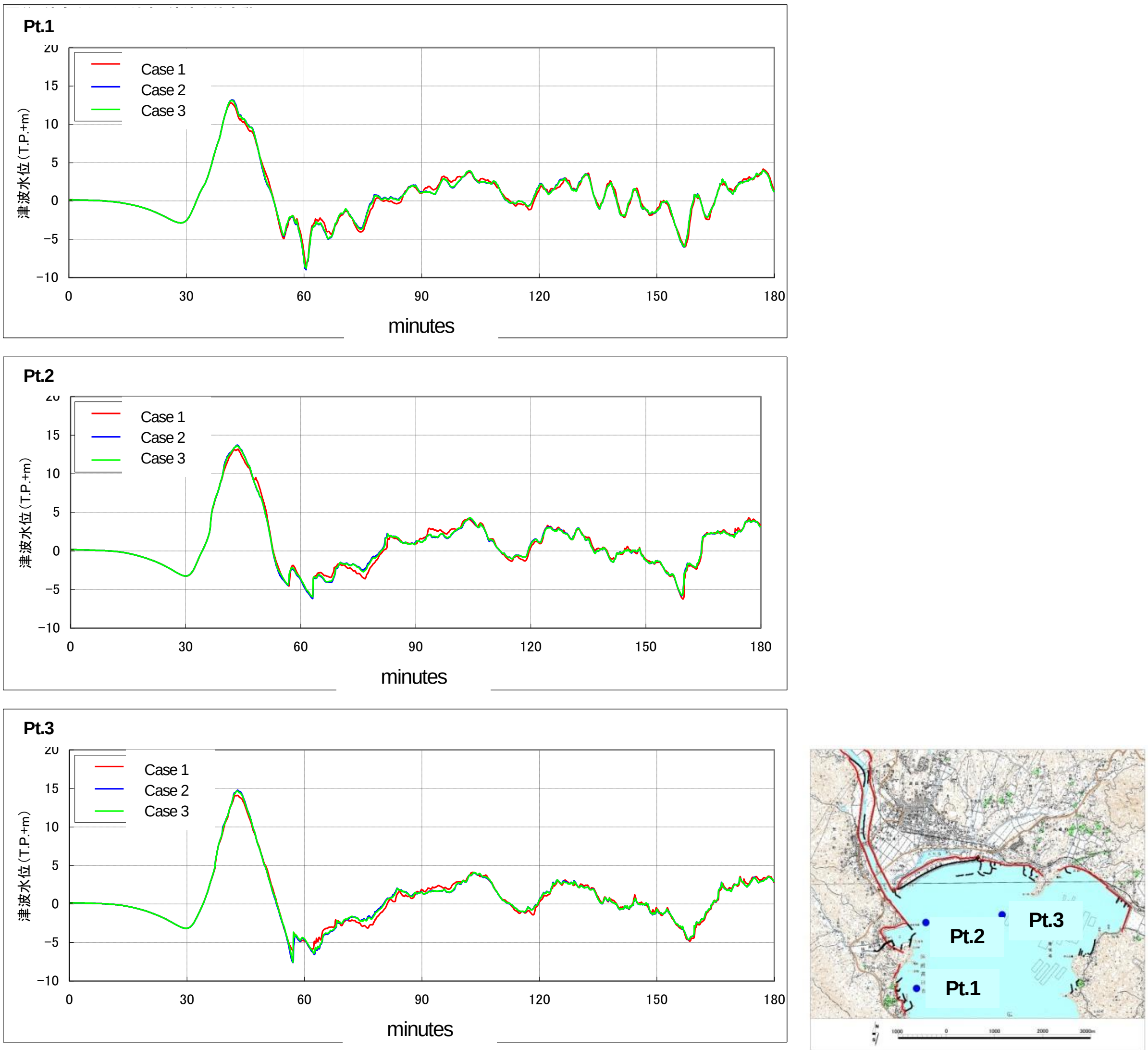

Figure 3.2.2.34 Time-series Data on Tsunami Water Levels (Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

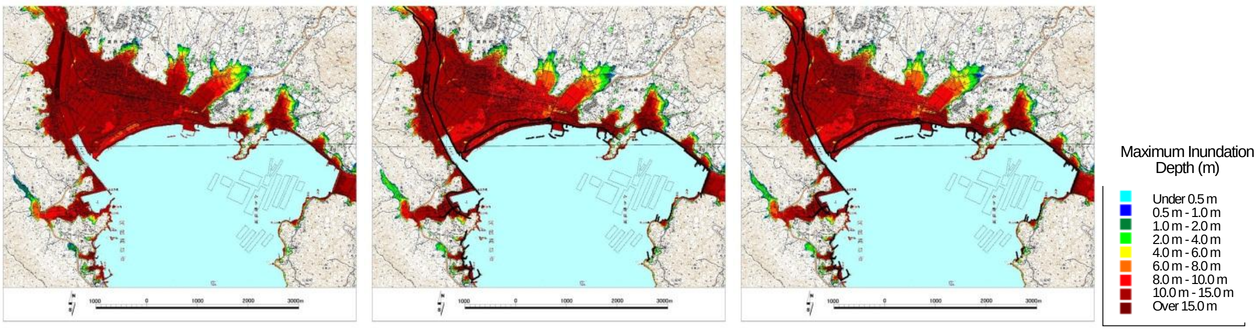

Figure 3.2.2.35 Maximum Inundation Depth (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

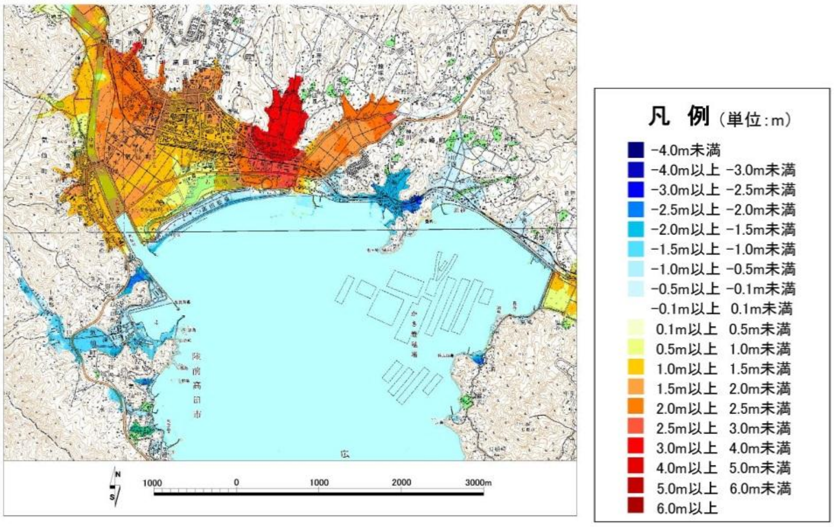

Figure 3.2.2.36 Difference in Maximum Inundation Depth (between Case 1 and Case 2)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

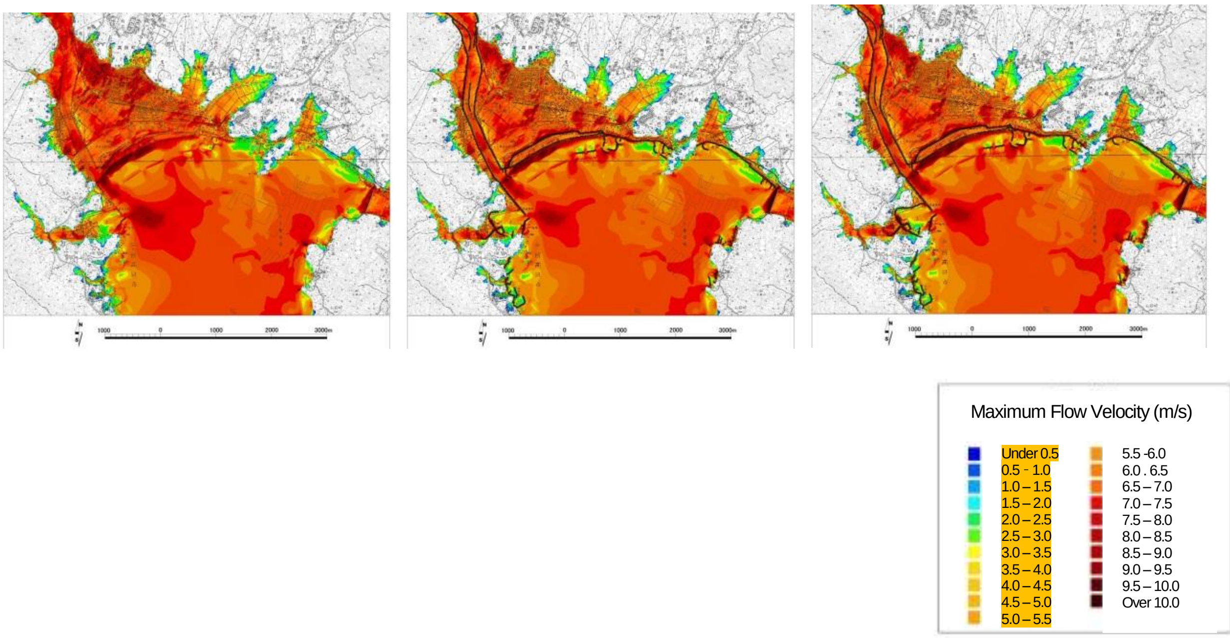

Figure 3.2.2.37 Maximum Flow Velocity (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

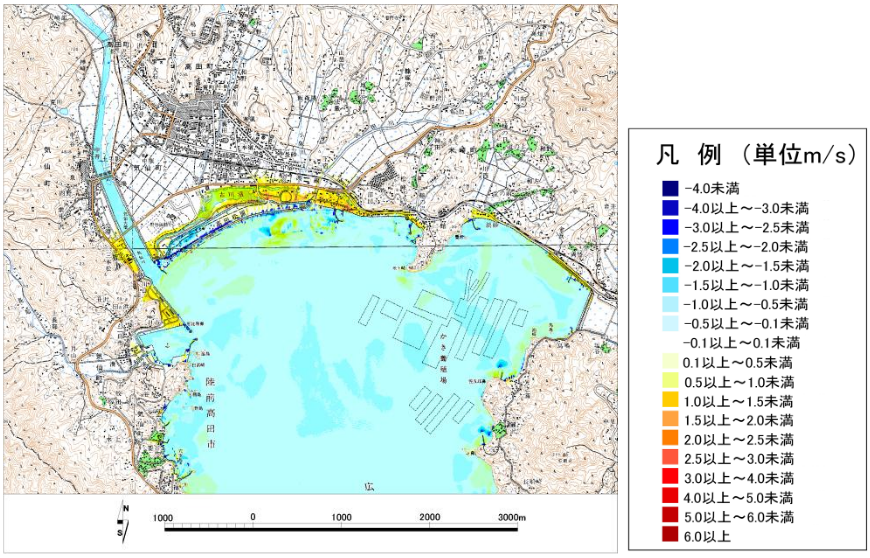

Figure 3.2.2.38 Difference in Maximum Flow Velocity (between Case 1 and Case 2)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

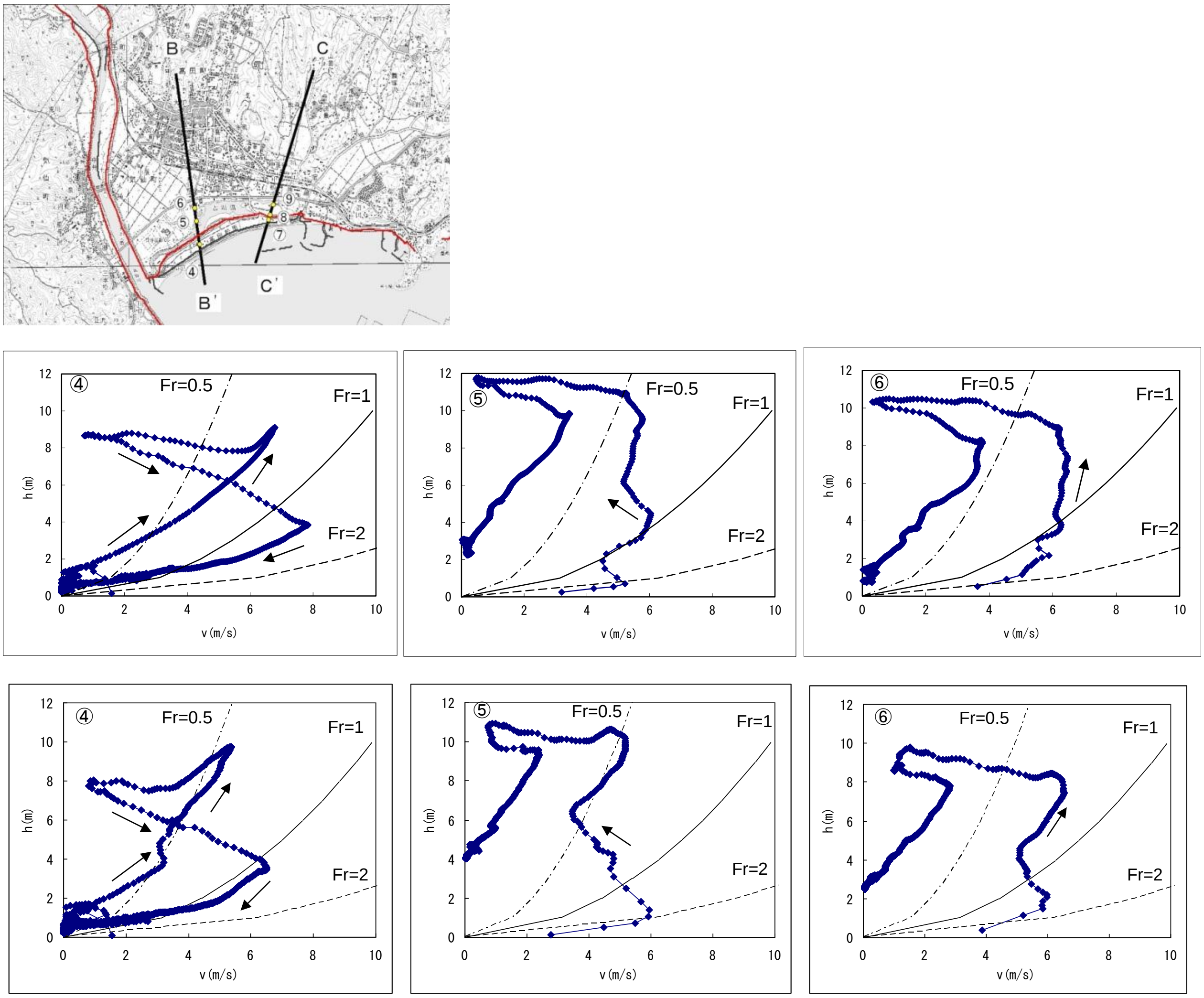

Figure 3.2.2.39 Relationship Between Inundation Depth and Flow Velocity (Top: Case 1; Bottom: Case 2)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

4) The simulation on the Taro District of Miyako City

Table 3.2.2.4 shows the computational conditions for calculating tsunami inundation. The grid spacing for the calculations was set at 3,240m, 1,080m, 360m, 120m, 40m, 20m, and 10m from the offshore area including the source area of the tsunami, so that it became smaller the closer it came to the area concerned.

Table 3.2.2.4 Computational Conditions (Taro District of Miyako City)

Item	Content
Grid spacing for calculations	(Wave source - coast) 3,240m, 1,080m, 360m, 120m, 40m, 20m, 10m
Calculation time	3 hours
Calculation time interval	0.2 seconds
Tide level condition	High water (T.P. +0.69m)
Truncation depth of wave front during runup on land	10^{-5}m
Roughness coefficient	0.025
Overflow boundary (breakwater, embankment, etc.)	Overflow calculated using the Honma formula.

Moreover, based on the results of simulations carried out by the Iwate Prefecture Expert Committee on Tsunami and Disaster Prevention Technology, the slip in the fault model was set at 2.9 times that in the Fujii and Satake model ver.4.0, in order to increase the fitness of the tsunami in the areas concerned.

As shown in the upper part of Figure 3.2.2.40, the conditions relating to structures such as seawalls were set as follows: in Case 1, there was assumed to be no seawall; in Case 2, there was assumed to be a seawall of the same height as that in place at the time of the Great East Japan Earthquake (seawall height: T.P. +10.0m); and in Case 3, the seawall at the front line (the yellow line on the map in Figure 3.2.2.40) was assumed to have a height of T.P. +13.0m (the height at which there would have been no overflow from the 1933 Sanriku Earthquake).

Looking at time-series data for inundation depth at the four points shown on the map in Figure 3.2.2.40, there is hardly any difference between cases at Point (1), which is the point at which the water depth is 10m, but at the three points on land (Points (2)-(4)), in Cases 2 and 3, which assume the existence of a seawall, the time at which inundation starts is later and the maximum inundation depth is lower than in Case 1, which assumes no seawall.

According to figure 3.2.2.41, one can see that, compared with Case 1, in which the maximum inundation depth reaches at least 10m over an extensive area, the maximum inundation depth is lower in almost all areas within the seawall in Cases 2 and 3, which assume the existence of a seawall. This tendency is also clear in figure 3.2.2.42, which compares maximum inundation depth in Cases 1 and 2, and in the northwest of the inundation zone, which is located within the secondary seawall, there are places where the inundation depth declines by at least 6m.

Figure 3.2.2.43 shows the planar distribution of the maximum flow velocity in each case. In Case 1, which assumes that there is no seawall or similar structure, the area where the velocity is at least 6m/s is extensive, with velocity reaching at least 8m/s in some parts. In Cases 2 and 3, which assume the existence of a seawall, while there are places on the immediate landward side of the seawall where the velocity reaches at least 8m/s, it is less than 6m/s on the seaward side and a little way further inland from the seawall. The same tendency can also be seen in Figure 3.2.2.44, which compares the maximum flow velocities in Case 1 and Case 2. The decline in the maximum flow velocity in the cases where the existence of a seawall was assumed is pronounced compared with the situation on the southern Sendai Plain and in Rikuzentakata; this is believed to be an effect resulting from the fact that the seawall in the Taro district is comparatively high.

Thus, it was concluded that a seawall leads to a reduction in the maximum inundation depth on its landward side. However, it is necessary to bear in mind the fact that the maximum flow velocity will increase on the immediate landward side of the seawall.

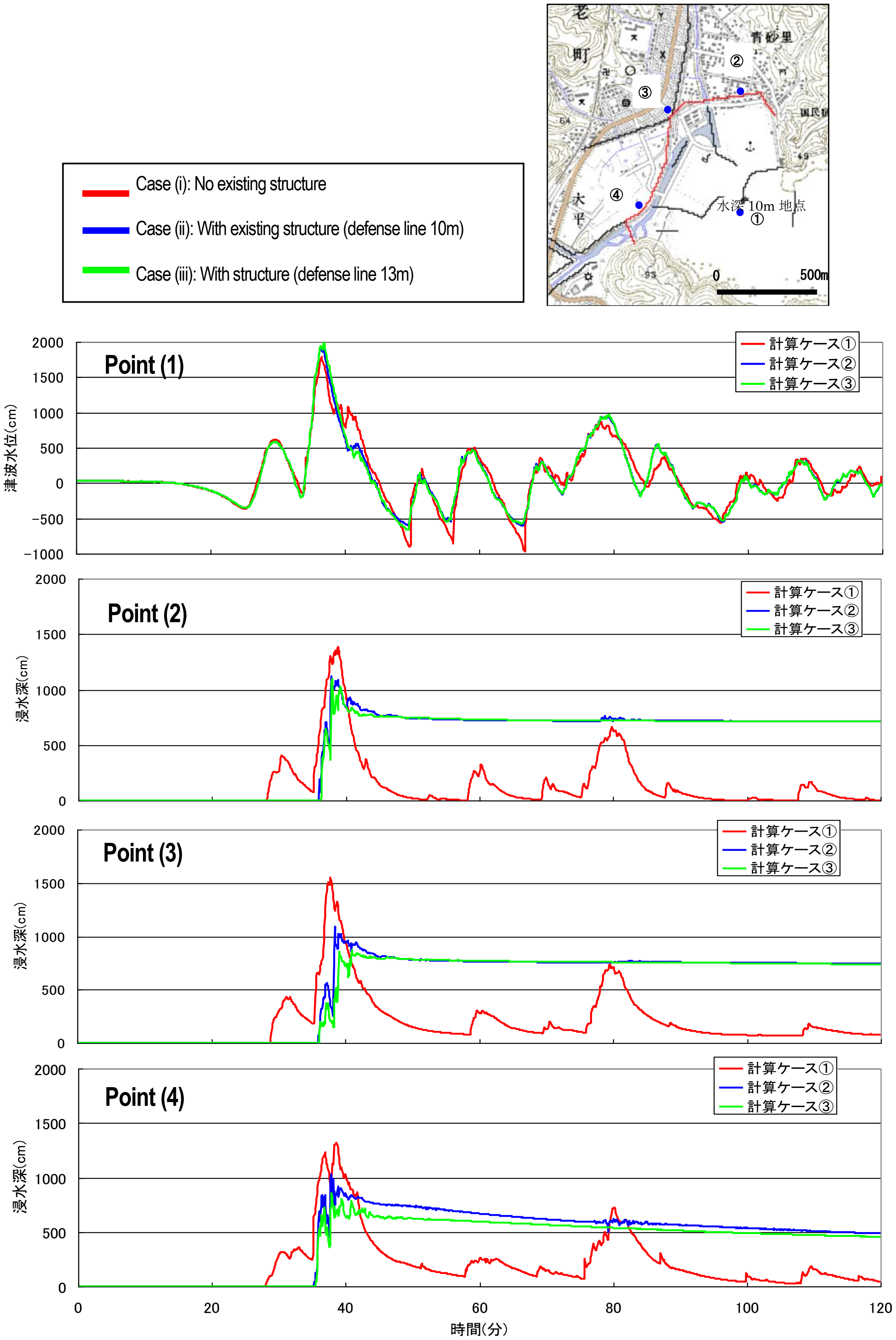

Figure 3.2.2.40 Time Series Data for Tsunami Water Level
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

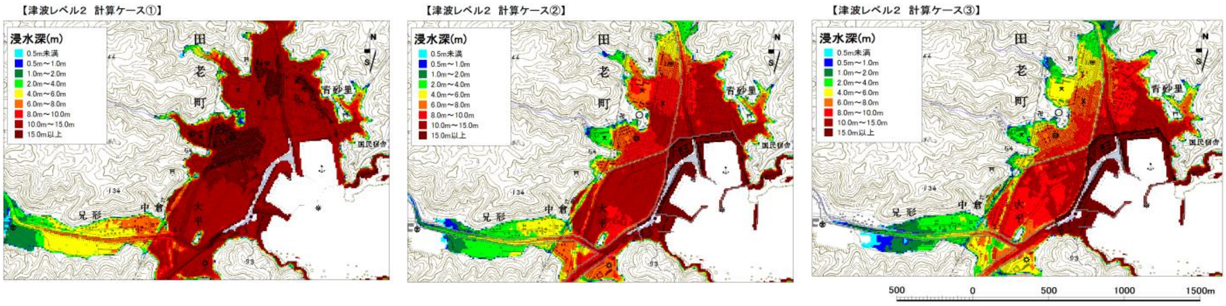

Figure 3.2.2.41 Maximum Inundation Depth (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

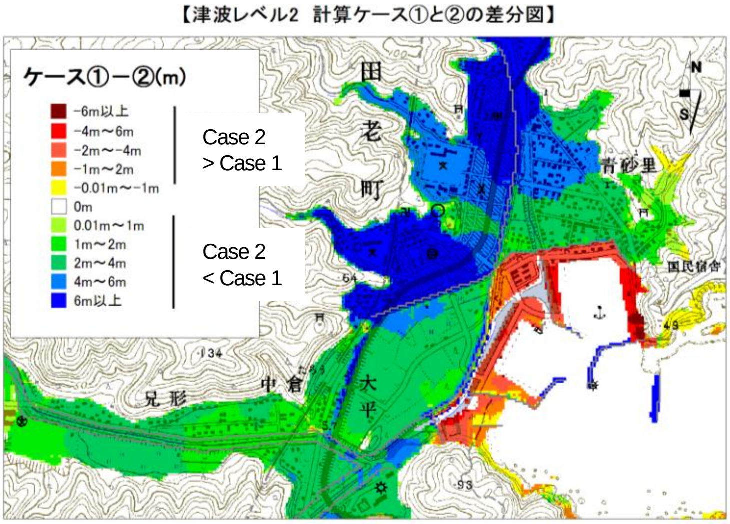

Figure 3.2.2.42 Difference in Maximum Inundation Depth (between Case 1 and Case 2)
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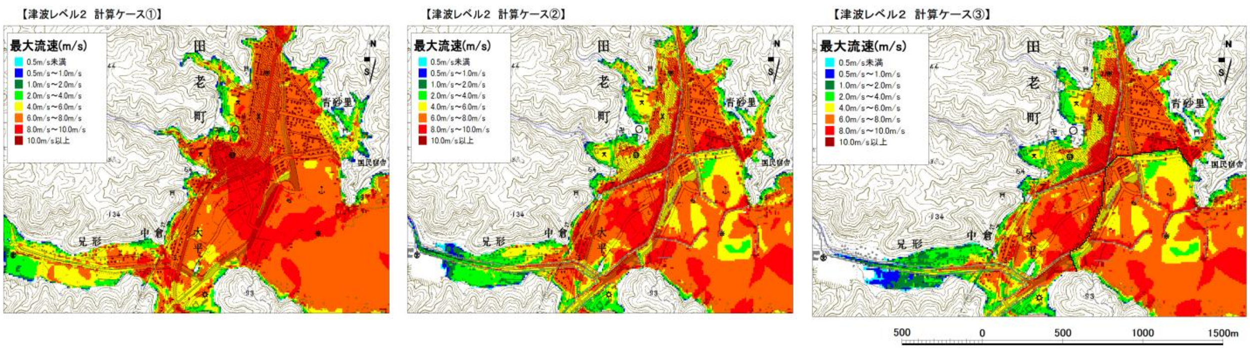

Figure 3.2.2.43 Maximum Flow Velocity (Left: Case 1; Middle: Case 2; Right: Case 3)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

【津波レベル2　計算ケース①と②の最大流速差分図】

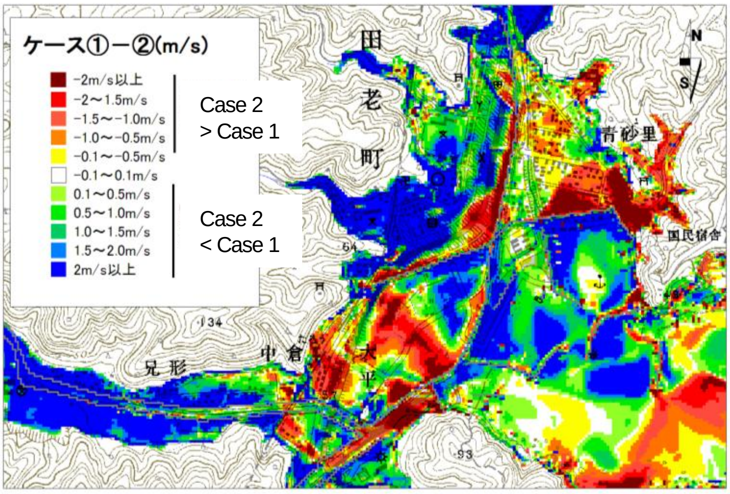

Figure 3.2.2.44 Difference in Maximum Flow Velocity (between Case 1 and Case 2)
(Using the Geospatial Information Authority of Japan's Digital Map 25,000 (Map Image) as the background)

5) Conclusion

As a result of tsunami inundation calculations to examine the attributes of the tsunami that ran up on shore, it emerged that trends in changes over time in inundation depth and flow velocity differ between the southern Sendai Plain and Rikuzentakata. Moreover, it was concluded that even if a tsunami higher than the design assumptions overtopped the seawall, the seawall itself would have the effect of reducing the inundation depth. As the ability of a seawall to stand firm and achieve its intended purpose, even if it is overtopped by a tsunami, contributes to reducing the damage in the area behind it, this demonstrates the importance of giving consideration to building resilient structures.

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3.2.2.2 Ports

(1) Tsunami Height

In order to ensure prompt restoration, it is important to investigate the status of damaged facilities and to find the causes of damage resulting from the Great East Japan Earthquake. NILIM conducted disaster surveys at the request of MLIT and other bodies. All of the surveys were carried out jointly with the Port and Airport Research Institute.

These disaster surveys consisted of tsunami surveys and earthquake surveys. The following is a report on the results of the tsunami surveys.

(Summary of Surveys)

① March 16-19, 2011 1 staff member dispatched to conduct disaster surveys at Kamaishi and Ofunato ports

② March 16-19, 2011 2 staff members dispatched to conduct disaster surveys at Hachinohe and Kuji ports

③ March 27-30, 2011 1 staff member dispatched to conduct disaster surveys at Kamaishi and Miyako ports

④ April 5-8, 2011 2 staff members dispatched to conduct disaster surveys at Soma and Onahama ports

⑤ April 5-6, 2011 1 staff member dispatched to conduct disaster surveys at Kashima and Ibaraki ports

Figure 3.2.2.45 shows the distribution of traces of tsunami heights obtained from the field surveys (at a total of 105 points). For details of tsunami heights and their measurement conditions, please refer to the report in the Urgent Survey[1)]. It should be noted that all of these tsunami heights are calculated from the astronomical tide level at the time of the tsunami arrival, because the time when the largest wave of the tsunami appeared was not clear.

Focusing on the inundation height (blank triangle in Fig.3.2.2.45), a massive tsunami in excess of 13m was observed along the coast from Kesennuma City to Onagawa Town and the maximum height was observed at Onagawa Port in Onagawa Town (18.4m). A tsunami of almost 10m was observed along the coast from Miyako City to Ofunato City, and the coast from Sendai City to Soma City. At Kamaishi Port in Kamaishi Bay, the trace of the tsunami height was about 7-9m while in Ryoishi Bay it was about 16-17m, immediately north of Kamaishi Bay. This confirmed the tsunami reduction effect in the bay resulting from the breakwater at the mouth of the bay. Even within neighboring regions, there were variations in the tsunami height, due to the effects of existing structures and topography.

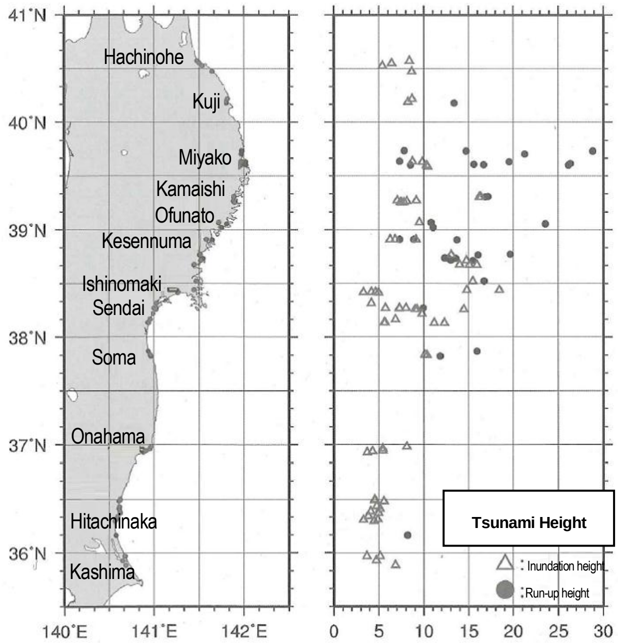

Figure 3.2.2.45 Distribution of Traces of Tsunami Height (Triangles and Circles Indicate Inundation Heights and Run-up Heights, Respectively)[1)]

In Aomori, Iwate, Miyagi and Fukushima Prefectures, damage prediction was carried out for each design tsunami. The following are the predicted tsunami heights for the Meiji-Sanriku Earthquake in 1896, which often reached the maximum predictions. In Aomori Prefecture, the maximum inundation height of 4.0-6.0m was reached in the Shirogane district of Hachinohe Port. In Iwate Prefecture, the maximum run-up height of 16.8m was reached in the Taro district of Miyako City, while heights were recorded of 8.4m in the Tsugaruishi district of Miyako, City, 8.0m inside Kamaishi Bay in Kamaishi City, and 7.0m inside Ofunato Bay in Ofunato City. In Miyagi Prefecture, a maximum water level rise of 3.0m was recorded in

Ishinomaki City, and 2.3m inside Sendai Port in Sendai City. In Fukushima Prefecture, a maximum run-up height of 4.9m was reached at Soma Port in Soma City, while a height of 4.0m was recorded at Onahama Port in Onahama City. It should be noted that the damage prediction survey for Miyagi Prefecture was released in February 2011, before the occurrence of Great East Japan Earthquake.

Each tsunami height shown in Figure 3.2.2.45 is much higher than that estimated in the damage prediction survey for the Meiji-Sanriku Earthquake. In particular, great tsunami heights were observed along the coast south of Iwate Prefecture.

(2) HF Radar Observation of Tsunami Waves

High-frequency ocean surface radar (HF radar) systems are expected to play an important role in tsunami observation, in combination with existing offshore wave gauges. HF radar systems can detect velocity fluctuations on the sea's surface in two – dimensions, as well as the subsequent resonances due to topographic conditions in bays and channels. Signals from the tsunami waves induced by the Great East Japan Earthquake and from subsequent resonances were successfully detected as radial velocity variability by the HF radar systems installed by MLIT on the coast of the Kii Channel, Japan[2),3),4)]. This confirmed the findings of a number of earlier theoretical and numerical studies, focused on detecting tsunami waves by HF radar.

The HF radar systems were installed at Saikazaki and the Minato district of Wakayama City in Wakayama Prefecture by MLIT's Kinki Regional Development Bureau and are operated continuously. Figure 3.2.2.46 shows the monitoring points of HF radar systems and sea surface monitoring systems using offshore wave gauges. From 17:00 on March 11 to 00:00 on March 14, data acquisition was carried out for 10 minutes of every 15 minutes. The surface velocities were calculated for data recorded between 17:00 and 22:38 on March 11.

Figure 3.2.2.47 shows the detected sea surface heights and the radial velocities. A profile of the radial velocities detected by HF radar installed in the Minato district shows that the first to the third tsunami waves indicate the characteristics of the progressive waves. Resonant oscillation subsequently occurred in the channel.

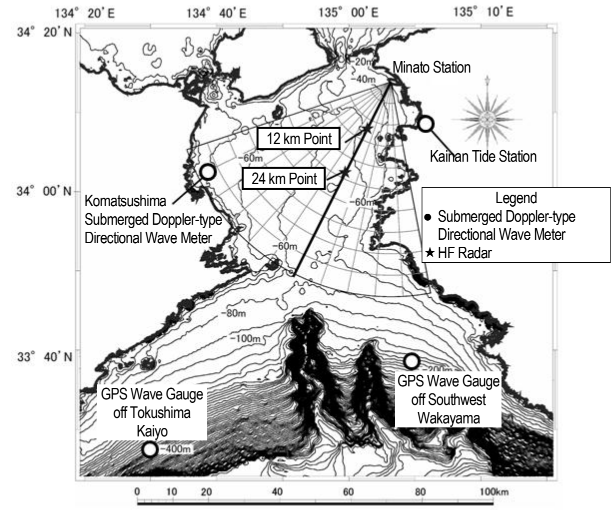

Figure 3.2.2.46 Monitoring Points of HF Radar Systems (Stars) and Sea Surface Monitoring Systems (Circles) in Kii Channel, Japan[3)]

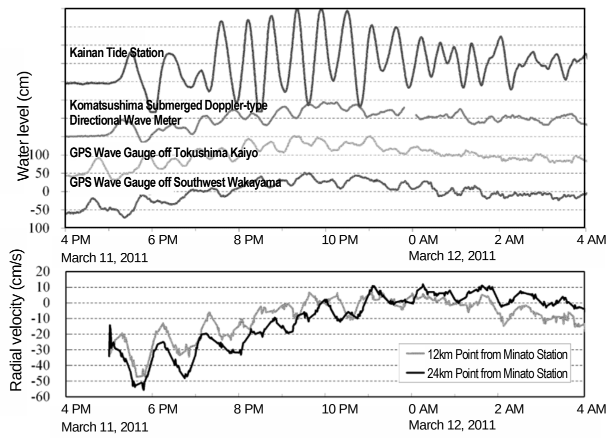

Figure 3.2.2.47 Detected Sea Surface Heights (Top) and Radial Velocity (Bottom) from 16:00 on March 11, 2011 to 04:00 on March 12, 2011[3)]

Indented coastlines are often seen along the Japanese coast. HF radar has the advantage of making it possible to ascertain the spatial distribution of surface velocities. In reducing tsunami damage, it is important to calculate the spatial distribution of the natural modes for resonant oscillation along the coast in advance.

If HF radar could detect tsunami waves and the subsequent resonances simultaneously and in a stable manner, it would be useful in making preparations against tsunami. For this purpose, it is necessary (i) to speed up the calculation of the spatial distribution of surface velocities, (ii) to extend the observation area and increase its resolution, (iii) to improve communications, and (iv) to improve methods of data storage and power supply.

Acknowledgments

In conducting disaster surveys, we received the full support of the Tohoku and Kanto Regional Development Bureaus, MLIT, as well as the cooperation of the relevant local governments. In HF radar observation of tsunami, we made use of data from the continuously operated HF radar systems installed by the Kinki Regional Development Bureau, MLIT. We would like to take this opportunity to express our deep appreciation for their great assistance.

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3.2.2.3 Rivers

At the request of the Ministry's Tohoku Regional Development Bureau, NILIM conducted field surveys of the Kitakami, Naruse, Natori and Abukuma rivers, aimed at gaining a general understanding of the status of damage, with the objective of obtaining information that would contribute to disaster recovery efforts. This chapter summarizes the water levels and flow direction based on information gained at the time of the field surveys, with the addition of various data obtained by organization including the Tohoku Regional Development Bureau and the Geospatial Information Authority of Japan, such as tsunami runup traces and image data.

(1) General Overview of Tsunami Runup in River Channels

Based on images of the runup situation at the time of the first tsunami wave in the vicinity of rivers with estuaries on the Sendai Plain, and the results of calculations of tsunami runup in this area[1)], the status of runup in river channels before the tsunami runup reached the land behind levees along those rivers was ascertained. Moreover, the configuration of scouring (formation of pools by erosion during flooding) in flood channels at the edge of the foot of levee slopes is unclear, even in areas where the water overflowed from areas behind the levee, and it appears that there was marked erosion of the slope at the top near the crest of the levee. Accordingly, this would appear to suggest that the water level in the river channels rose before it did in the areas behind the levees.

Figure 3.3.2.48 shows time-series data for water levels at the time of the tsunami runup, which were recorded at two water level gauging stations on the Shin-Kitakami River. Between the two gauging stations, the trace water level is lower than the levee

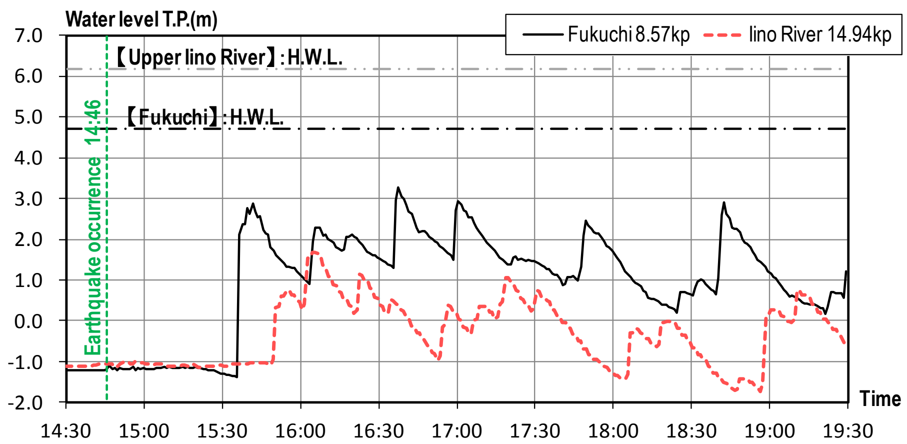


Figure 3.2.2.48 Results of Observation of Changes of Water Level Over Time During the Tsunami Runup on the Kitakami River

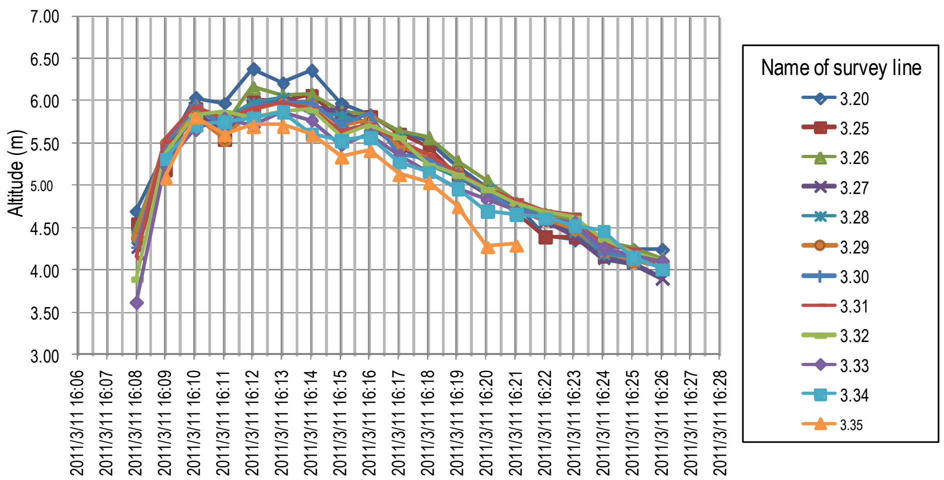
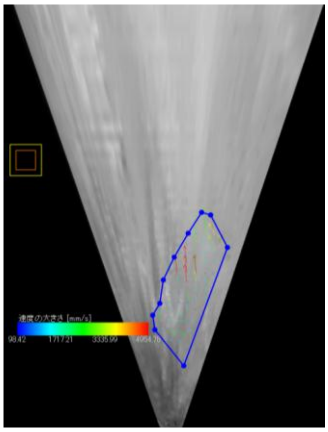


Figure 3.2.2.49 Water Level Changes During the Tsunami Runup Interpreted Via Image Analysis of CCTV Images (Naruse River, 3.4kp)



(a) Image extracted from the CCTV image (arrow shows the tsunami wavefront) (b) Result of PIV analysis of a planar projection of the image on the left

Figure 3.2.2.50 Velocity Distribution on the Water's Surface Calculated Using PIV Analysis of a Planar Projection of a CCTV Image (Kitakami River, 14.3kp)

height (see Figure 3.3.2.51), while at the Fukuchi gauging station, located downstream, a rapid rise in the water level of approximately 3m in two minutes occurred at the time of the tsunami runup during the first wave. This appears to show a fluctuation corresponding to the bore-type tsunami runup seen on video footage from a CCTV camera installed alongside the river, which captured images of the tsunami runup. Pass points were set for the images captured by a CCTV camera on the upstream side of Naruse Bridge (left bank of the Naruse River, 3.4kp), and Figure 3.3.2.49 shows the results of having interpreted fluctuations in the water's surface based on an analysis of these images. There are several survey lines on the images, from which it is possible to see the same rapid rise in the water level as observed on the Shin-Kitakami River.

The speed at which the tsunami traveled upstream was approximately 8m/s, which was calculated as a quotient of the time lag between the peak water level during the first wave being recorded at the two gauging stations and the longitudinal distance between the stations (6.37km). Moreover, the surface velocity at the time of the tsunami runup was measured using PIV analysis of the CCTV images when the runup of the first wave occurred; with a maximum velocity of 5m/s, it was even slower than the propagation velocity. With regard to the images from the CCTV camera installed on the Fukuchi floodgate (Kitakami River, 8.6kp), it was not possible to calculate the surface velocity because there was a lot of vegetation growing between the camera and the river, the camera was located a long way from the river, and the resolution was poor. Using the images from the CCTV camera installed on the downstream side of the Iinogawa Bridge (Kitakami River, 14.3kp), located 5.7km further upstream than the Fukuchi floodgate, it was ascertained that the surface velocity of the tsunami as it traveled up the right-hand side of the river channel was around 5m/s (Figure 3.3.2.50). However, as shown in Figure 3.3.2.50(a), there was more disturbance on the surface of the water, and the precision of the calculation was deemed to be low. In Figure 3.3.2.48, the wave height dwindles as the tsunami travels upstream, but the time when the water level was at its highest was later at Fukuchi gauging station, on the estuary side, than it was at the Iinogawa upstream gauging station, which is something that should be borne in mind when drawing the longitudinal profile of the maximum water level resulting from tsunami runup.

(2) Results of Tsunami Trace Water Level Surveys in the River Channel and Behind the Levee

Figure 3.3.2.51 shows the tsunami trace water levels recorded on the Abukuma, Natori, Naruse, and Shin-Kitakami rivers. In the trace surveys, there were sectors where the water reached not only the slopes of levees, but also bridges, floodgates, and even structures and foothills behind the levees; the traces found in these sectors were limited to structures higher than the aforementioned river levees, so there are few data. Moreover, it is surmised that even some of these structures were submerged, and there are also data corresponding to the height (runup height) at which the tsunami washed up on foothills. Accordingly, based on the results of observations during field surveys, Figure 3.3.2.51 shows the results of a rough estimate of the distribution of the maximum water level as the curves marked "General trend in the water level change".

Based on a combination of the distance between the water levels behind the levee and on the river side of it, taking the levee crest as the benchmark, it is possible to broadly classify the status of tsunami runup in the river as it travels upstream from the estuary, as shown in Figure 3.3.2.52. The part closest to the estuary is the "levee submersion sector", in which the highest water level reached surpasses the crest both behind and in front of the levee, while the area upstream is the "levee overflow sector", where the water level behind the levee is lower than the height of the crest and water from the river in front of the levee flows over the top of it. Furthermore, even in the levee submersion sector, there are times - both before and after reaching the maximum water level - when water might overflow from either in front of the levee or behind it. Upstream of this section is the "below-levee runup sector", where the runup on both sides of the levee is lower than the height of the levee crest.

At the observation points at the Watari Bridge, over the Abukuma River, the trace water level on the right bank side is much higher than that on the left bank side. With regard these data, the plants caught in the railings of the Watari Bridge are believed to be traces resulting from the tsunami runup, and are believed to be highly reliable as traces indicating the point reached by the tsunami. At this location, the river channel bends to the left, facing downstream, and it appears that the water level was higher because this corresponded to the outer bank from the perspective of the tsunami runup.

(3) Effects on Tsunami Runup of Levee Alignment and Shape, and Higher Ground, Including Mounds and Spurs

Photographs 3.2.2.1 show the direction of flow of the tsunami runup in aerial photographs[2)] taken of the lower reaches of the Shin-Kitakami, Naruse, Natori, and Abukuma rivers (blue arrows on the photographs), merged with the runup status categories (see Figure 3.3.2.52). The direction of flow of the tsunami runup was estimated from such data as the direction in which telegraph poles fell, as interpreted from aerial photographs, as well as the direction in which vegetation had fallen and the direction in which the paving of levee crests had been detached or washed away, as confirmed during field surveys. In addition, the arrows on the levees show the direction in which the water overflowed, either into the river or into the area behind the levee, but readers should bear in mind that this is not necessarily the direction of flow in the strict sense.

Based on these photographs and the trace water levels shown in Figure 3.3.2.51, the tsunami runup situation can be summarized as follows.

a) If the levee runs more or less perpendicular to the strandline in a broadly straight line

Typical examples of this are the right bank of the Natori River and the left bank of the Naruse River. In the levee submersion sector, traces could be seen on both sides of the river levee. Near 1kp on the left bank of the Naruse River, the paving of the levee crest had been washed away on the river side in adjoining sections and there appears to be a possibility that flows in a single direction that topped the levee occurred for a time throughout one section (Photograph 3.2.2.2).

Going further upstream from that sector, the maximum water level gradually decreases on both sides of the levee, but this occurs to a greater degree on the side behind the levee than on the river side, so this sector is the levee overflow sector, where water flowed over the levee from the river side, and the area further upstream again is the below-levee runup sector.

b) If there are areas of high ground, such as mounds or spurs, adjacent to the type of river levee referred to in a)

Typical examples of this are the left bank of the Natori River and the right bank of the Shin-Kitakami River. In the case of the Natori River, this is located at the road embankment on the Yuriage Bridge, while in the case of the Shin-Kitakami River, such points are found where spurs approach the levee (at the 1.2-1.8km points on the left bank and at the 3.8km point on the right bank; in both cases, the spur does not come right up to the levee and there is a waterway between them) (indicated by means of the gray arrows on Photographs 3.2.2.1(a) and (c)).

In areas of high ground, it appears that the tsunami that traveled up the area behind the levee became swollen and raised the water level, and flowed over the levee into the river. Consequently, although the areas downstream of the high ground constitute the levee submersion sector, the disparity with a) caused the water flowing toward the river in the downstream part of the high ground to flow over the levee.

In the case of the Shin-Kitakami River, the area upstream of the spur area was the levee overflow sector in which water flowed over the levee into the area behind. On the right bank, a levee breach of approximately 400m occurred in this sector. A photograph has been taken of the situation upstream of the spur area, where it is surmised that tsunami inundation occurred after traveling along the waterway adjacent to the levee[3)].

In the case of the Natori River, the water level of the tsunami runup was much lower upstream of the road. The tsunami did not top the road embankment near the river levee, but traveled upstream around the road embankment, which gradually decreases in height as it runs away from the river levee; it appears that this was because the wave height decreased due to the effects of the increase in the tsunami runup distance due to traveling around the road embankment, as well as the effects of current diffusion.

c) If the levee runs diagonally to the strandline so that the slope on the river side faces the estuary

A typical example of this is the area approximately 1km from the estuary on the right bank of the Abukuma River (area downstream of the bend). In this area, even in the levee submersion sector, slopes collapsed and pools were formed by erosion during flooding at the foot of the slopes, due to water overflowing from the river side, as will be described in 3.3.3(1). Moreover, on the metal handrail above the parapet on the levee crest, one could see deformation surmised to have resulted from the buildup of vegetation and the collision of debris picked up by the tsunami, which suggested that water overflowed from the river side. Furthermore, a section of the parapet collapsed and was washed into the area behind the levee. Based on the situation above, it was surmised that there were cases in which water from the river flowed over the levee in sections where the levee is aligned diagonally to the strandline, so that the slope on the river side faces the estuary. Chapter 3.3.3(1) below examines the status of damage in this section.

d) Sections where the outer bank (from the perspective of the tsunami runup) of the levee bends

A typical example of this is the bend on the right bank of the Abukuma River. As stated in (2), results suggestive of an increase in the water level on the outer bank were obtained from the trace survey at the Watari Bridge, which is located on the bend in the river.

(4) Tsunami Wavefront Propagation Interpreted from Aerial Images

A Japan Coast Guard helicopter was used to take photographs of the runup situation resulting from the first tsunami wave, focusing on the area from the Natori River estuary to the Abukuma River estuary. Figure 3.3.2.53 shows the places where the position of the tsunami wavefront (the boundary between the area covered with water due to tsunami runup and the area not covered with water) and its movement could be confirmed from those images, and the dotted lines show places where the time spent photographing them was shorter than in the places indicated by solid lines. Photographs 3.2.2.3 show the results of recording (at intervals ranging from every few seconds to every few dozen seconds) the position of the wavefront interpreted at each point; at points where it was possible to spend enough time photographing the area, the propagation distance L and the time taken to travel through that sector T were sought, and the average propagation velocity was calculated by dividing L by T. The results were used to confirm the reproducibility of the tsunami simulation carried out by the Coast Division.

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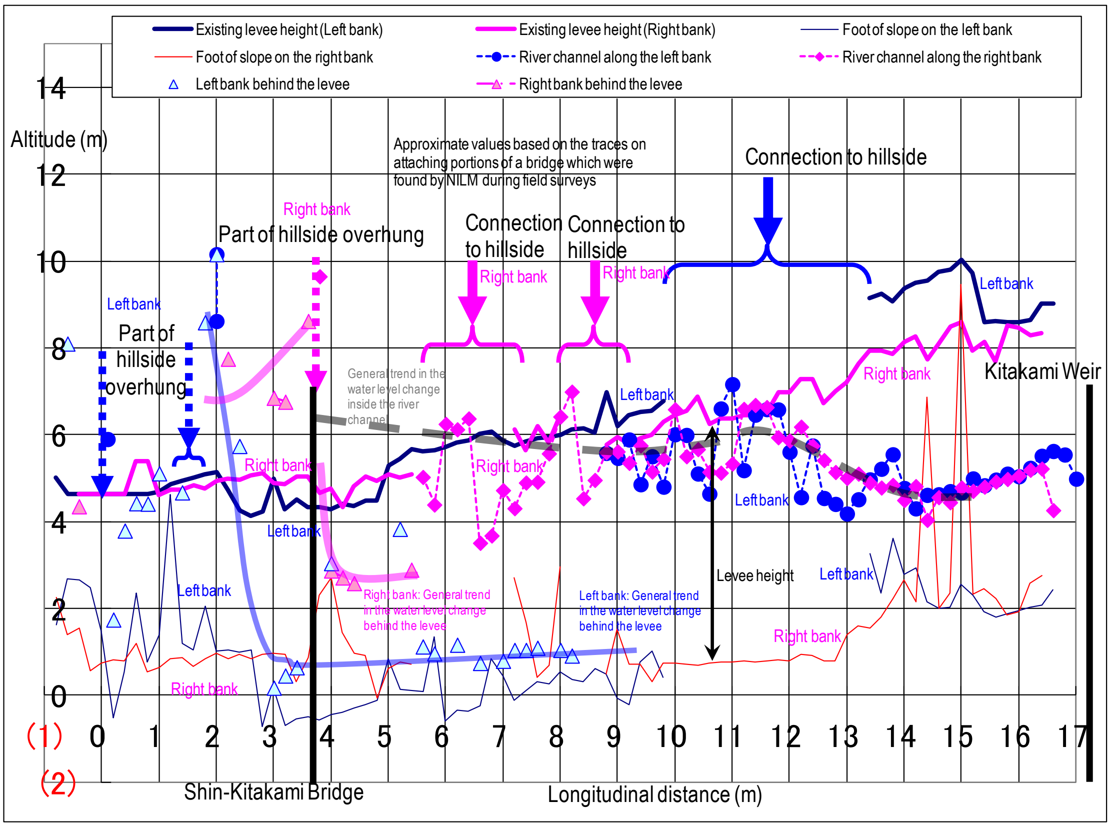


Figure 3.2.2.51(a) Results of a Trace Water Level Survey of the Shin-Kitakami River (data provided by the Tohoku Regional Development Bureau)

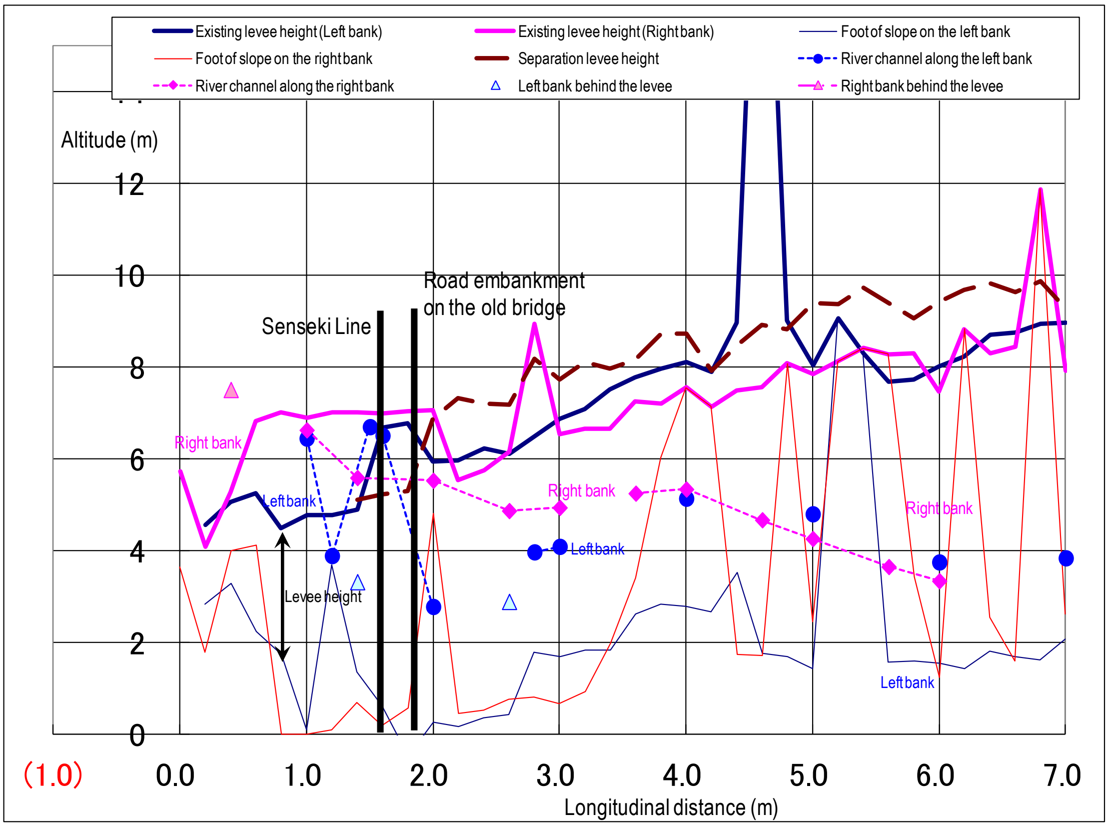


Figure 3.2.2.51(b) Results of a Trace Water Level Survey of the Naruse River (data provided by the Tohoku Regional Development Bureau)

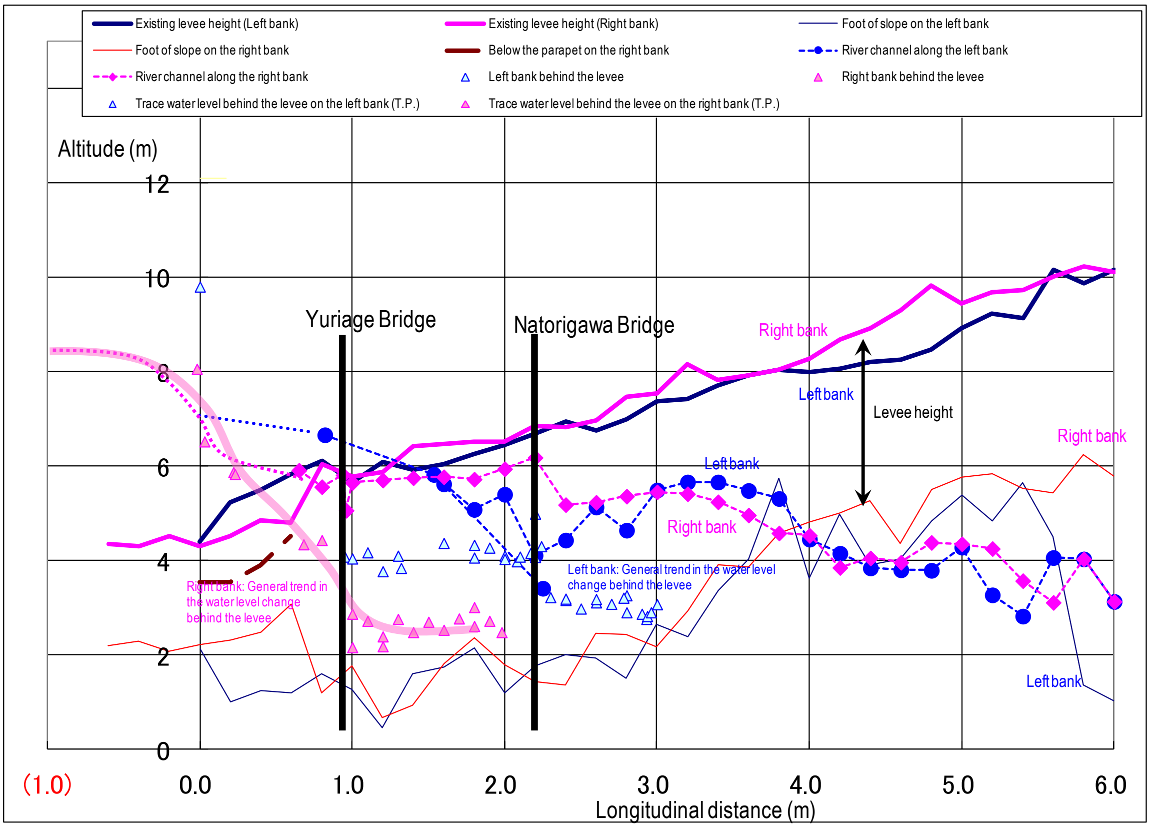


Figure 3.2.2.51(c) Results of a Trace Water Level Survey of the Natori River (data provided by the Tohoku Regional Development Bureau)

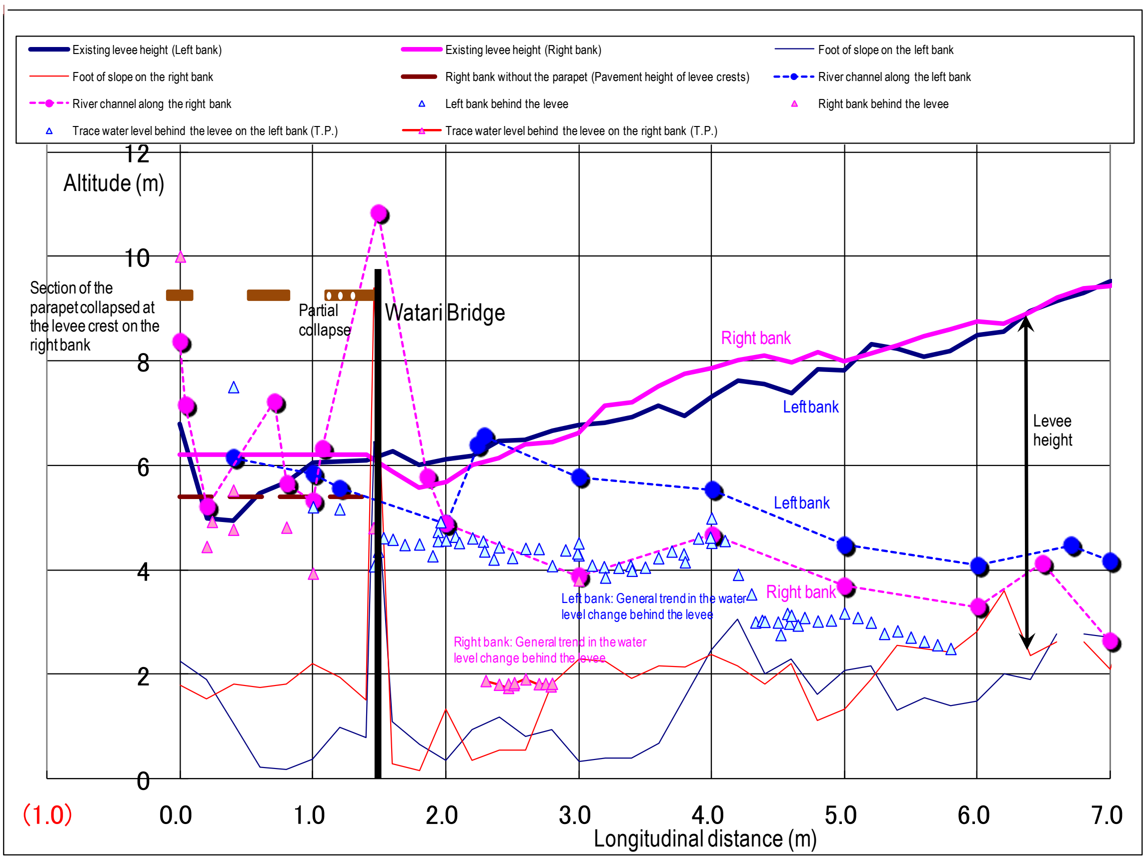


Figure 3.2.2.51(d) Results of a Trace Water Level Survey of the Abukuma River (data provided by the Tohoku Regional Development Bureau)

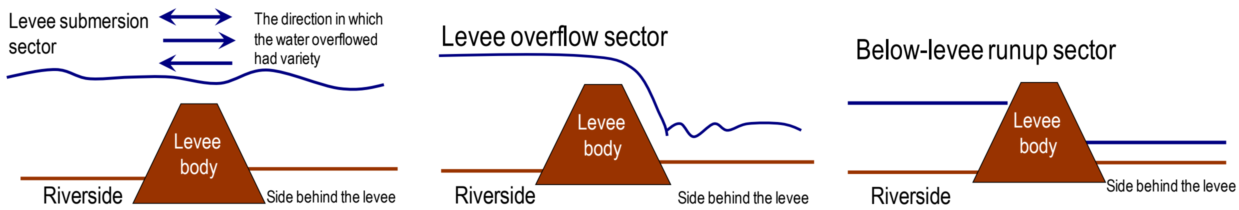


Figure 3.2.2.52 Three Status Categories of Tsunami Runup into Rivers

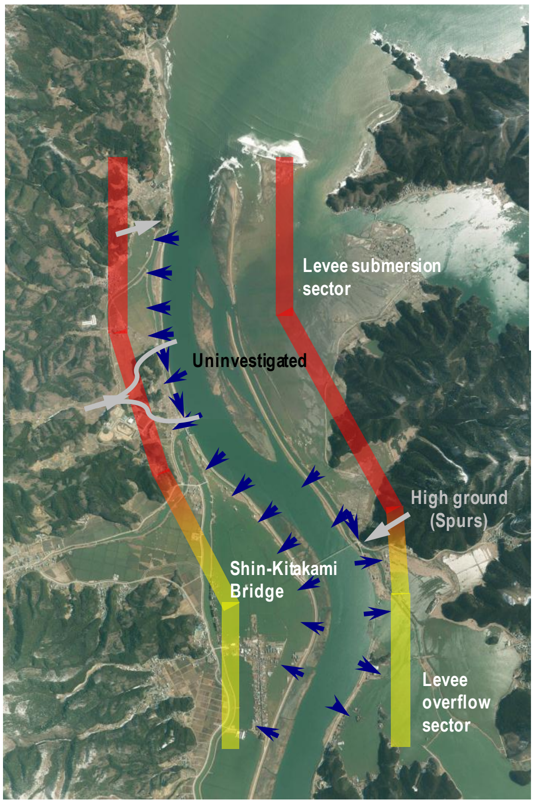


Photo 3.2.2.1(a) Status of Tsunami Runup into the Shin-Kitakami River

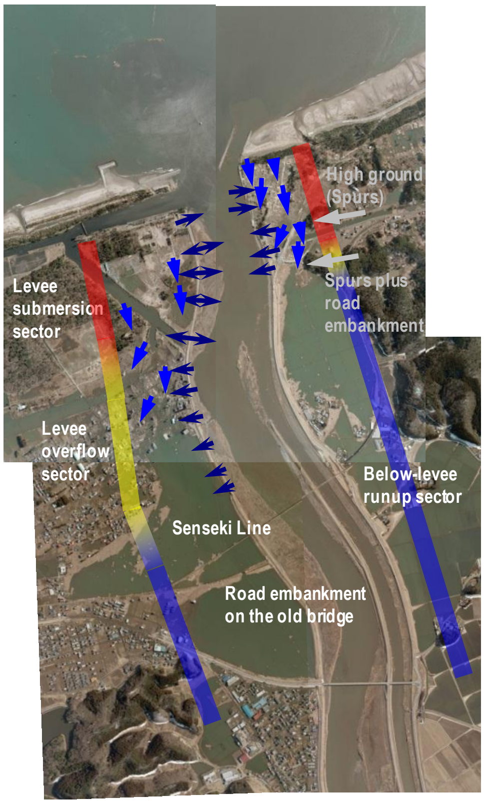


Photo 3.2.2.1(b) Status of Tsunami Runup into the Naruse River

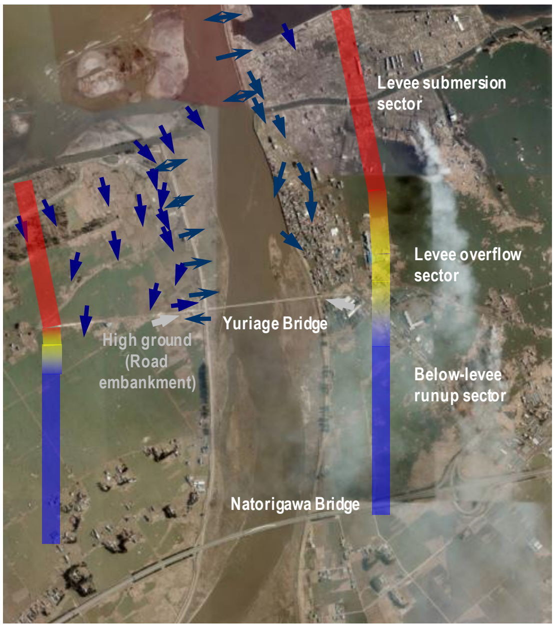


Photo 3.2.2.1(c) Status of Tsunami Runup into the Natori River

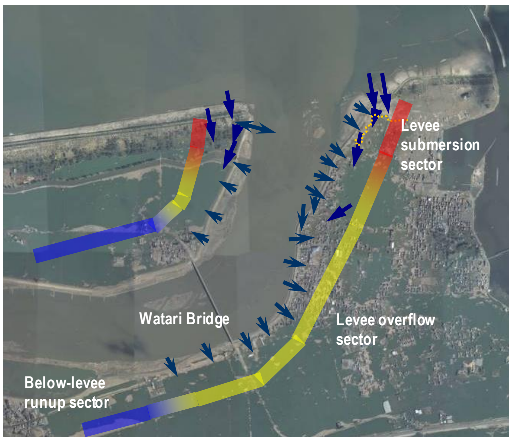


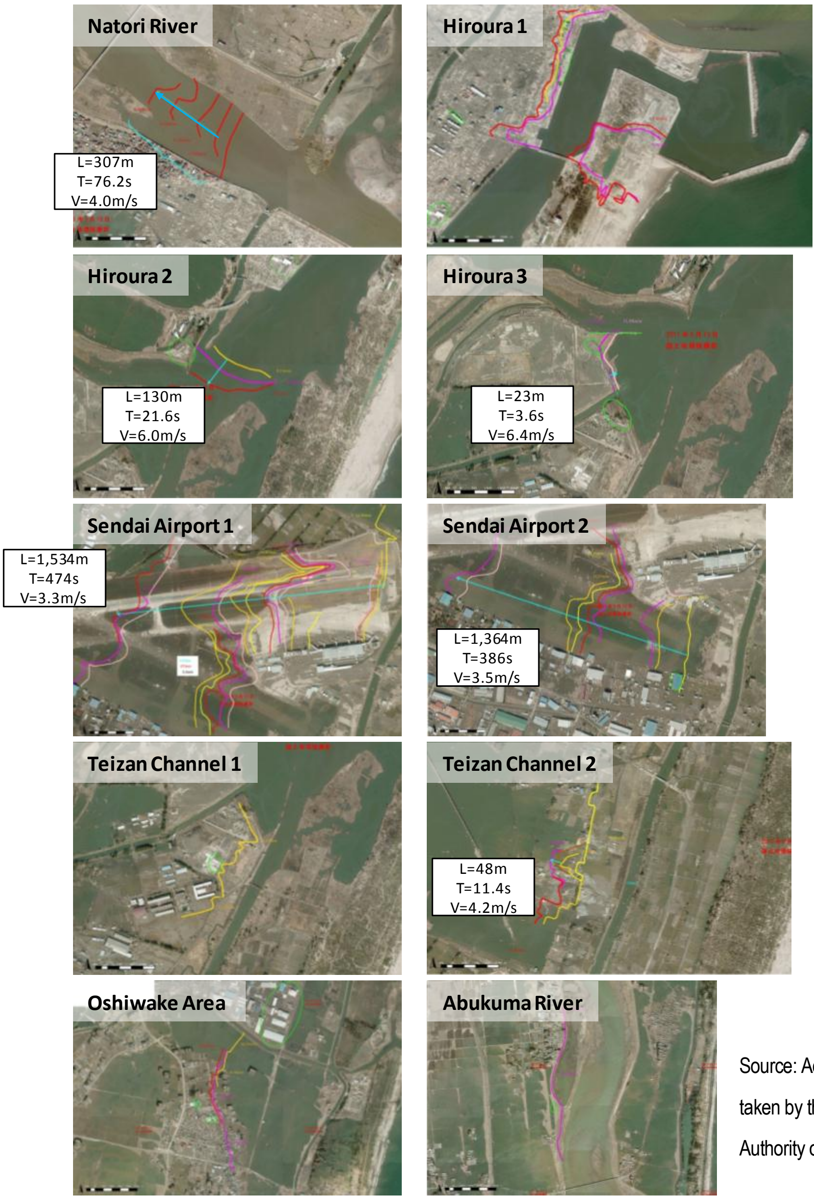
Photo 3.2.2.1(d) Status of Tsunami Runup into the Abukuma River

Source: Aerial photographs are images taken by the Geospatial Information Authority of Japan

Photo 3.2.2.2 Detachment of Asphalt Paving at the Crest of the Levee (near the left bank of the Naruse River, 1kp)

Figure 3.2.2.53 Areas Where the Status of Tsunami Propagation was Checked Using Images Taken by a Japan Coast Guard Helicopter

Source: Background created using Kashmir 3D http://www.kashmir3d.com/



Source: Aerial photographs are images taken by the Geospatial Information Authority of Japan

Photo 3.2.2.3 Status of Tsunami Propagation at Each Point on Figure 3.3.2.53

3.2.3 Soil Liquefaction

(1) Committee to Study Countermeasures against Soil Liquefaction

The Tohoku Earthquake generated soil liquefaction phenomena over wide areas and caused enormous damage to houses and residential areas as well as to infrastructure facilities. The Ministry of Land, Infrastructure, Transport and Tourism organized the “Committee to Study Countermeasures against Soil Liquefaction” in May 2012, and advanced reviews on the technological matters common to each infrastructure facility such as the grasp of damage conditions and the verification of the liquefaction judgment method[1)].

The organization of the committee is shown in Fig. 3.2.3.1; specifically, the liquefaction occurrence situations in the Kanto area were grasped by field surveys and it was confirmed that the liquefactions occurred mainly in the reclaimed lands in at least 96 communities.

Based on the comparison and analysis of the actual liquefaction events and the result of the liquefaction judgment using the FL method, which is a representative liquefaction judgment method, verification was performed on this method and future problems for its improvement was brought up.

In the following sections (2)-(4), the results[2)] obtained regarding the validity of the FL method and the applicability of the effective stress analysis are described through the analysis of the strong motion records from the Tohoku Earthquake performed by NILIM with cooperation from the Public Works Research Institute (Incorporated administrative agency). Refer to 3.3.9.2 (6) about the liquefaction analysis conducted in the architecture field.

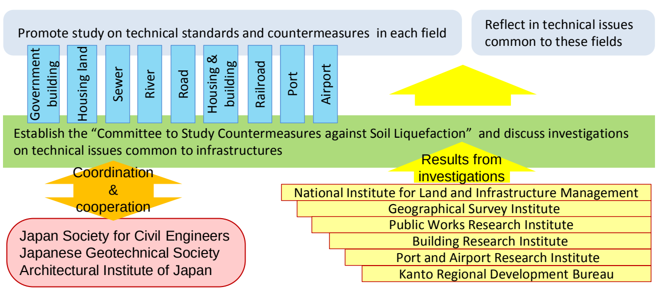
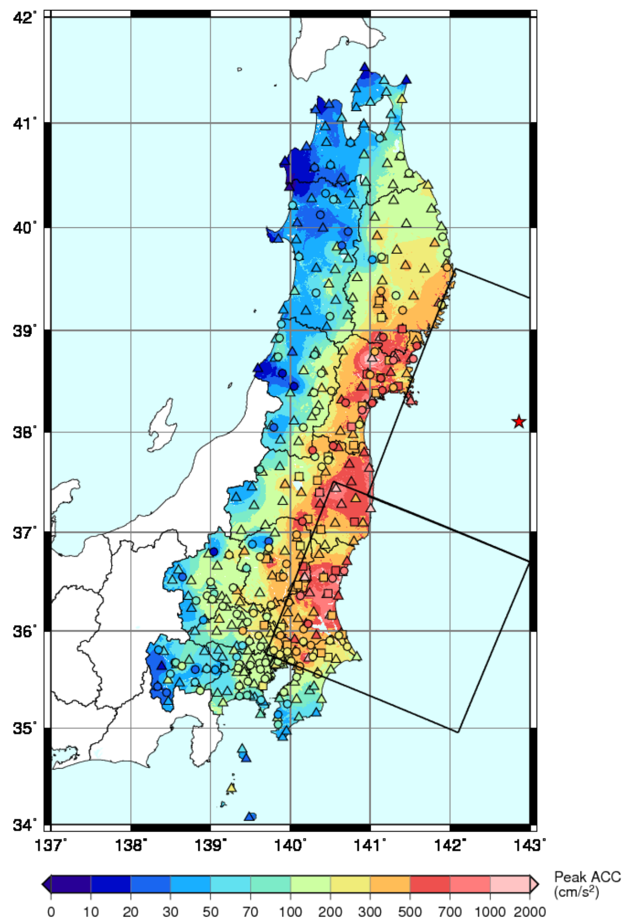
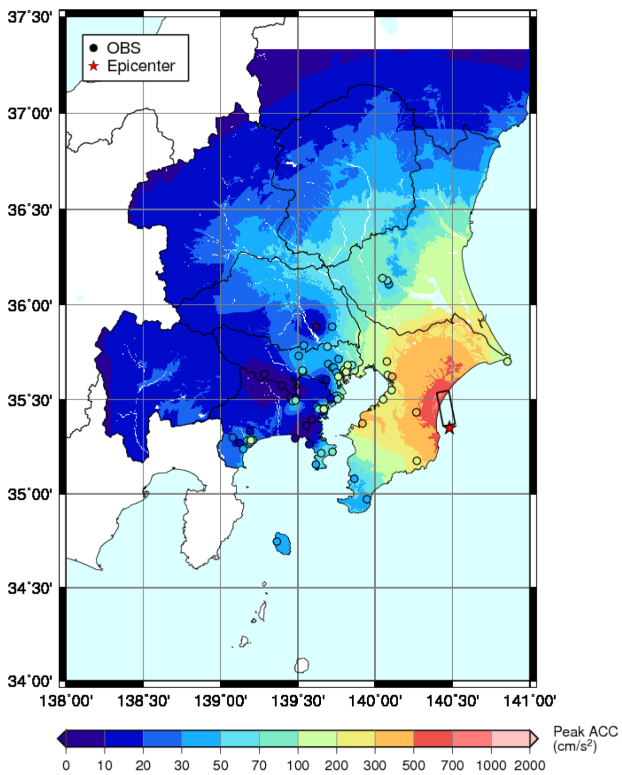


Figure 3.2.3.1 The organization of the Committee to Study Countermeasures against Soil Liquefaction



(a) the 2011 Tohoku Earthquake



(b) the 1987 off east Chiba earthquake

Figure 3.2.3.2 Estimated distribution of peak ground acceleration

(2) Estimation of distribution of peak ground acceleration and validity examination of estimation of the FL method

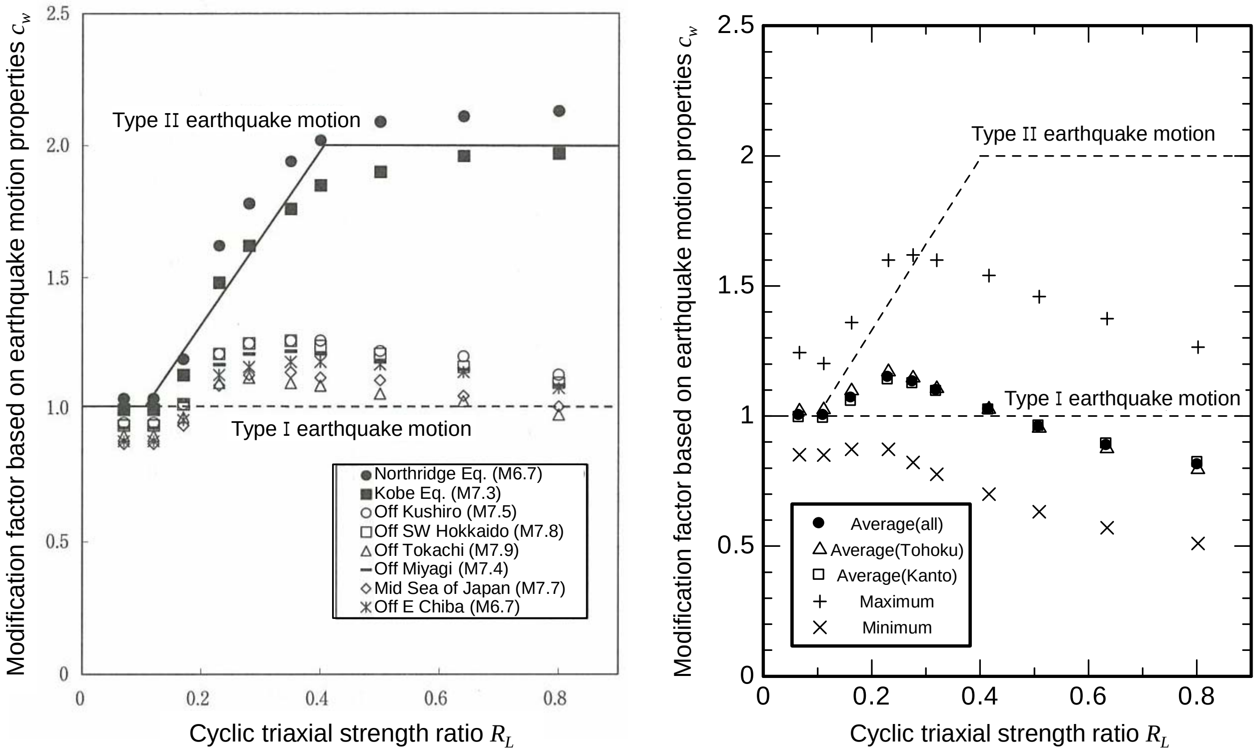
Since plenty of characteristic ground motions with long durations have been observed and such characteristics might affect the possibility of liquefaction, the validity of the FL method was examined based on the strong motion records and the survey of the damage situations.

The FL method adopts "liquefaction resistant ratio FL" that is the ratio of "dynamic shear strength ratio R" to "shear stress ratio during an earthquake L", namely, (FL=R/L) as an index, and judges that the soil layer of FL less than 1.0 is to liquefy. Since L is calculated from peak ground acceleration (PGA), distribution of PGA due to the Tohoku Earthquake was estimated. In addition, for a comparison with ground motion with a short duration, we estimated distribution of PGA due to the 1987 off east Chiba earthquake (Japan Meteorological Agency magnitude 6.7) in a similar manner (Fig.-3.2.3.2). Here, as for the Tohoku Earthquake, public data by the Japan Meteorological Agency, K-NET of the National Research Institute for Earth Science and Disaster Prevention (Independent administrative cooperation) and the Ministry of Land, Infrastructure, Transport and Tourism were used. As for the off east Chiba earthquake, public data of the Architectural Institute of Japan[3] were used.

It was confirmed from the calculation result by the FL using this PGA distribution that while the effect of duration was observed in a part, the liquefaction outbreak was not found at the sites of FL>1.0, and hence there was no overlooking of the events in the judgment by the FL method.[2]

(3) Examination of the modification factor based on earthquake motion properties

In the liquefaction judgment using the FL method, the dynamic shear strength ratio R is expressed as R = c_w*RL. Here, RL is the cyclic triaxial stress ratio defined as the ratio (cyclic shear stress/effective confining pressure) necessary to produce 5% of axial strain at 20 cycles in the cyclic triaxial test. In addition, c_w is the modification factor based on earthquake



(a) Specifications for Highway Bridges, V:Seismic Design[4] (b) Strong motion records of the Tohoku Earthquake

Figure 3.2.3.3 Comparison of the modification factor based on earthquake motion characteristics, c_w

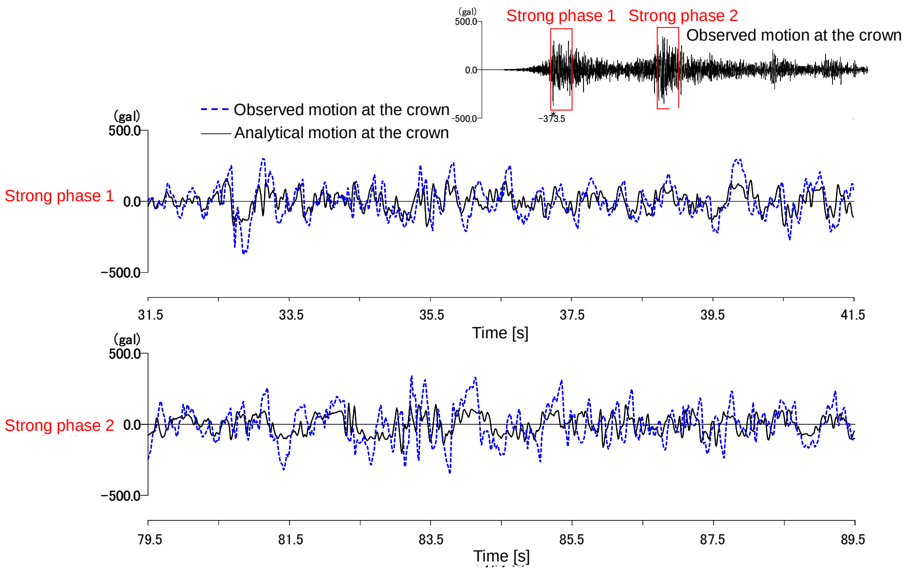


Figure 3.2.3.4 Comparison between the effective stress analysis result and the observation record (acceleration time history)

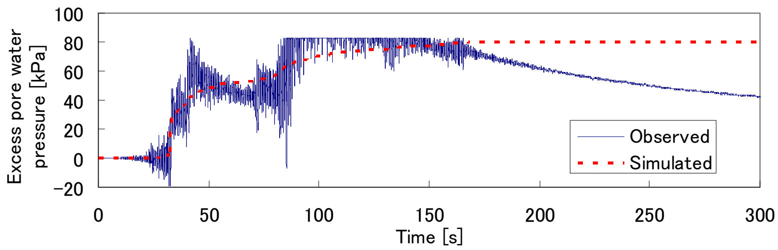


Figure 3.2.3.5 Comparison between the effective stress analysis result and the observation record (excess pore water pressure)

motion properties; c_w=1 corresponds to ground motion equivalent to 20 cycles and c_w greater than or less than 1 corresponds to either more than or less than 20 cycles, respectively.

We calculated c_w from 32 acceleration waveforms recorded during the Tohoku Earthquake and conducted the comparison with and the verification of c_w prescribed in Specifications for Highway Bridges Part V: Seismic Design[4]. The factor c_w was calculated in a similar manner to Azuma and Tamura (1997)[5] based on the damage accumulation theory.

The analytical results are shown in Fig. 3.2.3.3. According to the comparison with Fig. 3.2.3.3 (a), figure (b) shows that the c_w values are nearly equal to 1 for the range RL < 0.4, i.e. soil with low liquefaction strength, although they are less than 1 for the range RL > 0.4. These values are consistent with the existing results.

(4) Reproducible examination by the earthquake response analysis of the ground[6]

It is necessary to consider the influence of the liquefaction due to rise in excess pore water pressure for the seismic performance evaluation of levees. There are, however, few examples where the acceleration waveform and the excess pore water pressure were observed at the same time and at the same site during actual earthquakes, and hence there are few examples for which we compared the excess pore water pressure estimated by the earthquake response analysis (effective stress analysis) with the observed record.

Time history records of acceleration at the crown and base ground and excess pore water pressure at a liquefiable layer of a levee near Naruse River mouth were obtained during the Tohoku Earthquake. One-dimensional effective stress analysis[7] was conducted using the acceleration time history record at the base ground and the soil survey results at the site obtained during installation of the seismographs. The analytical time histories of acceleration at the crown and excess pore water pressure at the liquefiable layer were compared with the observed records in Figures 3.2.3.4 and 3.2.3.5.

The vibration properties such as the phase of the acceleration waveforms tended to behave in a similar manner to the record, while the short period components were small.

It could be concluded that the excess pore water pressure was estimated well as a whole, but the dissipation properties of the water pressure were not reproduced satisfactorily.

(5) Ongoing actions

We are proceeding with examination of dynamic analysis techniques of the ground using the strong motion records obtained this time in order to improve the estimation precision of deformation of the ground, and to contribute to the rationalization of liquefaction measures in turn.

Acknowledgements

This study was discussed in the MLIT "Committee to Study Countermeasures against Soil Liquefaction" and conducted under cooperation with the Soil Mechanics and Dynamics Research Team, Geology and Geotechnical Engineering Research Group, Public Works Research Institute (Independent administrative cooperation).. The observation records obtained by the Japan Meteorological Agency, Architectural Institute of Japan, National Research Institute for Earth Science and Disaster Prevention, and the Ministry of Land, Infrastructure, Transport and Tourism were used in this study. We would like to express our appreciation to these organizations.

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3.3 Technical Support for Restoration/ Reconstruction Measures

3.3.1 Sediment Disasters

3.3.1.1 Overview of sediment disasters

After the Great East Japan Earthquake on March 11, 2011, landslides and slope failures occurred widely in the Tohoku and Kanto regions. A March 12-29 helicopter-based survey confirmed multiple landslides and slope failures in Fukushima, Tochigi and Ibaraki Prefectures.

A total of 141 sediment disasters were reported as caused by the March 11 Great East Japan Earthquake, the March 12 northern Nagano Prefecture earthquake and the March 15 eastern Shizuoka Prefecture earthquake, including 13 debris flows, 29 landslides, 97 steep slope failures and two snow avalanches. These disasters killed a total of 19 people (as of August 6, 2012, by the Ministry of Land, Infrastructure, Transport and Tourism). Particularly at such locations as Fukushima Prefecture's Shirakawa City and Tochigi Prefecture's Karasuyama City, the Great East Japan Earthquake triggered large-scale landslides, wreaking havoc. Furthermore, an earthquake with its epicenter at Fukushima Prefecture's Hamadori on April 11 caused slope failures mainly in Iwaki City. No large-scale landslide dam was formed through the series of earthquakes. No major changes were observed at landslide dams formed through the 2008 Iwate-Miyagi Inland Earthquake and the 2004 Niigata Chuetsu Earthquake.

The National Institute for Land and Infrastructure Management conducted a March 12-29 helicopter-based survey in the Tohoku region and deciphered satellite images of the Tohoku and Kanto regions to widely ascertain sediment disasters caused by the Great East Japan Earthquake. The satellite image interpretation covered a total of about 40,000 square kilometers including areas where seismic intensities of 5 or more on the Japanese scale of 7 were posted upon the March 11 earthquake. Subject to the analysis were optical images taken by the PRISM and AVNIR-2 sensors on the Daichi Advanced Land Observing Satellite (ALOS) on March 12 and April 10 after the earthquake and post-earthquake high-resolution optical satellite images (taken from March 12 through April 6).

As a result, about 1,000 locations were extracted as those where the March 11 earthquake might have unleashed sediment movements (see 3.3.1.3(2)-3). The extracted slope failure locations were put on an estimated seismic intensity map published by the Japan Meteorological Agency (Figure 3.3.1.1). While we must note that small-scale slope failures are difficult to detect, that there are some areas where accumulated snow or clouds made it difficult to confirm conditions and that sediment movements failing to become visible cannot be detected, the map indicates that the incidence of slope failures was not so high despite the seismic intensity of upper 5 or more observed in a wide sphere. In contrast, the 2008 Iwate-Miyagi Inland Earthquake caused about 3,000 slope failures mainly around the border between the two prefectures. The sediment disasters stemming from the Great East Japan Earthquake featured a point that the incidence of sediment disasters was not necessarily proportionate to seismic intensity levels.

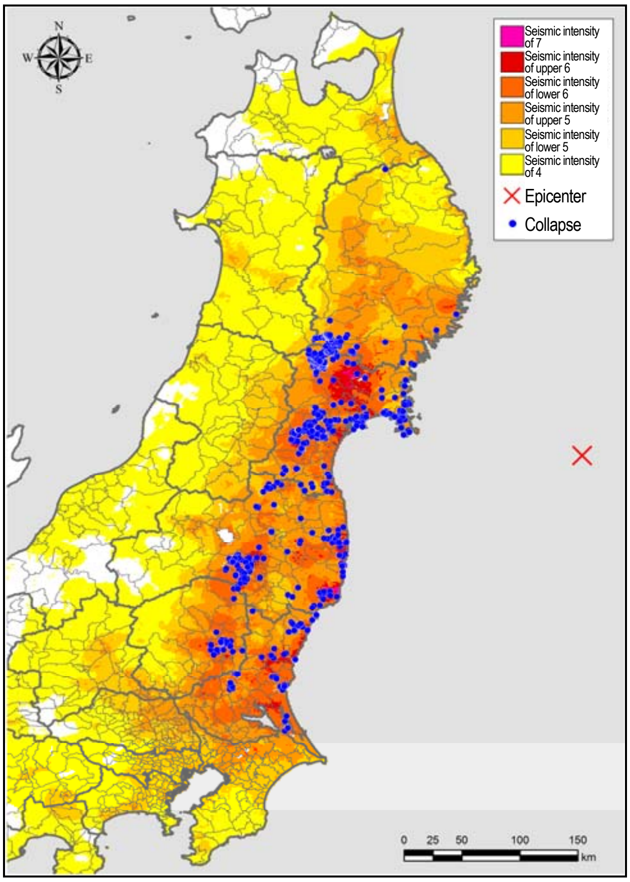

Figure 3.3.1.1 Estimated Seismic Intensity Map (Japan Meteorological Agency) and Distribution of Slope Failures Detected through Satellite Images

Table 3.3.1.1. shows relations between recent major earthquakes and sediment disasters. Although the recent earthquakes include only one ocean-trench earthquake, the table indicates that the incidence of slope failures is higher for an inland earthquake than for an ocean-trench earthquake. The indication might have been linked to distances from epicenters, earthquake vibration frequencies, earthquake deflections, earthquake durations, etc. Furthermore, the indication might have complex relations with earthquake vibration characteristics, geological characteristics as a predisposing cause, slope directions, geographical characteristics, etc. In the future, we plan to sort out and analyze factors contributing to slope failures upon earthquakes.

Table 3.3.1.1. Relations between Recent Major Earthquakes and Sediment Disasters

Major earthquakes	Date	Earthquake category	Magnitude	Maximum acceleration					Maximum seismic intensity
				North-south (gal)	East-west (gal)	Up /down (gal)	3-component synthesis	Observatory	
Southern Hyogo (Hanshin Awaji Great Earthquake)	5:46 January 17, 1995	Inland	7.3	818.0	617.0	332.0	-	Kobe Marine Observatory	7
Niigata Chuetsu	17:50 October 23, 2004	Inland	6.8	1716.0	850.0	564.0	1750.0	NIGO21 Tokamachi	7
Iwate-Miyagi Inland	8:43 June 14, 2008	Inland	7.2	1143.0	1433.0	3866.0	4022.0	TWTH25 Kansai	Upper 6
Great East Japan Earthquake	14:46 March 11, 2011	Ocean trench	9.0	2700.0	1268.0	1880.0	2933.0	MYG004 Tsukidate	7

* Data for the Niigata Chuetsu and later earthquakes are from K-net.

Major earthquakes	Slope failures detected through satellite images & aerial photos			Pre-failure precipitation			Disaster incidence			Epicenter depth (km)	Horizontal distance to slope failure location (km)
	Number of slope failures	Slope failure location survey	Failure density (number/ km^2)	Accumulated precipitation in a week before failure	Accumulated precipitation in a month before failure	Amedas observatory	Number of sediment disasters*1	People killed or missing due to	People killed or missing due to earthquake		

		area (km^2)						sediment disasters	(Total)		
Southern Hyogo (Hanshin Awaji Great Earthquake)	770	120	6.4	0 mm	37 mm	Kobe	28	40	6,437	16	30
Niigata Chuetsu	878	20	43.9	132 mm	375 mm	Koide	225	4	67	10	5-10
Iwate-Miyagi Inland	3,014	590	5.1	3 mm	293 mm	Komanoyu	48	18	23	10	11
Great East Japan Earthquake	172	590	0.29	12 mm	77 mm	Komanoyu	114	19	18,131*2	24	About 150

*1:Slope failures, landslides, debris flows
*2: Fire and Disaster Management Agency, 9/28/2012

3.3.1.2 On-site Surveys and Local Responses to Sediment Disasters

The National Institute for Land and Infrastructure Management conducted the following on-site surveys in response to requests from prefectural governments or regional development bureaus.

[1] On-site survey of damage to steep slope failure prevention facilities in Miyamachi, Mito City, Ibaraki Prefecture (Research Center for Disaster Management)

[2] On-site survey of Miyagi Prefecture's coastal region (Erosion and Sediment Control Division)

[3] On-site survey of a sediment disaster in Tabito, Iwaki City, Fukushima Prefecture, caused by an earthquake with the epicenter in Hamadori, Fukushima Prefecture (Erosion and Sediment Control Division, Public Works Research Institute's volcano and debris flow team)

Results of the on-site surveys have been reported to survey requestors and published. The results of these surveys follow:

(1) On-site survey of damage to steep slope failure prevention facilities in Miyamachi, Mito City, Ibaraki Prefecture

The Great East Japan Earthquake on March 11, 2011, caused changes in the slope and failure prevention facilities at a location designated as dangerous due to possible steep slope failures in Mito City, Ibaraki Prefecture. The National Institute for Land and Infrastructure Management conducted an on-site survey there at the request of Ibaraki Prefecture.

1) General situation

The Miyamachi dangerous steep slope location is at the center of Mito City. At an upper portion of the slope is Mito Kyodo General Hospital. At the lower portion are many houses. The slope is about 15 meters high. Slope failure prevention facilities have been developed since 1971.

The Great East Japan Earthquake on March 11, 2011, caused changes in the slope and facilities, prompting the Mito municipal government to issue an evacuation order for residents (58 people from 30 households) at the lower portion of the slope at 17:50 on March 13.

2) Disaster situation

At the hospital site at the upper portion of the slope, cracks were seen for the entire area subject to slope failure prevention measures. The maximum crack size was 10 centimeters and the maximum crack depth was about 30 centimeters. Some cracks reached building wall borders (under construction) (Photos 3.3.1.1, 3.3.1.2, 3.3.1.3, 3.3.1.4 and 3.3.1.5).

Of a facility consisting of a gravity retaining wall and a three-stage block pitching work (Photo 3.3.1.6), the top of the slope slipped off forward, distorting the lower block pitching work. No distortion was seen at the bottom retaining wall (Photo 3.3.1.7).

Photo 3.3.1.1 A crack along a building

Photo 3.3.1.2 A crack is seen

Photo 3.3.1.3 A crack is seen in a parking area

Photo 3.3.1.4 The slope's lower portion as seen from its top (broken cribwork pieces are scattered)

Photo 3.3.1.5 Broken cribwork pieces that dropped to the lower portion of the slope

Photo 3.3.1.6 Retaining wall, cribwork, block pitching work

Photo 3.3.1.7 Retaining wall, cribwork (no anomaly seen on retaining wall)

(2) On-site survey of Miyagi Prefecture's coastal region

On April 8, 2011, the National Institute for Land and Infrastructure Management conducted an on-site survey of Miyagi Prefecture's coastal region that was heavily damaged by the tsunami accompanying the Great East Japan Earthquake.

1) Steep slope failure prevention facilities' effects on failures upon earthquake

Earth and rock falls that might have been caused by the series of earthquakes were confirmed at cribwork sides in Onagawa Town's Kawajiri area (Photo 3.3.1.8) and Ishinomaki City's Yoshinocho area (under a soil conservation project) (Photo 3.3.1.9). But no structural cribwork damage was seen, indicating that the cribwork contributed to preventing slope failures.

Photo 3.3.1.8 Earth falls on the right side of the cribwork (Onagawa)

Photo 3.3.1.9 Earth falls on the right side of the cribwork (Ishinomaki)

2) Tsunami's effects on steep slope failure prevention facilities

The retaining wall in Ishinomaki City's Yoshinocho area (under a soil conservation project) belonged to a tsunami-flooded area. But no leg portion erosion was detected. Nevertheless, there was a 3 centimeter dip slip at a construction joint that might have been caused by the earthquake (Photos 3.3.1.10 and 3.3.1.11).

Photo 3.3.1.10 A dip slip of the retaining wall

Photo 3.3.1.11 A dip slip of the retaining wall (zoomed)

Meanwhile, the leg portion soil of the cribwork in Onagawa Town's Kawajiri was washed away by the tsunami, leaving the cribwork suspended (Photo 3.3.1.13). There was a crack caused by a 3-4 centimeter strike slip at a construction joint (Photo 3.3.1.13).

Photo 3.3.1.12 Cribwork leg portion washed away (Kawajiri area)

Photo 3.3.1.13 A crack at a cribwork construction joint

The bulging stone guard of a standby retaining wall at the lower portion of the south slope of Mt. Horikiri in Onagawa Town buckled at the upstream slope side due to the tsunami (Photo 3.3.1.14). Many scratch marks were seen on the surface of the concrete retaining wall, indicating that a substantial flow velocity and debris exerted heavy pressures on the wall in the initial phase of the tsunami flooding (Photo 3.3.1.15).

Photo 3.3.1.14 Stone guard buckling

Photo 3.3.1.15 Scratch marks on the retaining wall

In the tsunami-flooded inside of the cribwork, sprayed materials were broken away or washed away at many points (Photo 3.3.1.16). But the lath remained almost undamaged (Photo 3.3.1.17). We suspected that the cribwork's functions had not declined so much (but the lath's rusting after the seawater flooding was a matter of concern).

Photo 3.3.1.16 Sprayed materials are broken away from the lath

Photo 3.3.1.17 A zoomed lath inside the cribwork

In an area like Onagawa Town where the tsunami ran over a narrowing inner bay, the leg portion of the cribwork might have been eroded. The degree of such erosion and the stability of the entire cribwork may have to be confirmed and assessed.

3) Situation of the project for conserving a slope for specific uses at Mt. Horikiri in Onagawa Town

The project for conserving a slope for specific uses coordinates steep slope failure prevention and other public works programs to secure the stability of the slope and create a regional infrastructure development space for the purpose of regional invigoration. Japan's first project for conserving a steep slope for specific uses was completed at Mt. Horikiri in Onagawa Town in FY 1997. On the hill developed through the project are a town hospital, a regional welfare center and a health-care facility for the elderly. Evacuation steps have been developed for the hill that has been designated as a site for evacuation from tsunami or storm waves.

The height of the cut at the project site is given as 16 meters elevation (13 meters in the initial planning stage). But the elevation slightly rises toward the center of the hill (Photo 3.3.1.18).

Photo 3.3.1.18 An overview of the Mt. Horikiri slope for specific uses

Photo 3.3.1.19 The south side wall of the elderly welfare center

The elderly welfare center (Photo 3.3.1.20) on the south side of the hill is at the lowest site of the hill. On a slope from the center to Kumano Shrine on the mountain side was a trace of a flood of nearly 3 meters. A flood of around 1 meter was indicated at the town hospital on a higher site.

Several cars were suspended at the south wall of the elderly welfare center (Photo 3.3.1.19). Trash was suspended on steel bars and the hedge (Photo 3.3.1.21) on the east (sea) side of the hill. But the steel bars and hedge were not damaged so greatly. There was no trace of debris flowing into the inner hospital and parking area. (This was also confirmed through a helicopter-based observation on March 12).

Therefore, we suspect that the hill flooding started at the elderly welfare center on the slightly lower south side. The flooding speed might have been high in the initial phase and declined to almost zero when the flood at the elderly welfare center reached 1 to 2 meters. The flood height might have risen gradually.

Left undamaged were two steel stairways (Photo 3.3.1.22) built on the sea side for evacuation from tsunamis.

The abovementioned points confirm that the conservation of slopes for specific uses through such measures as the construction of stairways or pathways for evacuation and of key facilities on hills developed with upper slope portions cut are useful at steep slope failure danger zones that could be exposed to tsunamis.

Photo 3.3.1.20 A flood trace (at the top of the pole) at the elderly welfare center

Photo 3.3.1.21 Steel bars and hedge on the east side of the hill

Photo 3.3.1.22 A steel stairway for evacuation from tsunamis

Photo 3.3.1.23 A whole picture of the slope failure

(3) A Sediment disaster in Tabito, Iwaki City, Fukushima Prefecture, caused by an earthquake with the epicenter in Hamadori, Fukushima Prefecture

At around 17:16 on April 11, 2011, an earthquake with a magnitude of 7.0 occurred with the epicenter traced to Fukushima Prefecture's Hamadori. The epicenter depth was estimated to be 5 kilometers. The maximum seismic intensity of lower 6 was observed in Fukushima Prefecture's Iwaki City and Ibaraki Prefecture's Hokota City. The earthquake caused slope failures and landslides mainly in Iwaki. The National Institute for Land and Infrastructure Management and the Public Works Research Institute's volcano and debris flow team conducted an on-site survey of a slope failure in Tabito, Iwaki City, Fukushima Prefecture, on April 13, 2011, at the request of the Tohoku Regional Development Bureau. The survey results are reported as follows:

1) Slope failure data

Figure 3.3.1.2 gives an overview of the slope failure. Photo 3.3.1.23 indicates the whole picture of the failure.

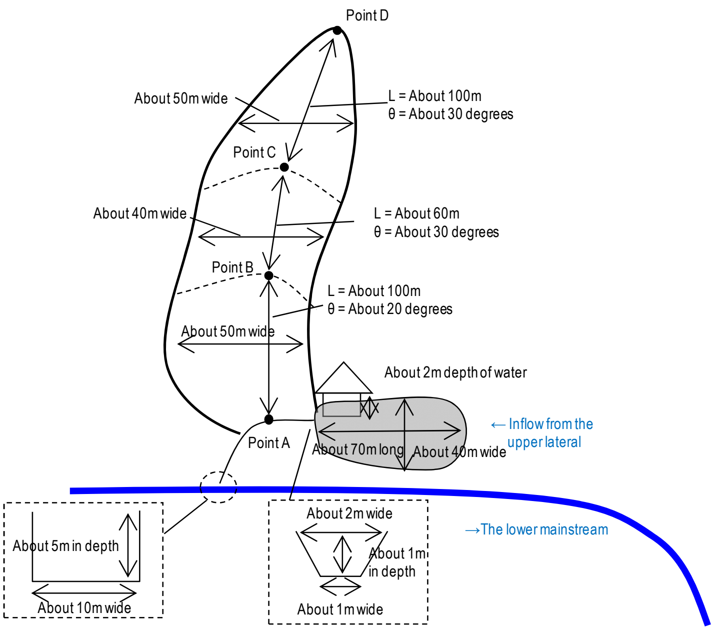

Figure 3.3.1.2 An overview of the slope failure

2) Overview of slope failure

In the failure, a rockslide occurred on a dip slope with an inclination of about 30 degrees at a ridge (Photo 3.3.1.24). Soil mass collapsed downward over about 150 meters from the upper limit of the failure. The point 150 meters down from the upper failure limit is a joint between the ridge and a valley on the left side of the slope (the point is called "the joint" hereinafter) (Photo 3.3.1.25). The failure/slide might have occurred as the earthquake shook the entire ridge where the earthquake vibration was released. Part of the collapsed soil mass was suspended on a terrace of a milder slope with an inclination of about 15 degrees at the joint. On the surface of the soil mass are stubs lined up in an orderly manner (Photo 3.3.1.26). Therefore, the movement pattern is suspected as a slide.

Photo 3.3.1.24 An upper portion of the collapse (an exposed rock is seen at the center)

Photo 3.3.1.25 The left side valley and the joint

Photo 3.3.1.26 Stubs lined up on the terrace

Sediment that flowed down from the terrace was scattered on the slope and reached a house at the lower portion of the slope (Photo 3.3.1.27). The sediment mainly included block-shaped rock pieces measuring 20 to 50 centimeters (Photo 3.3.1.28). Although the clayish matrix was somewhat wet, the sediment was not as wet as usual debris flow sediment. The slide might have been a dry sediment flow (there was no trace of mud water flowing down from the disaster-affected house).

Sediment includes stubs. Stub roots were relatively fresh. The situation was different from the so-called dangerous situation where the shear resistance declines as stubs rot in some 10 years after felling. Root lengths (depths) were as short as 30 to 50 centimeters (Photo 3.3.1.29), indicating that the surface soil of the slope was thin. Some stubs were left untouched at points close to the top of the collapsed slope (Photo 3.3.1.30), indicating that the slide was not attributable to the water-caused destabilization of the surface soil at the lower portion of stub roots. The slope failure or slide might have been attributable to the earthquake vibration.

Photo 3.3.1.27 Sediment reaching a house (seen from the terrace at the center of the slope failure)

Photo 3.3.1.28 Collapsed sediment at the terrace

Based on laser measurement results, total collapsed sediment was estimated at about 25,000 cubic meters (including about 22,000 cubic meters in collapsed sediment left after the failure and about 3,000 cubic meters in sediment blocking up the river channel). No sediment flowed into the mainstream.

Photo 3.3.1.29 A stub with shorter roots

Photo 3.3.1.30 Stubs left close to the top (seen from the top)

3) Situation of sediment surrounding collapsed area

While there were no cracks or any other indications of destabilization on the slope surrounding the collapsed area, some unstable sediment was seen. At the right side of the collapsed area's top was a block measuring 5 meters wide, 10 meters long and 1 meter thick (Photo 3.3.1.31). Seen on the strip roads at both sides of the collapsed slope were many cracks normal to the collapse direction (Photo 3.3.1.32).

On both sides of the collapsed slope were sediment upthrusts (1 to 2 meters high) similar to natural banks. Sediment suspended on the slope has an inclination of some 20 degrees and is relatively porous, indicating that the sediment is unlikely to flow.

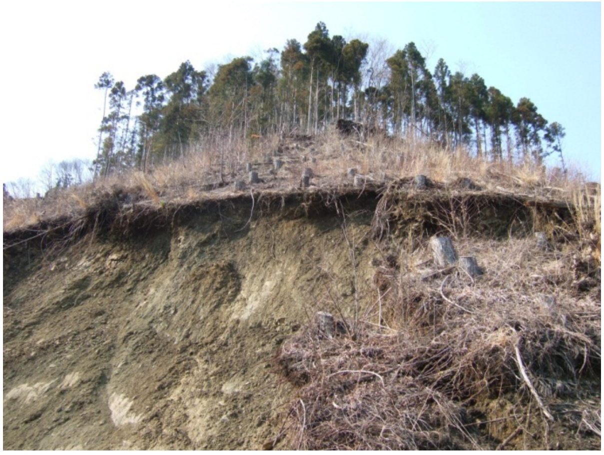

Photo 3.3.1.31 A block left on the right side of the top

Photo 3.3.1.32 A crack seen on a strip road at the left side of the slope

4) Situation of landslide dam

Sediment blocked up the river channel including a channel consolidation work (measuring about 3 meters deep and 3 meters wide) over an area measuring 50 meters wide (in the transverse direction) and 30 meters long (Photo 3.3.1.33). Sediment volume is estimated at about 3,000 cubic meters. The flood at the house on the right bank side was estimated at around 1 meter. The flood volume was estimated at about 5,600 cubic meters (about 40 m in width (transversal direction) x about 70 m in depth (traverse direction) x about 2 m in depth) (Photo 3.3.1.34). The sediment-blocked site was already opened with a cross-section measuring 1 meter deep and 1 meter wide (at the riverbed) (Photo 3.3.1.35).

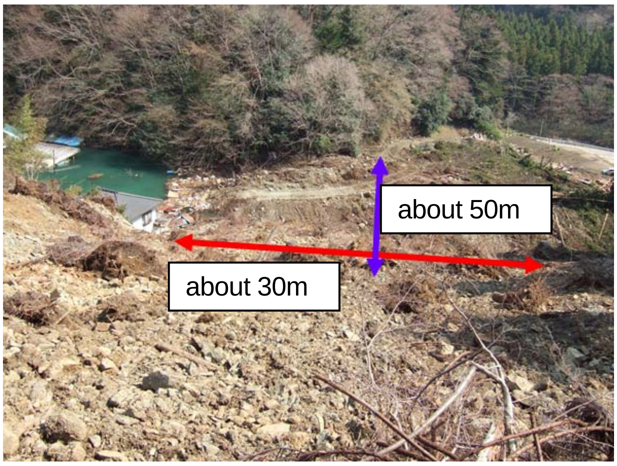

Photo 3.3.1.33 A blocked river channel seen from the center of the collapsed slope

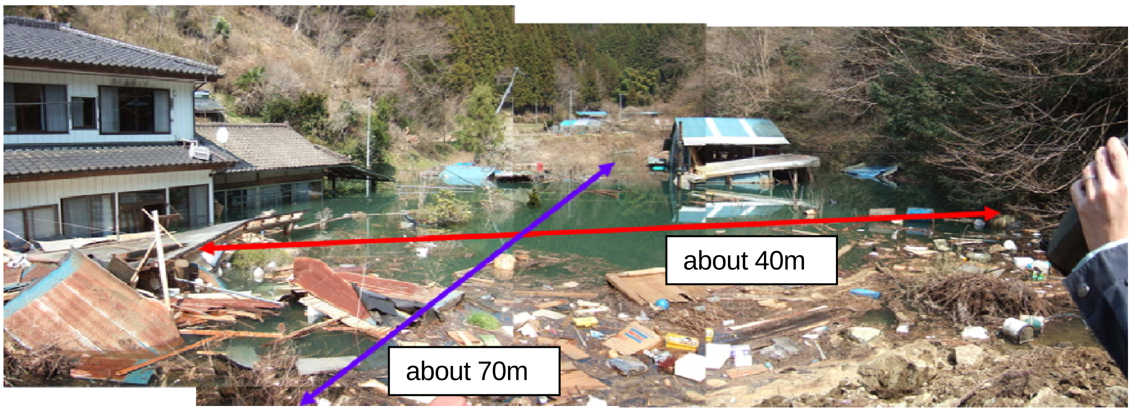

Photo 3.3.1.34 Situation of a flood pond

Photo 3.3.1.35 A cross section of the blocked river channel

(4) Conclusions of on-site surveys

[1] Steep slope failure prevention facilities were not damaged so much by the earthquake vibration, although a stone guard at the upper portion of a retaining wall buckled due to the tsunami. It was confirmed that these facilities demonstrated their slope failure prevention functions.

[2] In areas vulnerable to tsunamis, it is effective to develop evacuation pathways when steep slope failure prevention facilities are constructed.

[3] Collapses centered on ridge slopes, graded slopes and fills, meeting generally known trends of earthquake-caused slope failures.

[4] There was a case where an inland epicentral aftershock with less seismic intensity (acceleration) than the principal earthquake caused collapses.

[5] Earthquake-caused slope failures can be frequent at mountain ridges and failure scales can be increased. Therefore, attention must be paid to disasters at locations that are not viewed as ordinary sediment disaster danger zones.

3.3.1.3 Survey of Large-scale Collapses Using Optical Satellite Images

(1) Overview of survey

The Great East Japan Earthquake with the epicenter off the Tohoku region unleashed tsunamis that devastated coastal regions. In inland regions as well, high seismic intensity levels were observed widely, including the intensity of 7 posted in Kurihara City, Miyagi Prefecture.

As a result, sediment disasters occurred, including the Hanokidaira landslide.

In a bid to confirm slope failures, landslides, landslide dams and other large sediment disasters caused by the earthquake, the National Institute for Land and Infrastructure Management implemented the visual interpretation of optical images including Daichi ALOS PRISM and AVNIR-2 images provided by the Japan Aerospace Exploration Agency (JAXA).

The survey results are as follows:

(2) Extracting sediment disaster locations through visual interpretation of satellite images[1)]

1) Target area and data used for visual interpretation

Table 3.3.1.2 summarizes the data used for the visual interpretations. Table 3.3.1.3 outlines the ALOS optical sensors.

- Decipherment coverage and image situation

In locations where the seismic intensity of upper 5 or more is posted, the incidence of slope failures and other sediment disasters is likely to be higher. Therefore, our satellite image interpretation covered all locations with seismic intensity levels at lower 6 or more and most of the locations with seismic intensity levels at upper 5 or more (an area stretching some 100 kilometers from east to west and about 450 kilometers from north to south) in an estimated seismic intensity map published by the Japan Meteorological Agency (Figure 3.3.1.3).

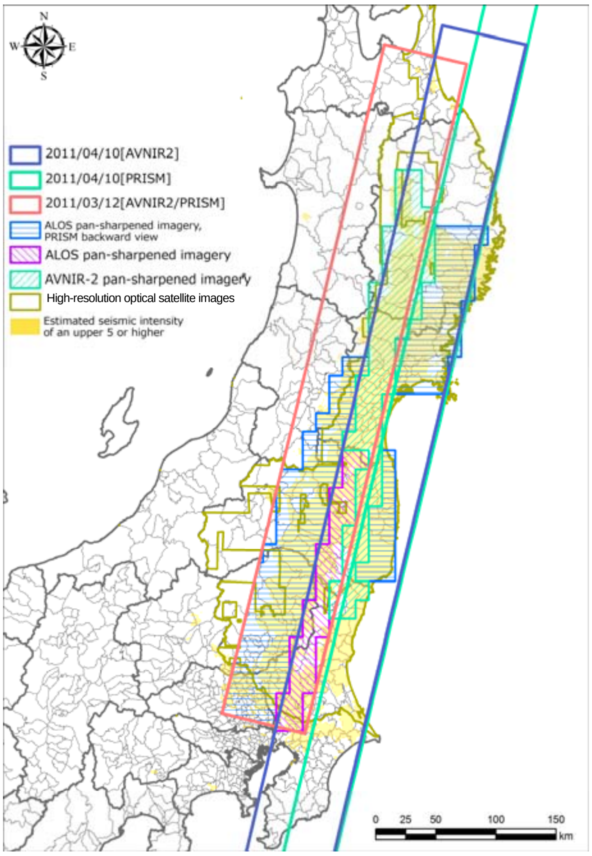

Figure 3.3.1.3 Locations with Seismic Intensity of Upper 5 or More, interpretation Coverage and Types of Satellite Images

Table 3.3.1.2 List of Deciphered Data

Image name	ALOS AVNIR-2 images	ALOS pan-sharpen images	ALOS stereo set (pair) images	High-resolution optical satellite images
Sensor name	・ALOS AVNIR-2	・ALOS AVNIR-2 ・ALOS PRISM viewing nadir	・ALOS AVNIR-2 ・ALOS PRISM viewing nadir ・ALOS PRISM viewing forward (or backward)	・GeoEye-1, IKONOS, WorldView-1, etc.
Ground resolution	10 m	2.5 m	2.5 m	About 1 m or less

Table 3.3.1.3 Overview of ALOS Optical Sensors

Sensor name	AVNIR-2	PRISM viewing nadir	・PRISM viewing forward ・PRISM viewing backward
Official name	Advanced Visible and Near Infrared Radiometer type 2 sensor	Panchromatic Remote-sensing Instrument for Stereo Mapping sensor	Panchromatic Remote-sensing Instrument for Stereo Mapping sensor
Ground resolution	10 m	2.5 m	2.5 m

Observation width	70 km	70 km	35 km
Note	Color image	Black-and-white images	Black-and-white images

The priority order of interpretation images is from high-resolution optical satellite images (GeoEye-1, IKONOS and Worldview-1) to ALOS stereo pair images, ALOS pan-sharpen images and ALOS AVNIR-2 images in order by resolution.

High-resolution optical satellite images were taken for the Tohoku region's coastal areas and central Sendai after the Great East Japan Earthquake, while no such images for inland mountainous areas were taken after the earthquake (red dot-lines in Figure 3.3.1.3).

Among optical satellite sensors, only the ALOS AVNIR-2 covered all mountainous locations with seismic intensity levels of upper 5 or more subject to the interpretation.

While our interpretation covered a wide area including most of the locations with seismic intensity levels of upper 5 or more, the ALOS AVNIR-2 sensor's observation width of 70 kilometers and its nadir-viewed images taken on March 12 and 14 allowed us to figure out an outline of disasters for most of the coverage at an early stage. As ALOS images continued to be taken later, we deciphered nadir-viewed images that were expected to feature the best resolution.

2) General information about interpretations

Less than one-meter resolution images from high-resolution satellites can be enlarged to indicate granulated rocks stemming from slope failures, making it easier for us to decide whether specific locations are collapsed or not. More than 2.5-meter resolution images cannot allow us to find granulated rocks stemming from slope failures. Therefore, less than one-meter resolution images are required for finding small collapses measuring around 50 meters.

Collapsed locations emerging in satellite images have different colors depending on sunlight. Shaded collapses can be overlooked. Images of steep valleys and other shaded locations must be adjusted for coloring to prevent landslide dams or natural dams from being overlooked or to find collapses along rivers accurately.

Rather than ALOS pan-sharpen images alone, ALOS stereo pair images combining pan-sharpen and forward-viewed images allowed us to find land rises and falls at collapsed locations and detect collapses more accurately.

3) Interpretation results

The interpretation of satellite images was conducted just after the earthquake and after an increase in post-earthquake high-resolution optical satellite images.

In the interpretation just after the earthquake, about 200 locations with potential sediment movements were extracted, confirming that large collapses forming landslide dams did not occur although there were the Hanokidaira landslide and other small slope failures that had been figured out through helicopter-based and other surveys just after the earthquake.

The second interpretation improved the accuracy as an increase in the scope and number of high-resolution optical satellite images allowed us to compare clearer and better-resolution images. The accuracy improvement enabled us to discriminate collapse-free bare locations (including locations for felling before the earthquake) and find new collapsed locations. As a result of the second interpretation, we extracted about 1,000 locations with potential sediment movements. Collapsed locations detected through the first and second interpretation are indicated in Figure 3.3.1.4.

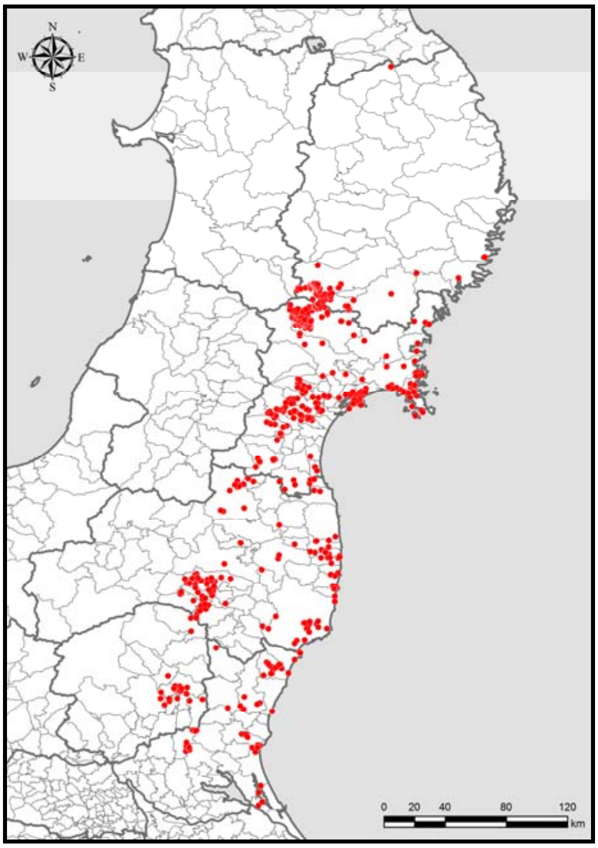

Figure 3.3.1.4 Collapsed Location Detection Results

(3) Satellite Image Survey Conclusions

We deciphered a wide range of satellite images for a sediment disaster survey involving the Great East Japan Earthquake. According to the survey, the availability and challenges of satellite remote sensing technology for a prompt survey to specify the distribution of sediment disasters are summarized as follows:

[1] The resolution of 2.5 meters for ALOS pan-sharpen images allowed us to detect the space distribution of large collapses measuring more than 50 meters. In order to detect small collapses measuring less than 50 meters, however, ultra-high-resolution images with 1 meter or less resolution are required to detect granulated rocks stemming from slope failures and to discriminate felling and quarry locations from collapsed locations.

Large-scale collapses measuring 20 to 30 times more than the resolution can be extracted more surely. Smaller collapses are difficult to detect and can be overlooked.

The stereoscopic vision using stereo pair images was useful for deciding whether any location was collapsed or not.

[2] About 1,000 collapsed locations extracted through the satellite image interpretation represented relatively large collapses and include large collapsed locations where no damage was caused. Therefore, their distribution differs from the distribution of sediment disasters covering small damage-causing collapses in the number of collapsed locations and positions.

[3] Although a very wide area was subjected to the satellite image interpretation, the survey allowed us to promptly figure out the space distribution of large collapses.

The ALOS AVNIR-2 images used mainly for the interpretation limited extracted collapses to relatively large ones because of their low ground resolution at 10 meters. We thus failed to detect small collapses. But we have achieved the purpose of promptly confirming any collapses large enough to form landslide dams over a very wide area of high seismic intensity locations after a giant earthquake like the Great East Japan Earthquake.

Over a wide area, particularly, a helicopter-based survey may overlook collapses with flight routes limited, leaving some locations free from observation. Therefore, optical satellite images allowing us to visually cover the entire area were very useful.

[4] Locations with higher collapse densities were not necessarily those with higher seismic intensity levels posted upon the principal earthquake.

3.3.1.4 Assessing Danger of Slope Failures through Earthquakes

In order to assess the danger of mountain slope failures through earthquakes, the National Institute for Land and Infrastructure Management built on data for collapses through the 1995 Southern Hyogo Prefecture Earthquake to develop a "discriminant for assessing the danger of slope failures through earthquakes" (hereinafter referred to as "the discriminant")[2]. The discriminant is a practical method that allows us to simply assess the danger of collapses even at locations free from earthquake-caused slope failures by using general available data such as the inclination, the average curvature factor and the maximum acceleration. But the discriminant was developed to assess the danger of relatively small surface slope failures in the Mt. Rokko granite area. The problems with the discriminant are whether it can accurately assess the danger of relatively large collapses in areas with complex geological conditions and whether it is available for an ocean-trench earthquake.

We have applied the discriminant to not only the Southern Hyogo Prefecture Earthquake but also seven others -- the Kozu Island Earthquake, the Niigata Chuetsu Earthquake, the Northern Kagoshima Prefecture Earthquake, the Northern Miyagi Prefecture Earthquake, the Noto Peninsula Earthquake, the Niigata Prefecture Chuetsu-oki Earthquake and the Iwate-Miyagi Inland Earthquake -- in a bid to confirm its accuracy. As a result, we successfully assessed the danger of collapses for the other seven earthquakes as accurately as for the Mt. Rokko area.

In an attempt to verify the discriminant's applicability to an ocean-trench earthquake and assess its accuracy quantitatively, we applied the discriminant to the Kurikoma area where the Great East Japan Earthquake on March 11, 2011, caused many slope failures. We also compared the results of this application with those of the discriminant's application to the same area regarding the Iwate-Miyagi Inland Earthquake. Through these procedures, we assessed the reasonability of the discriminant's application to the Great East Japan Earthquake as an ocean-trench earthquake. Finally, we compared and considered the results of the discriminant's application to the nine earthquakes for the verification of its applicability, analyzed the applicability and introduced our future research policy.

(1) Applying the discriminant to the Great East Japan Earthquake

1) Overview of the discriminant

The discriminant is an assessment equation derived from a discrimination analysis approach. The approach plots an independent variable as shown in Figure 3.3.1.5 to derive a border between a group of variable values for collapse cases and that of values for non-collapse cases and predict possible collapses. A mesh with higher discrimination scores determined through the discriminant is interpreted as indicating a greater vulnerability to collapses. A mesh with lower scores may represent a smaller vulnerability to collapses. The discriminant derived from data of collapses in the 1995 Southern Hyogo Prefecture Earthquake is given as follows, using the inclination and average curvature as predisposed data and the maximum acceleration as incentive data[2]:

$$F = 0.075I - 8.92C + 0.006A - 3.228 \quad \cdots (1)$$

In the equation, F stands for the discrimination score, I for the inclination (degrees), C for the average curvature, and A for the maximum acceleration (cm/s^2). The results of the discriminant's assessment of the Mt. Rokko area are shown in Figure 3.3.1.6. Black triangles in the figure indicate actual collapses. Generally, earthquake-caused collapses are more probable as the inclination is greater (but the inclination of 60 degrees or more indicates a lower collapse probability for reasons such as firmer-rock slopes), as the average curvature is smaller (indicating a convex slope geographically) and as the maximum acceleration is higher[3]. Equation (1) reflects such trend.

2) Methodology

Of the data used for calculating the discrimination score with Equation (1), the inclination and average curvature as predisposed data are computed from the 10-meter mesh data of the basic map information from the Geospatial Information Authority of Japan. An attenuation model is used to compute the maximum acceleration based on the fault model published by the National Research Institute for Earth Science and Disaster Prevention. The attenuation model is given as follows[4]:

$$\log 10\ A = 0.42Mw - \log 10\ (R + 0.025 \cdot 100.42Mw) - 0.0033R + 1.22 \quad \cdots (2)$$

In the equation, Mw stands for the moment magnitude and R for the distance (in kilometers) from a fault.

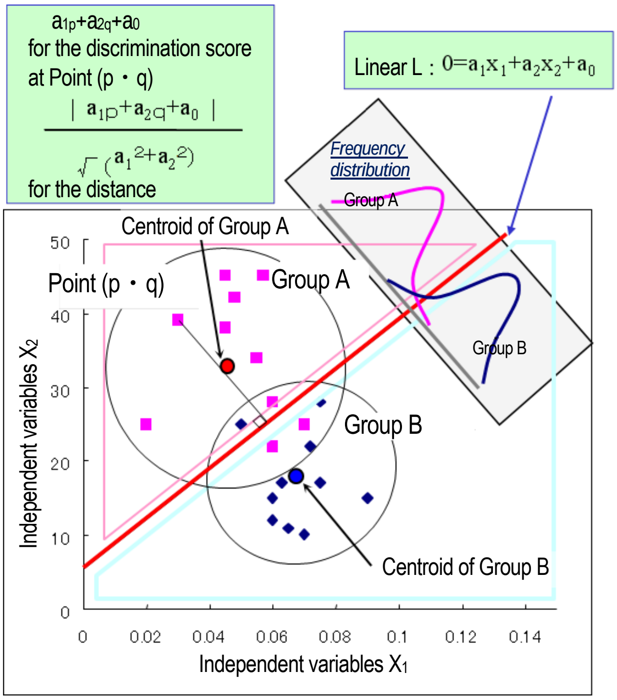

Figure 3.3.1.5 Concept of Discrimination Analysis

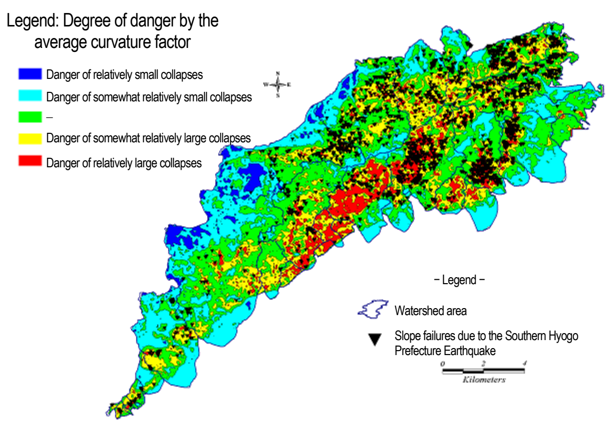

Figure 3.3.1.6 Results from Application of the Discriminant to the Mt. Rokko Area

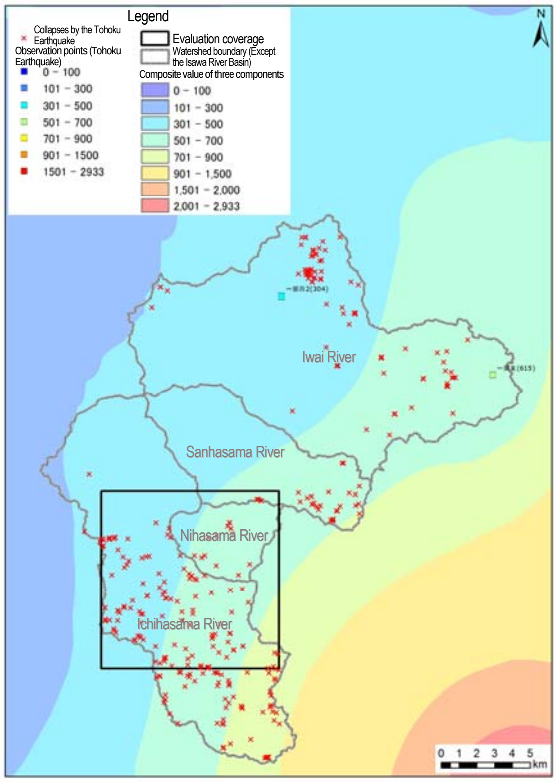

Figure 3.3.1.7 Distribution of Great East Japan Earthquake Acceleration Data and Collapses in the Kurikoma Area

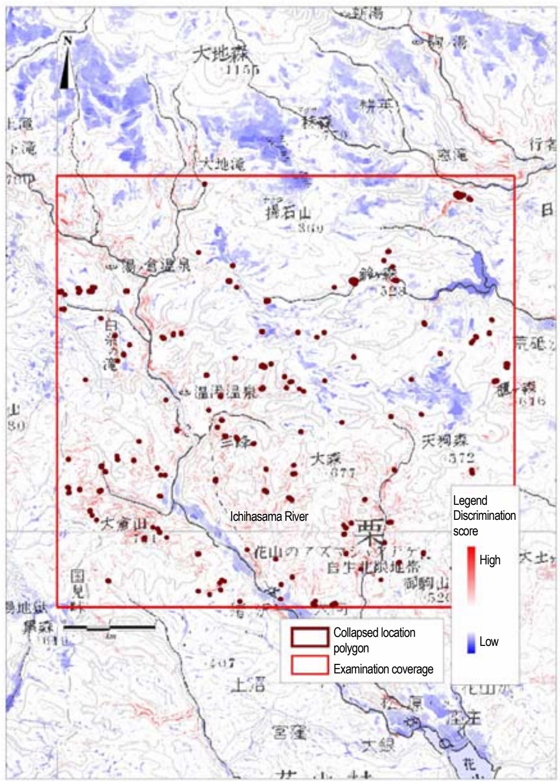

Figure 3.3.1.8 Discrimination Assessment Results for the Kurikoma Area

3) Collapsed location decipherment results

Figure 3.3.1.7 combines the distribution of acceleration estimates derived from the attenuation model with that of collapsed locations detected through the decipherment of aerial photos for the Kurikoma area. In the decipherment of aerial photos, we used data from the aerial photos taken by the Geospatial Information Authority of Japan from May to October 2011 after the earthquake and compared these data with aerial photos taken in December 2010 to confirm new and expanded collapses. As a result, we detected a total of approximately 330 collapses, including about 300 new collapses and about 20 expanded collapses, and estimated these collapses as caused by the Great East Japan Earthquake. For reference, the Iwate-Miyagi Inland Earthquake caused a total of approximately 2,060 collapses in the area.

4) Discriminant application results

We selected a 10/10 km zone (100 square kilometers) from the Kurikoma area for the application of the discriminant and combined the distribution of discrimination scores computed through Equation (1) and that of actual collapses in Figure 3.3.1.8. Figure 3.3.1.8 shows that red zones where collapses were indicated by the discriminant as more probable roughly match actual collapses (red points).

Table 3.3.1.4 Kurikoma Area Decipherment Results and Their Comparison with Results for Other Earthquakes

	Southern Hyogo Prefecture	Northern Kagoshima Prefecture	Kozu Island	Northern Miyagi Prefecture	Niigata Chuetsu	Noto Peninsula	Niigata Chuetsu-oki	Iwate-Miyagi Inland	Great East Japan
Correct prediction rate	64.3	49.0	68.9	57.2	74.2	84.4	78.7	69.0	50.2
Missed prediction failure rate	20.8	48.7	30.0	35.0	11.3	24.1	18.3	25.1	41.3

		Prediction	
		Collapse	No collapse
Actual	Collapse	A	B
	No collapse	C	D

	Correct prediction rate	(A+D)/(A+B+C+D)
	Missed prediction rate	B/(A+B)
	Incorrect prediction rate	C/(A+C)
	Threat score	A/(A+B+C)

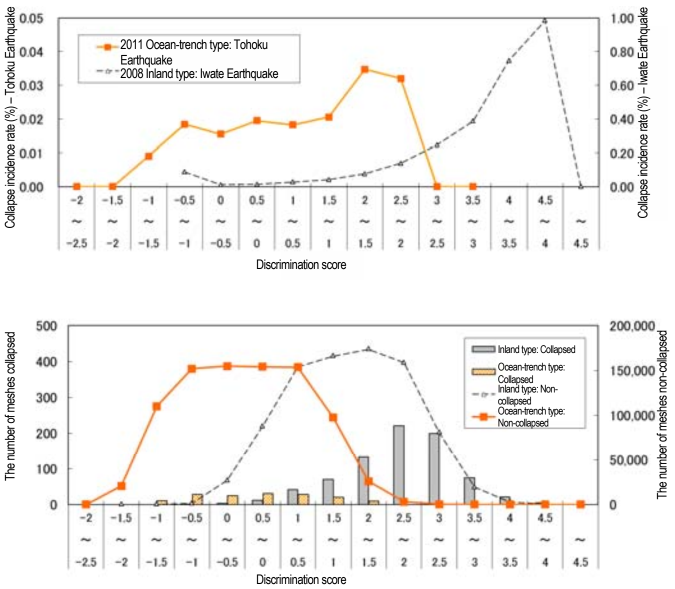

Figure 3.3.1.9 Collapse Incidence Rate by Score Range

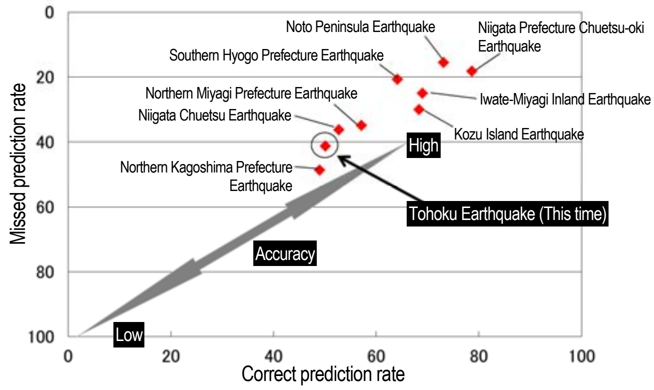

Figure 3.3.1.10 Relative Assessment of Discrimination Results for the Kurikoma Area

In a bid to quantitatively assess the accuracy, we computed the correct prediction and missed prediction rate. The correct prediction rate represents the rate of meshes where collapse and non-collapse cases were predicted correctly. The missed prediction rate is the rate of meshes where collapses actually occurred despite non-collapse case predictions (Table 3.3.1.4). A mesh where a collapse occurred is defined as a mesh located at the head of the collapsed location polygon data, as is the case with the assessment method for other earthquakes.

As a result, as shown by Figure 3.3.1.9, we can see the trend that the collapse incidence rate for each score range increases as the discrimination score rises. But this trend is unclear when compared to the discrimination results for the Iwate-Miyagi Inland Earthquake. The correct prediction rate was computed at 50.2% with the missed prediction rate at 41.3%, indicating a roughly lower accuracy as compared to accuracies indicated for other earthquakes as shown in Figure 3.3.1.10. The low rate of collapse incidences caused by the Great East Japan Earthquake in the area might be related to this discrimination result.

(2) Conclusion

In this study, the discriminant based on slope failures in the Mt. Rokko area caused by the Southern Hyogo Prefecture Earthquake was applied to the Kurikoma area where many failures were caused by the Great East Japan Earthquake as an ocean-trench earthquake. The application results indicated lower accuracy than ones for earlier inland earthquakes, being possibly influenced by the low rate of collapse incidences. The discriminant's applicability to the slope failure danger assessment for ocean-trench earthquakes should await further study.

At present, the National Institute for Land and Infrastructure Management is studying an approach to quantitatively assess post-earthquake loosening of slopes from the viewpoint of post-earthquake slope failure danger assessment. For sediment disaster warnings operated by the Ministry of Land, Infrastructure, Transport and Tourism and the Japan Meteorological Agency, 50-80% of the normal standard is tentatively used for locations posting seismic intensity levels at upper 5 or more, with consideration given to slopes' loosening caused by earthquake vibrations. In fact, tentative standards were set for 240 municipalities in 17 prefectures in April 2011 just after the Great East Japan Earthquake. As for sediment disasters that occurred between March 11 and October 31, 2011, after the Great East Japan Earthquake, precipitation data have been collected for verifying the effectiveness of the tentative standards (Figure 3.3.1.11). We would like to try to improve the accuracy of approaches for assessing the danger of slope failures through earthquakes, while collecting new data.

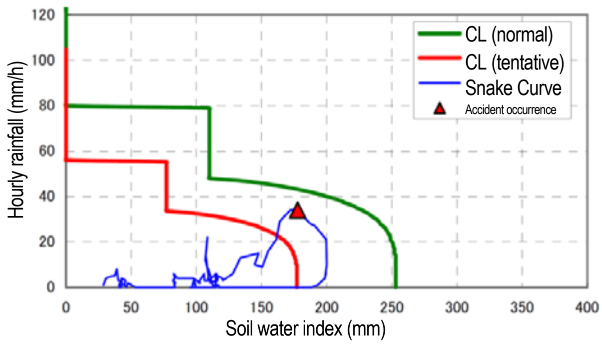

Figure 3.3.1.11 Image of Disaster Detection under Tentative Standards for Sediment Disaster Warnings

Acknowledgement

In compiling this section, we used the estimated seismic intensity map by the Japan Meteorological Agency. For the survey of collapses using satellite images, we received ALOS optical images from the Japan Aerospace Exploration Agency (JAXA) under our joint study with JAXA. We here make a most cordial acknowledgement to these agencies.

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4) Fukushima, Y., Tanaka, T.: Revised Attenuation Relation of Peak Horizontal Acceleration by Using a New Data Base, Collection of Speech Papers for the Seismological Society of Japan, p.116, 1992

3.3.2 Sewage

(1) Damage Survey and Local Responses

The tsunami devastatingly damaged sewage treatment plants and relevant facilities on the coast of the Tohoku and Kanto regions. A total of 120 sewage treatment plants and 112 pumping stations received damage including function injuries and breakdowns. A total of 642 kilometers sewer pipe conduits in 132 municipalities were damaged due mainly to ground liquefaction, bringing about sewage service disruptions including service suspensions lasting for some one month.

As the Great East Japan Earthquake brought about greater damage than assumed for in the rules for mutual support among local governments, the Ministry of Land, Infrastructure, Transport and Tourism undertook coordination regarding sewage services. The ministry gave top priority to measures against untreated sewage releases and urban overflow streams and established a sewage disaster recovery headquarters at the Tohoku Regional Development Bureau for liaison and coordination with relevant organizations. The National Institute for Land and Infrastructure Management sent a tec-force the day after the earthquake to launch the recovery headquarters. A total of 18 officials from the institute were sent for technical guidance and other operations over one month.

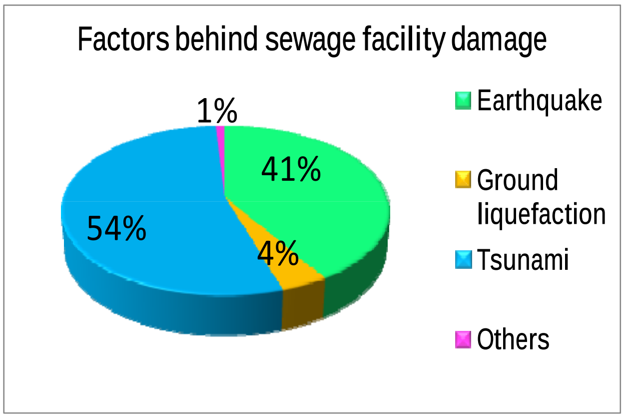
Photo 3.3.2.1 Sewage Disaster Recovery Headquarters (Tohoku Regional Development Bureau)

(2) Overview of damage

In order to specify factors behind sewage treatment plant and pipe damage caused by the Great East Japan Earthquake, the National Institute for Land and Infrastructure Management conducted a questionnaire survey of disaster-hit local governments (of which 69% gave valid responses). Figure 3.3.2.1 indicates factor-by-factor breakdowns of damage to individual sewage treatment plant facilities (one plant was divided into 23 facilities) and to sewer pipe conduits.

At sewage treatment plants, the tsunami accounted for 54% of the damage, followed by earthquake motion for 41% and ground liquefaction for 4%. Of damage to sewer pipe conduits, ground liquefaction accounted for about 90%. Of the percentage, liquefaction of backfill soil for sewer pipe conduits, which has been a problem since the Niigata Chuetsu Earthquake, was responsible for 66 percentage points, becoming the largest factor behind the pipe damage. Surrounding ground liquefaction accounted for 25 percentage points, far larger in the past.

Sewage treatment plants in coastal cities are built relatively close to the sea due to the adoption of the gravity flow system and the necessity of releases to public waters. Because of their proximity to the sea, the tsunami injured constructed structures with its strong wave power and flooded electrical and mechanical equipment. But existing anti-earthquake guidelines for sewage facilities included no descriptions about anti-tsunami measures. Therefore, a panel to be discussed later has considered a sewage facility design concept giving considerations to anti-tsunami measures, based on the damage realities. While many sewer pipe facilities lacking anti-earthquake measures were damaged, surrounding ground liquefaction led sediment to flow into lateral sewer pipe conduits to clog up them or affect flows, though with main sewer pipes damaged little. Given these findings, anti-earthquake guidelines have been expanded to require traditional anti-liquefaction measures for backfill soil liquefaction zones and for lateral sewer pipes that had been exempted from such measures and were damaged by surrounding ground liquefaction.



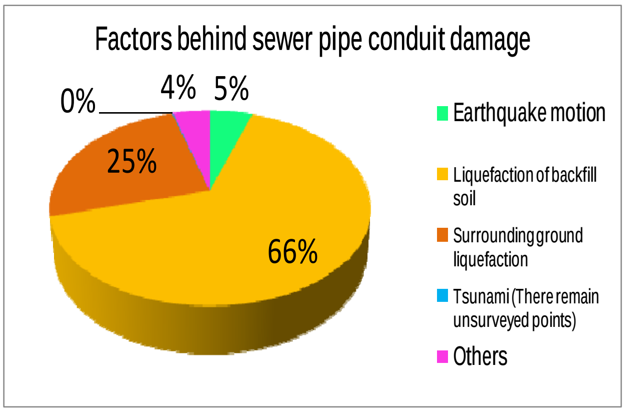
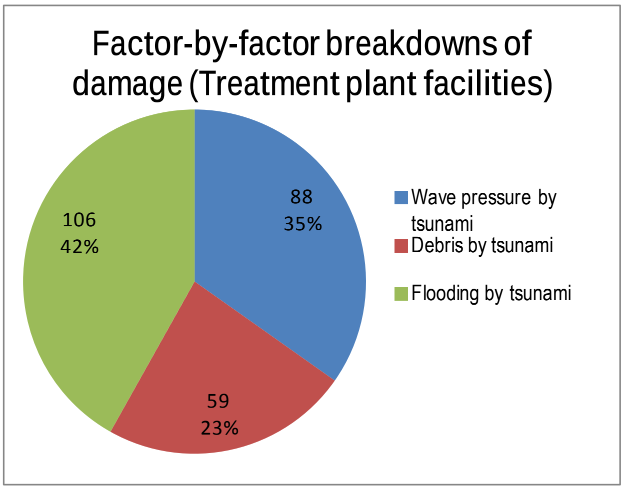


Figure 3.3.2.1 Factors behind Sewage Facility Damage

(3) Tsunami damage to sewage treatment plants and pumping stations

Tsunami damage factors include wave pressure, castaways and flooding. Figure 3.3.2.2 indicates factor-by-factor breakdowns of damage to sewage treatment plants and pumping stations (divided into 23 facilities). Each of flooding, wave pressure and castaways accounts for a large share of damage. At sewage treatment plants, particularly, flooding accounted for a larger share at 42%, followed by 35% for wave pressure. Mechanical energy might have been coupled with wetting and submerging to inflate damage. Representative damage is shown in Photo 3.3.2.2



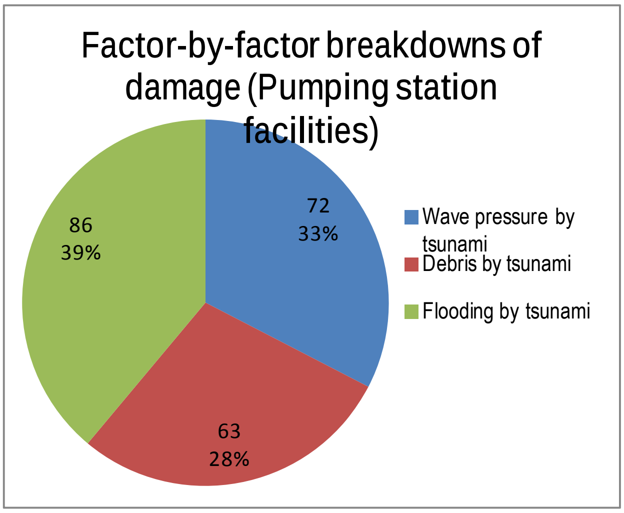


Figure 3.3.2.2 Factor-by-factor Breakdowns of Damage to Sewage Treatment Plants and Pumping Stations

(a) Wave pressure-caused damage to a sea-side wall

(b) Castaways' direct damage to a building

(c) Flooding-caused damage to interior equipment

Photo 3.3.2.2 Representative Tsunami-caused Damage to Sewage Treatment Plants and Pumping Stations

We here would like to analyze the characteristics of tsunami-caused damage to sewage treatment plant facilities (23 facilities) and pumping station facilities (five facilities) based on information from the questionnaire survey. In a comparison of earthquake motion- and tsunami-caused damage, tsunami-caused damage tended to focus on electrical equipment both at sewage treatment plants and pumping stations (Figure 3.3.2.3). Electrical equipment breakdowns stemming from the submersion or washout of control panels in switch rooms or water treatment facilities accounted for most of the damage to electric equipment. Figures 3.3.2.4-5 indicates that tsunami-damaged sewage treatment plants took more time for their restoration than other damaged plants that recovered normal functions roughly in one month, for which services were suspended. Some large plants took more than one year for recovering normal functions or ending service suspensions. Given that the Higashinada sewage treatment plant in Kobe took about100 days to restore normal functions after the Southern Hyogo Prefecture Earthquake, service suspension periods for these plants after the Great East Japan Earthquake were longer.

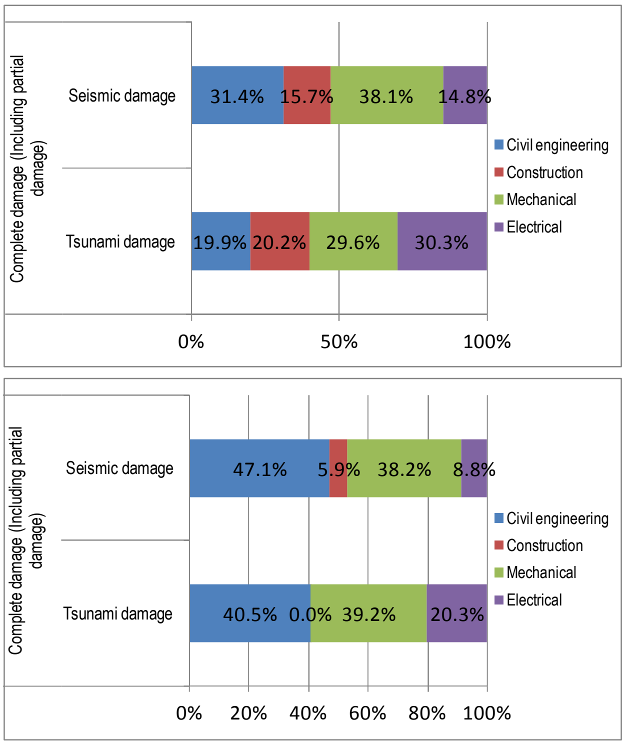


Figure 3.3.2.3 Relative Comparison of Earthquake- and Tsunami-caused Damage

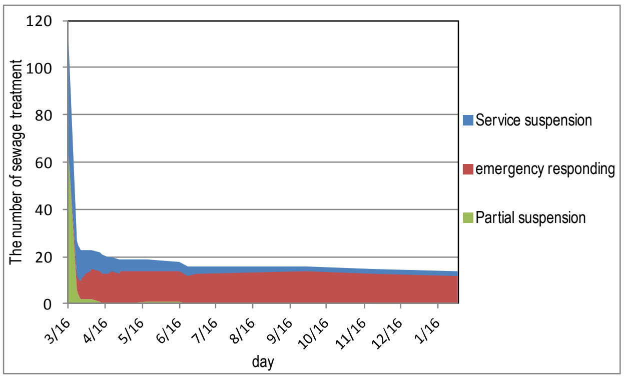


Figure 3.3.2.4 Service Suspensions at Sewage Treatment Plants

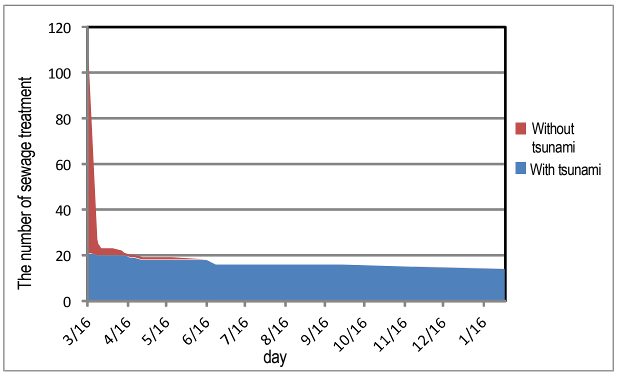


Figure 3.3.2.5 Comparison of Tsunami-caused and Other Damage to Sewage Treatment Plants

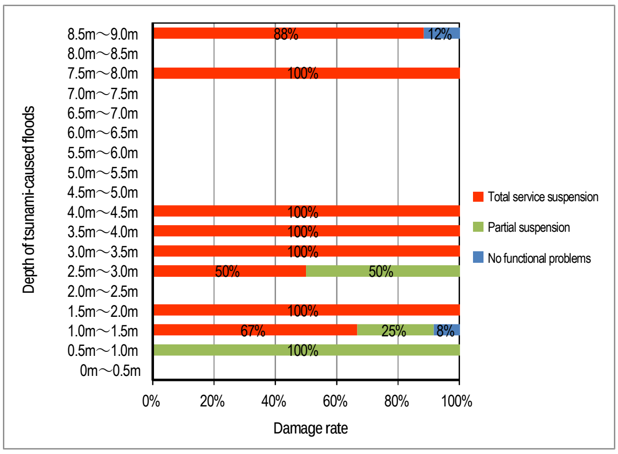


Figure 3.3.2.6 Relationship between Depths of Tsunami-caused Floods and Degrees of Service Suspensions (sewage treatment plants)

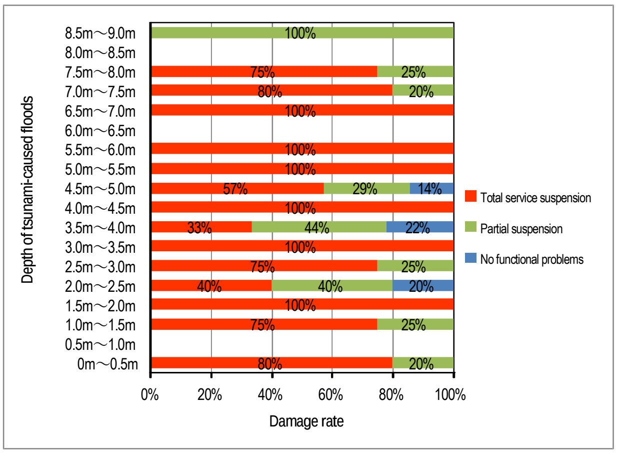


Figure 3.3.2.7 Relationship between Depths of Tsunami-caused Floods and Degrees of Service Suspensions (pumping stations)

The relationship between the depths of tsunami-caused floods and damage to equipment within sewage treatment plants (Figures 3.3.2.6-7) shows that plant service suspensions were limited to partial suspensions for cases where the depths were lower. More than a half of the sewage treatment plants were subjected to total service suspensions for cases where the flood depths exceeded 1 to 1.5 meter. This trend could be useful for considering the scope of anti-tsunami measures and specific approaches. Facilities where there were no functional problems even with high flood depths of 8.5 to 9 meters are civil engineering facilities that have no electrical or mechanical equipment at inlet and effluent discharge/outlet conduits. The rate of total suspensions was higher for pumping stations even with lower flood depths. The relationship between the depths of tsunami-caused floods and the types of damaged facilities (Figures 3.3.2.8-9) shows that facilities damaged by floods of up to 4 meters were mainly mechanical and electrical facilities. Higher depths led to complex damage (affecting civil engineering, construction, mechanical and electrical facilities). Anti-tsunami measures may thus be required for mechanical and electrical facilities for cases where flood depths are up to 4 meters. For cases where flood depths are higher than 4 meters, anti-tsunami measures may be required for all types of facilities. At pumping stations, meanwhile, the damage rate was high for mechanical and electrical facilities irrespective of the flood depths.

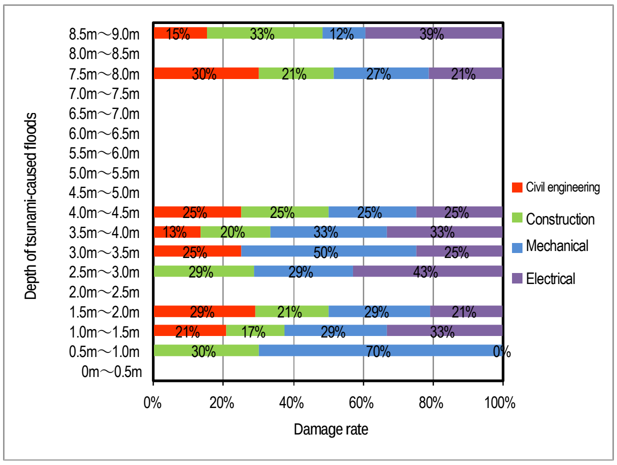


Figure 3.3.2.8 Relationship between Depths of Tsunami-caused Floods and Degrees of Damage by Type of Facilities (sewage treatment plants)

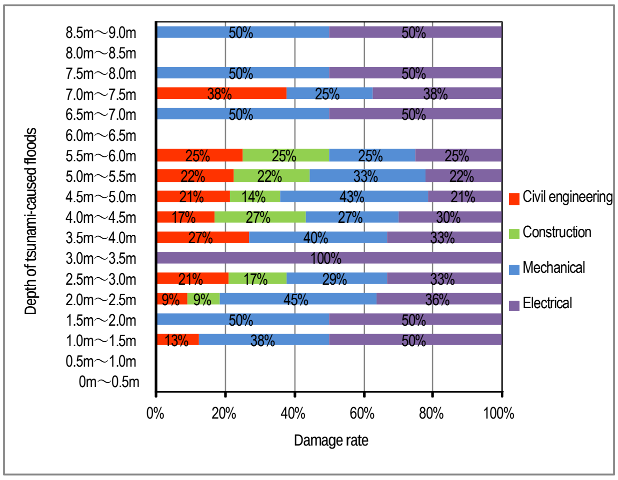


Figure 3.3.2.9 Relationship between Depths of Tsunami-caused Floods and Degrees of Damage by Type of Facilities (pumping stations)

(4) Anti-liquefaction measures for sewer pipe facilities and their effects

1) Anti-liquefaction measures for sewer pipe facilities

Anti-liquefaction measures for sewer pipe facilities are described in “Commentary on the Sewage Treatment System Earthquake Resistance Countermeasure Guidelines -- FY 2006 Edition.” There are three anti-liquefaction measures for sewer pipe conduits -- compaction of backfill soil, backfilling with crushed stones and solidfication of backfill soil -- indicated in Figure 3.3.2.10 as proposed urgently by a panel on anti-earthquake technologies for sewage facilities, which was created just after the Niigata Chuetsu Earthquake (FY 2004).

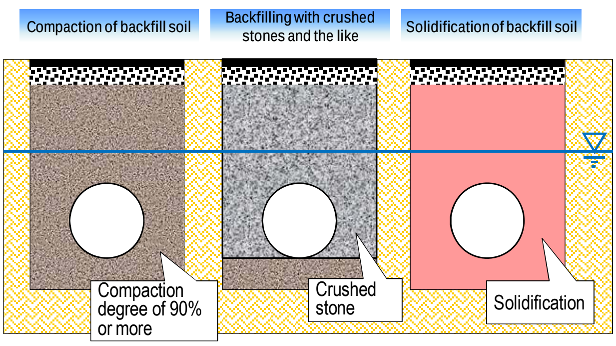
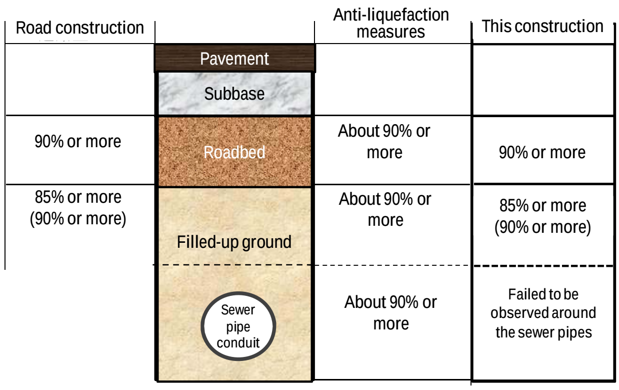


Figure 3.3.2.10 Three Backfilling Measures for Sewer Pipe Conduits

2) Compaction of backfill soil

This measure is designed to hold down the earthquake-caused liquefaction of backfill soil by compacting backfill soil around sewer pipe conduits at a degree of 90% or more. In regions affected by the Great East Japan Earthquake, no cases have been confirmed for the implementation of this anti-liquefaction measure. But road consruction guidelines in Miyagi and Fukushima Prefectures include the “compaction degree of 90% for roadbed” ((hereinafter referred to as the road standard), indicating that the compaction degree under the road standard has been secured (Figure 3.3.2.11).



*In case of controlling compaction of embankment using RI meter in parentheses

Figure 3.3.2.11 Compaction Standards

At some of the sewer pipe conduits at locations subjected to compaction under the road standard, however, damage including roadbed anomalies and loosening was confirmed. This may be because the road standard has been set for the roadbed and filled-up ground and failed to be observed for the sewer pipe conduit space and backfill soil below the filled-up ground. Therefore, tougher construction controls may be required for anti-liquefaction measures for sewer pipe conduits. Furthermore, there are many compaction-related problems, including the general absence of space for compaction machines for backfill soil on both lateral sides of sewer pipes, the possibility of over-compaction on the upper side of polyvinyl chloride (PVC) pipes during construction, and difficulties in securing the compaction degree of 90% depending on soil quality problems.

3) Backfilling with crushed stones

This measure uses crushed stones as a backfilling material. Ribbed PVC pipes that can resist crushed stones are mainly used for small-diameter sewer pipe conduits. When ribbed PVC pipes are installed, soil is replaced with crushed stones only around the pipes in a conventional way. Under the anti-liquefaction measure, however, it is important to replace soil with crushed stones beyond groundwater levels (or for the entire backfill).

In the disaster-hit region, the measure has been used only for some districts of Kurihara City that logged a seismic intensity of 7. The district has a sewer pipe conduit that includes locations subject to the conventional backfilling and the anti-liquefaction measure. Upon the Great East Japan Earthquake, a location subject to the conventional backfilling saw a major road surface anomaly making vehicle traffic impossible (Photo 3.3.2.3). At locations subjected to the anti-liquefaction measure, damage was limited to a slight surface subsidence (Photos 3.3.2.4-5), confirming the effect of the anti-liquefaction measure.

But slight damage including loosening and road surface anomalies was seen for a sewer pipe conduit (about 20 meters) subjected to the anti-liquefaction measure, prompting us to investigate the causes of such damage. In the investigation, we reviewed relevant construction documents and interviewed people in charge of the conduit construction. As a result, we suspected that there were problems with crushed stones and sheet pile removal during construction. Although the anti-earthquake guidelines recommend a 10% particle diameter (D10) at 1 millimeter or more for a highly permeable material, the D10 for the crushed stones used at the location was 600 micrometers or more. Many fine particles were included in the crushed stones used there. Therefore, we suspected that the excess pore water pressure reduction effect upon the liquefaction declined, leading to the damage. When sheet piles were removed, voids might have emerged in the ground and backfill, loosening the compacted backfill, as indicated by the people in charge of the construction.

Photo 3.3.2.3 Conventional construction (without any anti-liquefaction measure)

Photo 3.3.2.4 Construction subjected to the anti-liquefaction measure (no damage)

Photo 3.3.2.5 Construction subjected to the anti-liquefaction measure (slight damage)

4) Solidification of backfill soil

(a) Analysis on Damage Causes in Kurihara

The earthquake damaged 54 meters out of a total 2,500 meters of sewer pipe conduits subjected to cement-based solidification of backfill soil in Kurihara. The damaged part was in Uguisuzawa, where soil improved when a cement fixation agent was used for restoring a sewer pipe conduit damaged by the Iwate-Miyagi Inland Earthquake. The damage was limited to loosening and joint disconnections at a sewer pipe conduit subjected to backfill soil solidification, not going so far as to block sewage flow. At some manholes subjected to backfill soil solidfication, however, 4-to-11-centimeter uplifts were found. These uplifts were similar to the 5-to-10-centimeter uplifts seen in portions that were not subjected to any anti-liquefaction measure (Photos 3.3.2.6-7).

Photo 3.3.2.6 Conventional construction (without any anti-liquefaction measure)

Photo 3.3.2.7 A portion subjected to the anti-liquefaction measure (damaged part)

We here would like to discuss the results of a soil quality survey and a damage analysis conducted for the damaged portions to find damage causes. In the soil quality survey, we conducted standard penetration and uniaxial compressive strength tests at a damaged location and an undamaged one. A calcium oxide analysis was also implemented to estimate the cement mixing ratio. As a result, the uniaxial compressive strength test found the average uniaxial compressive strength per cross section surface slipping below the standard levels (50 to 100 kilopascals) at both locations, as shown in Table 3.3.2.1. Particularly, no compressive strength was seen for deeper soil. N-values at the two locations were similar. The cement mixing ratio was confirmed as close to the level for premixed concrete (50 kilograms per cubic meter) (Table 3.3.2.2).

Interviews with people in charge of construction implementing the anti-liquefaction measure found that cement and soil were mixed and churned (by a backhoe three times) at the construction site and that the mixture was left untouched for around one day after churning. Portions for backfill soil solidification were limited to those where troubles were found. The solidification failed to cover the entire span or the whole manhole circumference. As a result, the damage focused on portions that the solidification failed to cover.

The above results lead us to suspect that while the cement mixing ratio was sufficient, appropriate strength failed to be secured due to backfilling procedure problems.

A technical study committee on anti-earthquake measures for sewage systems, created after the Niigata Chuetsu-oki Earthquake, proposed notes for backfilling using cement-based solidification. A comparison of these notes, on-site soil quality test results and backfilling conditions indicates the following causes for the failure:

・Solidification was limited to problematic parts, failing to produce sufficient effects.

・While cement and soil were mixed and churned three times by a backhoe at the construction site, insufficient churning resulted in mixed strengths.

・ The churned cement-soil mixture was left untouched (for about one day), failing to achieve sufficient strength.

・Weak strengths in deep portions indicate that surface compaction around pipes was insufficient.

Table 3.3.2.1 Uniaxial Compressive Strength Test Results in Kurihara City

Tested depth	Damaged		Tested depth	Undamaged		Average by depth
	Hole No. 1	Hole No. 2		Hole No. 3	Hole No. 4	
1.8～2.75 m	76 kpa	68 kpa	1.5～2.3 m	42.5 kpa	18.4 kpa	51.2 kpa
2.75～3.35 m	12.6 kpa	12.2 kpa	2.6～3.54 m	12.6 kpa	11.4 kpa	12.2 kpa
Average per cross section	44.3kpa	40.1kpa	Average per cross section	27.6kpa	14.9kpa	31.7kpa

Table 3.3.2.2 Soil Quality Survey Results in Kurihara City

Survey name	Damaged		Undamaged	
	Hole No. 1	Hole No. 2	Hole No. 3	Hole No. 4
Penetration test (JGS1443)	Upper portion: 5	Upper portion: 4	Upper portion: 6	Upper portion: 7
	Lower portion: 5	Lower portion: 13	Lower portion: 8	Lower portion: 8
Calcium oxide analysis (JISR5202)	—	Upper portion: Estimated cement volume= 38.7kg/m3	—	Upper portion: Estimated cement volume= 69.4kg/m3
	—	Lower portion: Estimated cement volume= 43.9kg/m3	—	Lower portion: Estimated cement volume= 34.5kg/m3

*Upper portion: Tests were conducted at depths of 1.8 to 2.75 meters below ground level for holes at damaged sites and 1.5 to 2.3 meters below ground level for holes at undamaged sites.
*Lower portion: Tests were conducted at depths of 2.75 to 3.35 meters below ground level for holes at damaged sites and 2.6 to 3.54 meters below ground level for holes at undamaged sites.
*Calcium oxide analysis results include a cement content (%) on a dried basis measured through the analysis and a cement content estimated based on a dry density of soil obtained through the soil quality survey.

Table 3.3.2.3 Solidification and Disaster Recovery Distances by Fiscal Year

Sewage treatment district	Omagari Minami District			Omagari Kita District			Total		
Fiscal Year for construction	Solidification distance (m)	Disaster recovery distance (m)	Damage rate (%)	Solidification distance (m)	Disaster recovery distance (m)	Damage rate (%)	Solidification distance (m)	Disaster recovery distance (m)	Damage rate (%)
FY 2004	0	-	-	2,742	8	0.29	2,742	9	0.29
FY 2005	3,238	243	7.49	2,453	52	2.12	5,690	294	5.18
FY 2006	3,104	0	0.00	2,095	0	0.00	5,201	0	0.00
FY 2007	3,769	41	1.10	2,114	0	0.00	5,883	41	0.71
FY 2008	2,256	0	0.00	0	-	-	2,256	0	0.00
FY 2009	632	0	0.00	0	-	-	632	0	0.00
Total	12,999	284	2.18	9,405	60	0.64	22,404	344	1.54
Solidification distance (from FY 2005)	12,999	284	2.18	6,663	52	0.78	19,662	336	1.71

(b) Damage in Higashi Matsushima City

Higashi Matsushima City has implemented the cement-based backfill solidification as an anti-liquefaction measure since FY 2005 (Table 3.3.2.3). A detailed analysis of damaged locations found that the damage rate came to 5.2% at locations subjected to the solidification in FY 2005 and 0.0 to 0.7% at those subjected to the solidification between FY 2006 and 2009. Damage thus focused on locations solidified in FY 2005. In interviews, people in charge of the solidification said that solidification management guidance was insufficient in FY 2005 when the anti-earthquake project started and that some improvements including checks on advanced cement mixing and proper instructions were implemented in and after FY 2006. In these improvements in solidification management, considerations were given to the following points:

- Checks on on-site cement mixing (implemented on all cement used for mixing)
- A uniaxial compressive strength test was conducted for each soil sample (at three points for each solidification location) to determine the cement volume for mixing.

(5) Recovery measures

1) Study committee for earthquake and tsunami countermeasure techniques in sewage systems

In order to implement stopgap recovery of sewage facilities damaged by the Great East Japan Earthquake and full-fledged recovery for disaster prevention purposes, the Japan Sewage Works Association and the Ministry of Land, Infrastructure, Transport and Tourism created a Study committee for earthquake and tsunami countermeasure techniques in sewage systems including academic experts listed in Table 3.3.2.4, on April 12, one month after the earthquake.

The committee also included administrative sector members and special members from the ministry and the Japan Sewage Works Association. From the National Institute for Land and Infrastructure Management, the director of the Water Quality Control Department took part in the committee as a special member. At the National Institute for Land and Infrastructure Management, sewage researchers and the Wastewater System Division took the leadership in operating the committee's secretariat to coordinate topics for consideration at the committee, analyze factors behind disaster damage and give technical considerations to recovery measures.

The committee compiled and published technical proposals and recovery guidelines addressing technical challenges involving emergency responses, stopgap recovery and full-fledged recovery. Table 3.3.2.5 shows the chronology of the committee's deliberations. As the committee's final report, the Ministry of Land, Infrastructure, Transport and Tourism released the "Report of Study committee for earthquake and tsunami countermeasure techniques in sewage systems -- An Overview of sewage systems damage by the Great East Japan Earthquake and Desirable Future Earthquake and Tsunami Countermeasures Based on the Present Situation" on May 18, 2012.

In damaged areas, full-fledged recovery is going on based on these proposals.

Table 3.3.2.4 Members of the Study committee for earthquake and tsunami countermeasure techniques in sewage systems

Chairman: Masanori Hamada, Professor, Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Waseda University Academic expert members: Fumihiko Imamura, Professor, Disaster Control Research Center, Graduate School of Engineering, Tohoku University Tatsuo Omura, Professor, Department of Civil and Environmental Engineering, Graduate School of Engineering, Tohoku University Itsuki Nakabayashi, Professor, Graduate School of Political Science and Economics, Meiji University Mitsunobu Nomura, Director, Technology & Strategy Department, Japan Sewage Works Agency Koji Fujima, Professor, Department of Civil and Environmental Engineering, School of Systems Engineering, National Defense Academy of Japan Yasutaka Fujimoto, Associate Professor, Department of Electrical and Computer Engineering, Yokohama National University Osamu Matsuo, Director, Utilization Promotion Department, Advanced Construction Technology Center Susumu Yasuda, Professor, Division of Architectural, Civil and Environmental Engineering, School of Science and Engineering, Tokyo Denki University

Table 3.3.2.5 Chronology of Deliberations at the Study committee for earthquake and tsunami countermeasure techniques in sewage systems

Date	Committee meeting, etc.	Topics/technical support
April 12, 2011	1st meeting	・Damage to sewage facilities and recovery/support ・Technical challenges regarding recovery
April 15	Releasing an emergency technical proposal on sewage facility recovery (1st proposal)	The proposal compiled approaches on securing public health, on emergency anti-flood measures for the flood season and on recovering sewage facilities, and was sent by the Ministry of Land, Infrastructure, Transport and Tourism to the governments of disaster-damaged prefectures and designated major cities as a notice from the Planning Officer of the Sewerage Works Division at the ministry's Sewerage and Wastewater Management Department.
May 24	2nd meeting	・Damage and recovery conditions ・Desirable gradual stopgap recovery measures ・Desirable measures to promptly secure public health
June 13	Releasing desirable gradual stopgap recovery measures (2nd proposal)	The proposal compiled basic guidelines to gradually improve the quality of released water by implementing stopgap recovery measures according to the periods of time before full-fledged recovery, and was sent by the Ministry of Land, Infrastructure, Transport and Tourism to the governments of disaster-damaged prefectures and designated major cities as a notice from the Planning Officer of the Sewerage Works Division at the ministry's Sewerage and Wastewater Management Department.
July 19	3rd meeting	・Desirable full-fledged recovery of disaster-damaged sewage facilities
August 11	Releasing desirable recovery of sewage facilities damaged by the Great East Japan Earthquake (3rd proposal)	The proposal compiled basic policies on the full-fledged recovery of sewage facilities, policies on anti-tsunami measures in the full-fledged recovery, policies on measures addressing ground changes through liquefaction in the full-fledged recovery and other matters of concern, and was sent by the Ministry of Land, Infrastructure, Transport and Tourism to the governments of disaster-damaged prefectures and designated major cities as a notice from the Planning Officer of the Sewerage Works Division

		at the ministry's Sewerage and Wastewater Management Department.
October 17	4th meeting	・Recovery responses just after the Great East Japan Earthquake and desirable BCPs ・Recovery responses and challenges after the Great East Japan Earthquake ・Wide-area support conditions regarding the Great East Japan Earthquake ・Reports on specific general ground liquefaction damage cases, etc.
December 15	5th meeting	・Overview of sewage facility damage through the Great East Japan Earthquake ・Time schedules for recovering sewage facilities ・Approaches on sewage facility designs taking anti-tsunami measures into account
February 24, 2012	6th meeting	・Overview of sewage facility damage ・Approaches on sewage facility designs taking anti-tsunami measures into account ・Desirable guidelines for sewage facilities, etc.
March 6	Releasing approaches on sewage facility designs taking anti-tsunami measures into account (4th proposal)	Based on damage through the Great East Japan Earthquake, the proposal compiled approaches to be applied to sewage facilities in areas where massive earthquakes are expected to cause large-scale tsunamis. It was sent by the Ministry of Land, Infrastructure, Transport and Tourism to the governments of disaster-damaged prefectures and designated major cities as a notice from the Planning Officer of the Sewerage Works Division at the ministry's Sewerage and Wastewater Management Department.
March 22	7th meeting	・Disaster prevention and reduction targets for improving earthquake and tsunami protection ・Draft final report by the Technical Study Committee on Anti-Earthquake/Tsunami Measures for Sewage Facilities
May 18	Releasing the report by the Technical Study Committee on Anti-Earthquake/Tsunami Measures for Sewage Facilities	The committee compiled and published the "Report by the Technical Study Committee on Anti-Earthquake/Tsunami Measures for Sewage Facilities -- An Overview of Sewage Facility Damage by the Great East Japan Earthquake and Desirable Future Anti-Earthquake/Tsunami Measures Based on the Present Situation."

Following are new viewpoints for future anti-earthquake/tsunami measures as indicated by the committee's final report:

(a) Anti-earthquake measures for sewer pipe facilities

・Anti-liquefaction measures for the backfill should include the consideration of construction work management problems and their solutions and the expansion of manuals and the like to improve technical understanding on construction methods.

・Anti-liquefaction measures for the ground surrounding sewer pipes should include the development of technologies for preventing manhole shifts and sediment inflow through joints.

(b) Anti-tsunami measures for sewer pipes, sewage treatment plants and pumping stations

・Anti-tsunami measures for sewer pipes should include preventing manhole caps from being scattered and promoting sewage BCPs that assume sewage spills from sewer pipe bridges and the submersion of switchboards for manhole pumps.

・Anti-tsunami measures for sewage treatment plants and pumping stations should cover gradual measures including the adoption of concrete caps for waterproof purposes for facilities and equipment and for their early recovery, measures for preventing gas holders and the like from flowing out, and the adoption of facility structures giving considerations to tsunami loads and directions.

(c) New reconstruction efforts

・The full-fledged recovery of sewage facilities should positively introduce technologies suitable for hopeful reconstruction in the 21st century and systems that can contribute to regional communities.

・A reconstruction scheme study panel should be created to conduct a feasibility study on model projects in Kesennuma and Sendai Cities, based on not only technical knowledge but also the viewpoint of contributions to reconstruction/town-building and the distribution of renewable resources and energy.

(d) Present conditions and challenges of anti-earthquake/tsunami measures

・While promoting anti-earthquake measures for sewage facilities including the enhancement of these facilities' quakeproof performances and systematic measures, many local governments have failed to make smooth progress.
・A questionnaire survey indicates that few anti-tsunami measures have been implemented.
・Urgent challenges include launching anti-tsunami measures in addition to promoting the enhancement of existing facilities' quakeproof performances.

(e) Basic approaches on promoting anti-earthquake/tsunami measures

a) Basic approaches

・Basic approaches include the "prevention of disasters" through the enhancement of structural anti-earthquake/tsunami performances and the "reduction of disasters" to minimize impacts on citizens' daily life.
・A priority order should be specified for measures according to the necessity and urgency of sewage facility functions. Most feasible measures should be followed by less feasible ones to gradually enhance sewage facilities' anti-earthquake performances.
・New anti-tsunami technical standards should be considered. Under the anti-tsunami community building law, anti-tsunami measures should be implemented based on "tsunami inundation assumptions" that prefectural governors establish and publish with the maximum projected tsunami taken into account.
・The preparation of sewage facility BCPs to minimize social impacts of damage to sewage facilities and achieve their prompt recovery should be launched. Software measures including the preparation of disaster assistance rules should be expanded and combined with hardware development measures to promote anti-earthquake/tsunami measures.

b) Disaster prevention targets to improve anti-earthquake/tsunami performances

・Short-, medium- and long-term targets should be established according to the necessity and urgency of sewage facility functions upon earthquakes or tsunamis in order to gradually enhance anti-earthquake/tsunami performances of existing facilities.
・Short-term targets for anti-tsunami measures should include the enhancement of tsunami-proof performances for the backflow prevention functions of pipe facilities and the pumping functions of pumping stations and sewage treatment plants whose stoppage would result in massive damage, as well as the development of evacuation and other facilities required for securing human lives.

c) Disaster reduction targets to improve anti-earthquake/tsunami performances

・Anti-earthquake/tsunami measures should be based on the enhancement of anti-earthquake/tsunami performances of sewage facilities under disaster prevention targets. In order to secure immediate tentative responses to achieve minimum objectives when disasters come before such measures are completed, however, short- and medium-term targets should be established basically through the preparation of sewage system BCPs according to the gradual improvements of facilities.
・Short-term targets for anti-tsunami measures should include the early preparation of sewage system BCPs, the stockpiling of portable pumps and power generators for regular training and flood damage reduction, and the establishment of channels for their procurement upon disasters.

(f) Challenges and desirable concept of guidelines for anti-earthquake measures for sewage facilities

・Anti-liquefaction measures for branch pipes and how to prevent manholes' lateral shifts should be considered. Guidelines should be expanded and enhanced to include key points of construction work management for the three backfilling measures and new backfill materials.

・Detailed facility design methods for anti-tsunami measures should be considered along with how to set a priority order for facilities subject to anti-tsunami measures.

2) Study Committee on Sewage System BCP Manual (for earthquakes and tsunamis)

In order to share experiences and lessons from the Great East Japan Earthquake and recover sewage functions upon disasters for maintaining regional public health environments, the Ministry of Land, Infrastructure, Transport and Tourism on December 20, 2011, created the Study Committee on Sewage System BCP Manual (for earthquakes and tsunamis) , comprising academic experts and others as listed in Table 3.3.2.6.

Table 3.3.2.7 indicates the chronology of deliberations at the committee. As its final report, the "Study Committee on Sewage System BCP Manual (for earthquakes and tsunamis)", was published by the Ministry of Land, Infrastructure, Transport and Tourism on April 2, 2012. In not only disaster-damaged areas but also other areas, sewage system BCPs are being worked out based on this manual.

Figure 3.3.2.12 indicates the flow of sewage system BCP preparation procedures given in the committee's final report.

Table 3.3.2.6 Members of the Study Committee on Sewage System BCP Manual (for earthquakes and tsunamis)

＜Experts＞

Chairman: Itsuki Nakabayashi, Professor, Graduate School of Political Science and Economics, Meiji University

Koji Fujima, Professor, Department of Civil and Environmental Engineering, School of Systems Engineering, National Defense Academy of Japan

Yoshiyuki Tsuji, Chief Researcher, Science and Safety Research Division, Mitsubishi Research Institute, Inc.

＜Administration experts＞

Keiji Sugawara, Chief, Sewage Division, Civil Engineering Department, Miyagi Prefecture Government

Shozo Shibuya, Deputy Director and Director, Sewage Department, Construction Bureau, Sendai City Government

Toshiyuki Nagamine, Director, Urban Environment Department, Urayasu City Government

Shigeyuki Horoiwa, Chief, Planning Division, Planning and Coordination Department, Bureau of Sewerage, Tokyo Metropolitan Government

Satoshi Yamamoto, Director, Western Area Management Office, Construction Bureau, Osaka City Government

Keisuke Hata, Director, Sewage and River Department, Construction Bureau, Kobe City Government

＜Relevant organizations＞

Yasuhiro Shinoda, Director, Japan Sewer Collection System Maintenance Association

Go Saeki, Executive Director and Technology Department Chief, Japan Sewage Works Association

Ichiro Kobayashi, Managing Director, Japan Sewage Treatment Plant Constructors Association

Table 3.3.2.7 Chronology of Deliberations at the Study Committee on Sewage System BCP Manual (for earthquakes and tsunamis)

Date	Meeting	Topics/technical support
December 20, 2011	1st meeting	・Conditions and challenges of recovery responses after the Great East Japan Earthquake ・Desirable sewage system BCPs based on the Great East Japan Earthquake case
February 1, 2012	2nd meeting	・Direction of manual revision ・Tsunami damage caused by the Great East Japan Earthquake and projection methods ・Damage projections covered by sewage system BCPs ・Notes on reporting recovery response cases and preparing sewage system BCPs
February 29	3rd meeting	・Revised manual draft

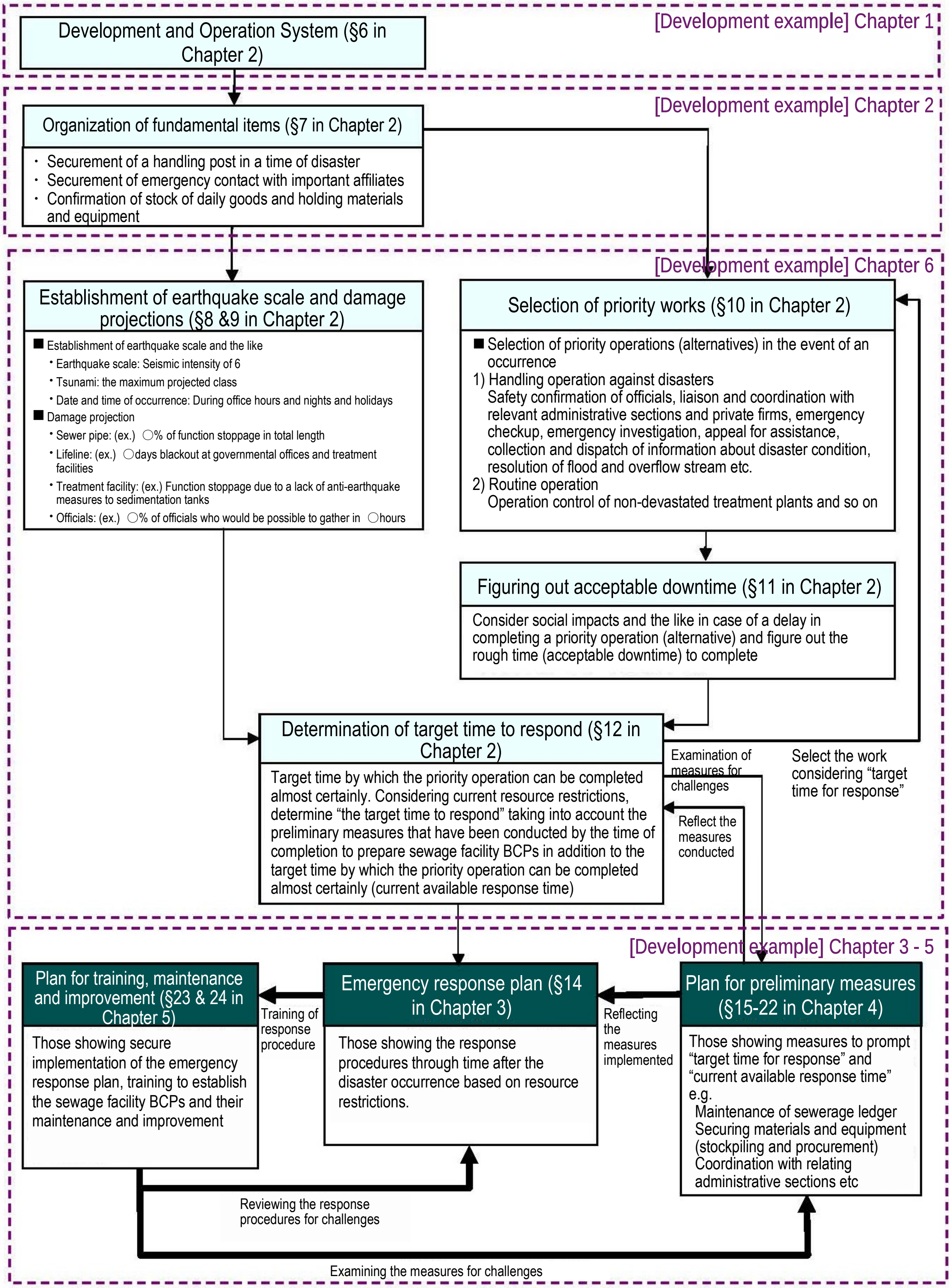


Figure 3.3.2.12 Flow of Sewage System BCP Preparation Procedures

3) Committee to review countermeasures on radioactive material pollution in sewage systems

In order to appropriately maintain the functions of sewage facilities indispensable as part of lifelines, the Sewerage and Wastewater Management Department at the Ministry of Land, Infrastructure, Transport and Tourism created the "Committee to review countermeasures on radioactive material pollution in sewage systems" comprising academic experts and others as listed in Table 3.3.2.8. The panel accurately grasped the conditions of damage caused by radioactive substances and compiled opinions from experts in various fields on future responses that sewage facility managers should take based on notifications and the like from the Nuclear Emergency Response Headquarters.

The panel includes not only the abovementioned academic experts but also members from local governments and special members from the Ministry of Land, Infrastructure, Transport and Tourism and the Japan Sewage Works Association. At the National Institute for Land and Infrastructure Management, sewage researchers and the Wastewater System Division took the leadership in operating the panel's secretariat to conduct a fact-finding survey and a technical analysis on the behaviors of radioactive substances.

The panel accumulated deliberations as indicated in Table 3.3.2.9. As its interim report, the Ministry of Land, Infrastructure, Transport and Tourism published the "Interim Compilation of Deliberations at the Committee to review countermeasures on radioactive material pollution in sewage systems" on November 25, 2011. The report made the following key points on measures against radioactive substances at sewage facilities:

Table 3.3.2.8 Panel Members (in random order with honorifics omitted) (as of May 28, 2012)

Chairman	Tetsuya Kusuda	Professor, Faculty of Environmental Engineering, University of Kitakyushu
Member	Hideo Kimura	Senior Researcher, Waste Safety Research Group, Nuclear Safety Research Center, Japan Atomic Energy Agency
〃	Hiroyasu Satoh	Associate Professor, Graduate School of Frontier Sciences, University of Tokyo
〃	Yutaka Suzuki	Leader, Materials and Resources Research Group, Public Works Research Institute
〃	Masaki Takaoka	Professor, Graduate School of Engineering, Kyoto University
〃	Hiroyuki Fujimoto	Director for Technical Development and International Office Chief, Japan Sewage Works Agency
〃	Yuichi Moriguchi	Professor, Department of Urban Engineering, Graduate School of Engineering, University of Tokyo
〃	Shinsuke Morisawa	Professor, Center for iPS Cell Research and Application, Kyoto University
〃	Hirokuni Yamanishi	Associate Professor, No. 3 Research Office, Kinki University Atomic Energy Research Institute
Special member	Mitsuhiro Kurozumi	Director, Planning and Coordination Department, Bureau of Sewerage, Tokyo Metropolitan Government
〃	Shinichi Nagasawa	Chief, Sewage Division, Civil Engineering Department, Fukushima Prefecture Government

Former member	Hitoshi Nakazawa	Director for Technical Development and International Office Chief, Japan Sewage Works Agency
〃	Nobuyuki Sugiura	Director, Research Center for Radiation Emergency Medicine, National Institute of Radiological Sciences
Former special member	Masayuki Matsuura	Director, River-Basin Sewage Headquarters, Bureau of Sewerage, Tokyo Metropolitan Government
〃	Yoshihiro Narita	Chief, Sewage Division, Civil Engineering Department, Fukushima Prefecture Government

Table 3.3.2.9 Chronology of Panel Deliberations

Date	Meeting	Topics
June 17, 2011	1st meeting	Figuring out radioactive substances found in sewage sludge, future topics, etc.
July 25	2nd meeting	Environments around sewage treatment plants, radioactive substances' behaviors at sewage treatment plants, etc.
August 29	3rd meeting	Radioactive substances' behaviors, how to store highly radioactive sewage, etc.
October 4	4th meeting	・Guideline for methods for disposal of incinerated sewage ash with radioactivity density readings ranging from above 8,000 becquerels per kilogram to 100,000 Bq/kg ・Interim compilation draft, etc.
November 16	5th meeting	・Interim compilation draft, surveys under the third supplementary budget for FY 2011, etc.
May 28, 2012	6th meeting	・Report on fact-finding surveys under the third supplementary budget for FY 2011, etc.

(a) Challenges and responses regarding sewage sludge with radioactive substances found

Radioactive substances have been widely detected in environments mainly in the Kanto and Tohoku regions. At a wide range of sewage treatment plants, radioactive substances have been detected in sewage sludge. But radioactivity density readings have been declining and are expected to decline in the future. But the effective utilization or disposal of sewage sludge has been suspended, leading sewage sludge stocks to increase. Measures are urgently required to secure facilities for accepting and storing sludge and to reduce sludge volume.

(b) Situation regarding stored sewage sludge including radioactive substances and relevant information service

A questionnaire survey of local governments on sewage sludge storage and radioactivity monitoring conditions, how to secure the safety of residents surrounding storages, desirable information service and other problems has been conducted, confirming that sludge containers have been enclosed to prevent sludge from scattering and covered with liner sheets to prevent rain water from permeating into sludge, securing safety appropriately. But the survey has found that sludge smells and other problems have been emerging as sludge has been stored long.

Radioactivity monitoring has been done with sludge radionuclide analyses and steady air radiation measurement at borders with sewage treatment plant sites, securing safety for residents surrounding these plants. Radioactivity density readings have been well informed to citizens through websites and briefings. Efforts meeting regional characteristics (including residents' participation in radiation measurement) have also been made. The panel's interim compilation of deliberations proposed specific appropriate information provision measures in an orderly manner based on actual information service cases.

(c) Radioactive substances' behaviors related to sewage facilities

A survey on radioactive substances' flow into sewage treatment plants has been conducted, confirming that massive radioactive substances flew into combined sewage systems upon rainfall. An analysis of radioactive substances' behaviors within sewage treatment plants indicated that radioactive substances are accumulated mainly in air ration tanks at these plants and enriched through sludge condensation, dehydration and other processes. Radioactive substances, though circulating within sewage systems through returned water, have tended to decline through a fall in their inflow into the systems and sludge removal. Radioactivity density readings for dehydrated sludge have tended to decline over a long time.

Radioactive substances have not been detected in most of the released water. Even when radioactive substances were found in released water, their density readings slipped far below the maximum allowable density in water (60 Bq/L for Cesium 134, 90 Bq/L for Cesium 137, their percentage shares' combination at 1 or less). No radioactive substances were detected in exhaust gas from sludge incineration facilities.

Tests using incinerated sewage sludge ash and melted slag to elute radioactive substances confirmed that little such substance was eluted even upon water's contact with the ash and slag.

These results indicated that radioactive cesium shifted mainly to sludge and that appropriate sludge disposal would be the most important (Figure 3.3.2.13).

(d) Storing sewage sludge containing massive radioactive substances

Based on an approach on immediate handling of water and sewage treatment by-products found to include radioactive substances, as notified by the Nuclear Emergency Response Headquarters on June 16, the panel considered specific future measures for storing sewage sludge including massive radioactive substances and for prolonging storage duration.

The panel concluded that flexible containers can usually be used for storing sewage sludge and that if containers are required to be piled up high at a small storage site, flexible containers may be put into 20-feet containers or 200-liter drum cans may be used instead of flexible containers.

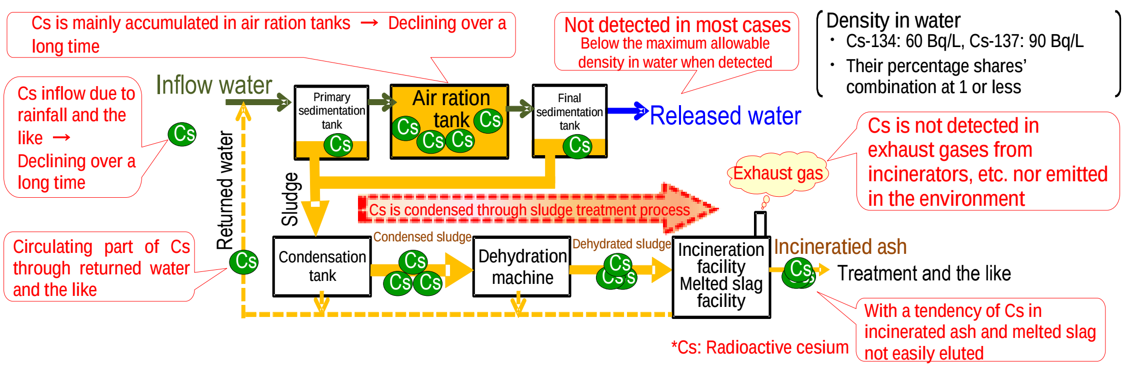
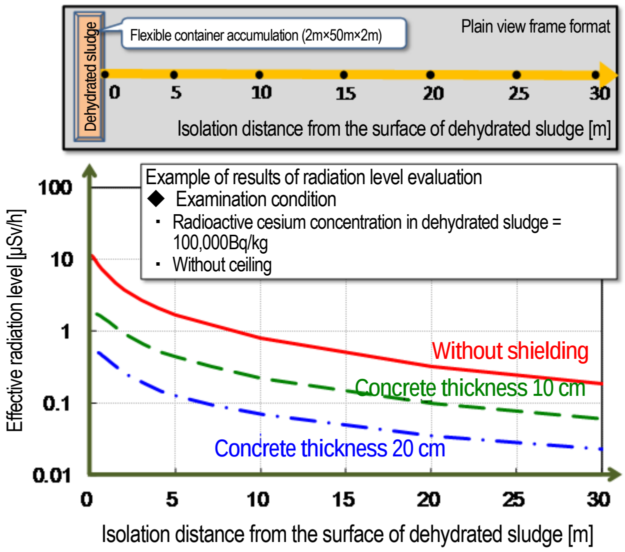


Figure 3.3.2.13 Image of Radioactive Cesium's Behaviors in Sewage Treatment Processes



【Specific case for radiation shielding evaluation results】

In the case of flexible container accumulation（2 m × 50 m × 2 m）and the radioactivity density of 100,000 Bq/kg for storage, any of the following measures can reduce workers' radiation exposure to 1 microsieverts per hour or less

・Maintaining an isolation distance at 10 meters or more
・Shielding radiation with a 20-centimter or thicker concrete wall
・Shielding radiation with a 5-centimeter or thicker steel plate

Figure 3.3.2.14 Effects of Isolation Distance and Shielding Regarding Effective Radiation Levels

On blocking radiation, we computed specific effects of shielding with concrete structures and isolation distances for reducing radiation exposure and illustrated the results in an easy-to-understand manner (Figure 3.3.2.14).

Specific appropriate radiation surveillance methods include measuring radioactivity density in dehydrated sludge and the like regularly and after rainfall, monitoring air radiation rates at work areas and borders with sewage system sites, checking radiation with personal passive dosimeters, and confirming that the radiation density in exhaust gas at incineration facilities slips below the maximum allowable density in air (20 Bq/m^3 for Cesium 134, 30 Bq/m^3 for Cesium 137, their percentage shares' combination at 1 or less).

As for sludge including radioactive substances, appropriate management arrangements must be developed under an assumption that such sludge may have to be stored over a long time. To this end, types of radioactive wastes and their surface radiation levels and rates should be recorded and managed rationally on a lot basis.

(3) Methods to reduce sewage sludge volume

The panel concluded that sludge volume reduction methods (drying, carbonizing, incinerating and melting) should be selected with considerations given to their respective characteristics, their key points and evaluation viewpoints when hydrated sludge storage and volume reduction facilities are introduced. Drying equipment installation requires less time and mobile dryer vehicles can be used tentatively. It may thus be easy to introduce such equipment. But it should be noted that organic matters may still be left even after drying.

While sludge volume reduction is useful for securing sites for long-term sludge storage, it should be noted that radioactive cesium in sewage sludge can be enriched through sludge volume reduction. Therefore, measures should be implemented securely to prevent radioactive cesium from scattering and relevant workers from being exposed to radiation.

4) Responses to disaster support liaison conferences

In addressing the expected great Nankai Trough earthquake, the National Institute for Land and Infrastructure Management has promoted anti-earthquake measures and implemented the report by the abovementioned Study committee for earthquake and tsunami countermeasure techniques in sewage systems At disaster support liaison conferences, the institute reported approaches and development targets for anti-liquefaction and anti-tsunami measures.

・July 10, 2012: 18th Chugoku/Shikoku Block Liaison Conference on Disaster Support
・August 9, 2012: FY 2012 Kanto Block Liaison Conference on Disaster Support
・August 24, 2012: FY 2012 Chubu Block Liaison Conference on Sewage Disaster Support
・August 30, 2012: FY 2012 Hokkaido/Tohoku Block Liaison Conference on Sewage Disaster Support
・September 4, 2012: 19th Kinki Block Support Liaison Conference on Sewage Disaster
・October 11, 2012: FY 2012 Kyushu/Yamaguchi

Block Liaison Conference on Sewage Disaster Support Arrangements

Useful reference website

1) Report of Study committee for earthquake and tsunami countermeasure techniques in sewage systems
http://www.mlit.go.jp/mizukokudo/sewerage/crd_sewerage_tk_000170-1.html

3.3.3 River

The National Institute for Land and Infrastructure Management (NILIM) launched a field survey on the day after the Great East Japan Earthquake on March 11, 2011 (hereinafter referred to as the "3.11 Earthquake"), and examined river management facilities, such as levees, to examine the extent of damage caused by seismic motion and tsunami[1]. With respect to damage to levees caused by the tsunami, characteristics of damage were analyzed by type and magnitude of damage, the correspondence of spatial distribution to longitudinal distribution of high-water level, and relations between the magnitude of levee erosion due to overflow and water depth and time period of overflow. The results of the survey were provided periodically to the Tohoku Regional Development Bureau, the Ministry of Land, Infrastructure and Transport and Tourism (MLIT), and used as reference materials for the various committees, mentioned later. The summary is described in the following section (1).

The following committees on river management facilities were established in response to the 3.11 tsunami disaster: "Research Committee on River Tsunami Countermeasures," "Urgent Study Committee on Earthquake-proof Measures of River Levees," "Research Committee on Anti-seismic Reinforcement Technology for River-mouth Weir and Floodgate based on the Lessons Learned From the Great East Japan Earthquake," "Research Committee on Reconstruction Technology for Levees of the Kitakami River, etc.," and "Research Committee on Reconstruction Technology for Levees in Kanto Region." An outline and recommendations/reports of these Committees are described in (2) through (6).

(1) Characteristics of damage to levees

The number of river management facilities under the direct control of MILT damaged by the earthquake and tsunami was 1195, widely covering from the Mabuchi River in the north to upstream of the Abukuma River in the south. Among 773 damaged levees, severe damages, such as destruction and failure of levees, are concentrated in the Kitakami River, the Naruse River and the Abukuma River. "Destruction/failure" and "subsidence/sinking/crevice" account for about 60 percent, stretching over 66km[2]. Failure of levees was limited to at around 2.8kp of the left side and around 4.2kp of the right side of the Shin-Kitakami River (installation point of Tsukihama Daini Floodgate), the special levee at around 0.2kp of the right side of the Naruse River and at the junction with the seawall of the left and right sides of the river-mouth of the Abukuma River. The next largest damage after the failure of levees was the damage to the back slopes of levees and to the protected land at the rear side of the levees due to overflow. Damage to the slope caused by the high flow rate of the tsunami was slight.

This section examines the relations between the magnitude of the tsunami damage and the external force at the time of the tsunami uprush, focusing on the erosion of the back slopes of levees and the protected land at the rear side of the levees of the Abumuma River due to overflow, which was the second largest damage after the failure of levees.

Photo-3.3.3.1 is an aerial photograph near the river-mouth of the Abukuma River taken right after the disaster, which gives zones to show the relations between the high water level and the crest height and damage to the levee slopes, in accordance with the following criteria. As for the relations between the high water level and the crest height, the area was divided into three zones: submerged zone, overflow zone, and uprush zone below the crest height, using the results of field survey and survey on tsunami traces as a reference (see Figure 3.2.2.5). As Table 3.3.3.1 shows, the damage is classified into four levels in accordance with the severity. No notable damage was incurred in the zones where no damage level was given. The back slopes were not covered with concrete and herbaceous plants grew thickly.

The submerged zone was limited to the areas near the river-mouth, and an overflow zone and uprush zone below the crest height appear as it goes upstream. This confirms that the water level receded as the tsunami traveled. However, the length of the overflow zone is greatly different between the left and right sides of the bank. While the left bank has about 0.5km in length, it is longer on the right bank with about 2km. Except for the river-mouth area, the height of the tsunami trace exceeded the height of the levee by nearly 5 m at around the right bank of the Watari Ohashi (bridge), and it is assumed that the height of tsunami waters was high at the right bank where the outer bank of the river bend was hit by the tsunami attack.

In the submerged zones around the river-mouth, both the left and right banks were collapsed where the river levees are connected with the seawall. Besides this area, the damage to the left bank was mostly level I except for the level III damage at around the floodgate at 0.55km point. However, the damage to the right bank was more severe with damage level III to IV. The same is observed in the overflow zones; the magnitude of damage was greatly different between the right and left banks. Whereas the damage to the left bank was at level I, that to the right bank was at level II and III in a wide area running along about 2km. Furthermore, on the right bank, level I damage was recorded in the 0.8-1.2 km zones and level II/III damage was incurred as it goes further upstream from those zones.

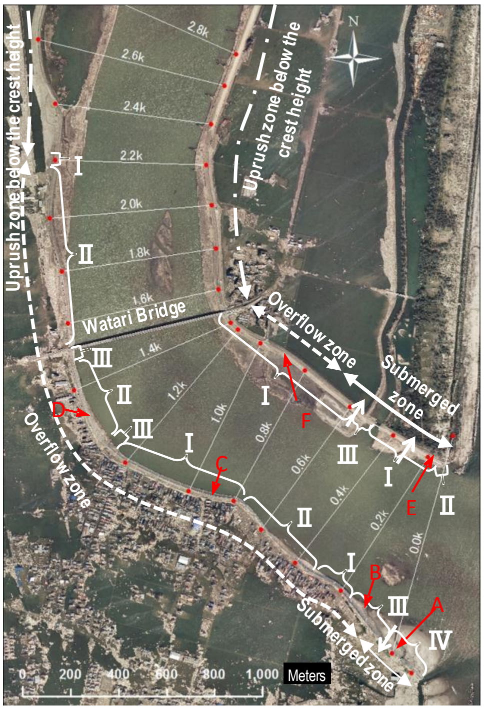


Photo 3.3.3.1 Relations between high water level of the tsunami and height of levees and the extent of damage

Table 3.3.3.1 Category of Disaster

Damage level	State of damage
I	Herbaceous plants are lodged due to the stream, but little detachment is observed
II	Partial detachment of plants living on the slope and erosion of levees in the form of gullies are observed. No or little formation of pools dug by the stream is observed.
III	Total erosion and failure of slopes, with vertical planes. It is followed by the formation of pools dug by the stream in some cases.
IV	Slope is washed away and erosion and failure have reached to the crest. It is followed by the formation of pools dug by the stream in some cases.

Judging from the observation that the high water level of the right bank of the Watari Ohashi was higher than that of the downstream, it is estimated that the damage level corresponds, to some degree, to the overflow water depth. However, this alone cannot fully explain the difference in damage level between the left and right banks. On this point, it is assumed that erosion of back slopes and toes of slopes was mitigated by the water cushion effect (Figure 3.3.3.1). This effect is caused either by inundation of protected land earlier than the overflow from the river side or by inundation of protected land shortly after the overflow. The following paragraph provides a quantitative study on the factors that determine the magnitude of disaster, using the results of simulation of the tsunami of 2011[3)] (hereinafter referred to as “simulation result”).

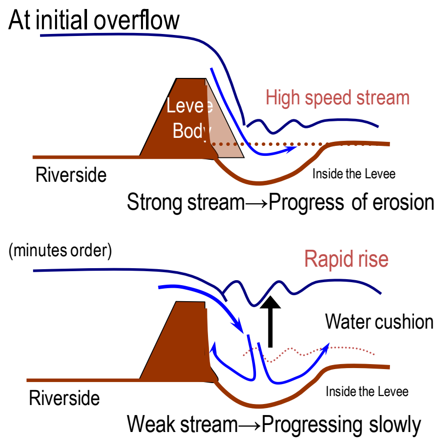


Figure 3.3.3.1 Image of progress of erosion due to a rapid rise in water level inside the levee

Figure 3.3.3.2 shows how the tsunami propagates using the simulation result. The tsunami climbed over the seawall and spread to the left and right sides with nearly the same magnitude. About three minutes after overflowing the seawall, the tsunami stopped at the left side of the bank but it still progressed up the right side of the bank. At the left side of the bank, the water level rose to about 6m (green area in the legend) at nearly the same time as the tsunami traveled upstream. And at the right side of the bank, a low water level area of less than 3m of water level (blue area in the legend) was observed after the tsunami traveled upstream. At the right side of the bank, where this alignment of levee moves away from the right bank as the tsunami travels upstream, overflow continued with a relatively low level of inundation inside the levee, although there is a slight difference in the duration among zones. An obvious cause of this is the situation in the first three minutes after the overflow of the seawall. In the areas inside the red dotted lines, overflow occurred several minutes before the tsunami traveling in the protected land arrived at the edge of the levee.

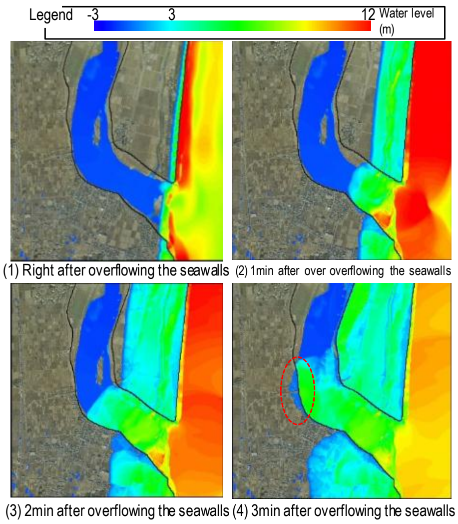


Figure 3.3.3.2 Propagation of tsunami (Aerial photograph in the background is photographic data of the Geospatial Information Authority of Japan)

In order to elaborate this phenomenon, chronological change in the water level of the river and inside the levee at locations from A through F in Photo-3.3.3.1 were calculated from the simulation result, which are shown in Figure 3.3.3.3 together with the overflow period and damage level. The figures in the brackets next to overflow time, etc. are the overflow period and initial overflow period in the unit of seconds. Here, the term ‘overflow period’ refers to the time period during which the water level of the river exceeds the levee height. When the water level inside the levee exceeds the water level of the river side, like at the location E, time until that moment is identified as the overflow period. The initial overflow period is the time period between when the water level of the river side exceeds the levee height and when the edge of the levee is inundated to the level where hydraulic jump of the overflow water almost occurs near the toe of slope. This is thought to be the level where the effect of water cushion can be produced.

The overflow period of the location A and location E is almost the same. The maximum overflow water depth was different: about 6m at the location A and about 3m at the location E. Still, both figures are large considering the vulnerability against overflow of levee. While the initial overflow period at the location A is 6 minutes, that of the location E is zero, which confirms that the effect of water cushion occurred at the location E when the overflow started. Therefore, it is fair to conclude that the level of disaster at the location E was mitigated by the water cushion.

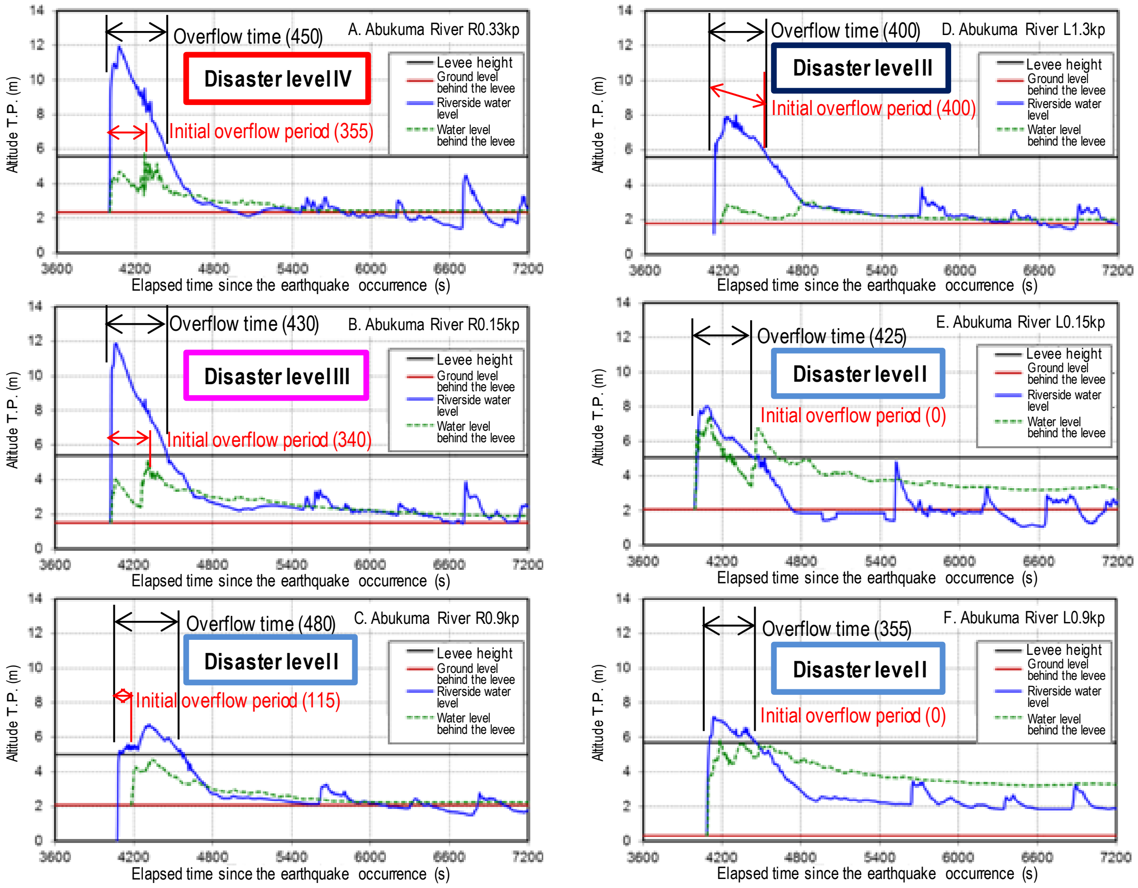


Figure 3.3.3.3 Chronological change in the water level of the river side and inside the levee at the toe of levee slope

When compared between the left and right sides of the levee in overflow zones, the maximum water depth at the locations B, C, and D on the right side of the bank is much higher than that at the location F on the left side of the bank; however, the overflow period is around 6 to 8 minutes with little difference between the left and right sides. Comparison of the initial overflow period shows the difference in locations with the location F zero and the locations B, C, and D from 2 to 7 minutes. The results of four profiles of these overflow zones show that the longer the initial overflow period is or the deeper the overflow water depth during this period is, the larger the magnitude of the disaster. The difference in the damage level by each zone observed on the right bank can be explained by the inundation inside the levee as seen in the three profiles at the locations B, C and D.

The results on the six profiles obtained above were compared in all profiles of inundation zones and overflow zones, which show that the initial overflow period is identified as a critical factor that determines the magnitude of damage to levees.

For the assessment of the magnitude of damage, the magnitude of damage to levees should be represented using more objective indicators, instead of roughly grouped zones obtained from the field survey. A cross-sectional view of the levee including the foundation inside the levee, divided by an equal distance of 10 meters, was created, and the eroded area of the back slope and the foundation inside the levee is considered as lost area. The lost area is divided by the standard sectional area of back slope shown around the center of the Figure 3.3.3.4 to obtain the loss ratio. The calculation of the loss ratio of the levee used aerial survey data and periodical profile survey data before and after the earthquake, in which horizontal and vertical displacements of the ground due to the earthquake were corrected. Before the volume of loss of the levee is used as a substitute for the survey result, the relations between the two were compared (see Figure 3.3.3.4). Most of the area in damage level I has a loss ratio of 0-2% and all the area in damage level VI has a loss ratio of 100% or more. Areas in damage level II and III are dispersed with different loss ratios, many areas in damage level II are found in lower loss ratios and many areas in damage level III are found in higher loss ratios, showing that the loss ratio corresponds to the magnitude of damage. From this, it is fair to use loss ratio as a substitute for the damage level.

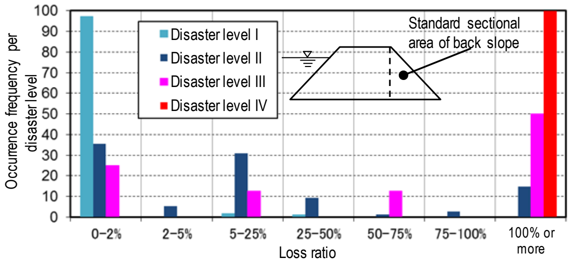


Figure 3.3.3.4 Relations between loss ratio of dike and damage level

Figure 3.3.3.5 shows the overflow period assigned to the horizontal axis and the average overflow water depth to the vertical axis and the shape of the plot is changed by each loss ratio, plotted in accordance with the conditions of overflow. Also, the plots are shown in different colors. Here, the average overflow water depth refers to the average value of water depth of overflow that occurred during the overflow period. As it goes to the upper right corner, the conditions of overflow are thought to become severe and the loss ratio is believed to become larger; however, the boundary of plots by loss ratio is vague. Figure 3.3.3.6 is the result obtained by assigning the average value of water depth of overflow during the initial overflow period to the vertical axis of Figure 3.3.3.5 and the initial overflow period to the horizontal axis. Except for some parts surrounded by dotted red lines, the boundary of loss ratio is now clear.

From the result above, it is assumed that the reason why the magnitude of damage was different in the areas with relatively the same overflow conditions is the inundation situations in the protected land, and if the period of overflow without inundation is longer, the profile has larger erosion damage.

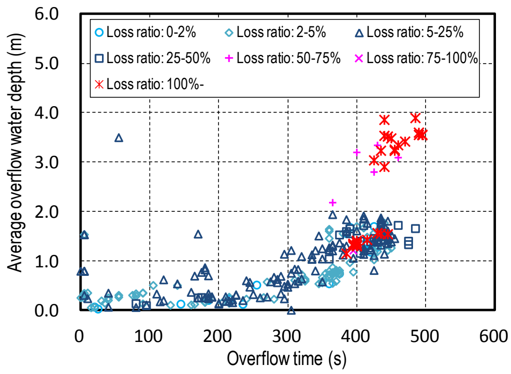


Figure 3.3.3.5 Relations between overflow situations and loss ratio of levee

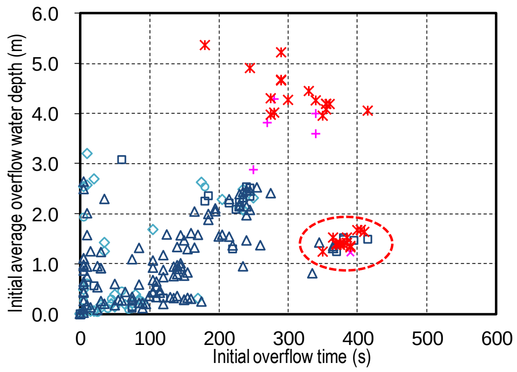


Figure 3.3.3.6 Relations between overflow situations and loss ratio of levee (with consideration to inundation in the protected land)

(2) Research Committee on River Tsunami Countermeasures

Based on the basic principle, "disaster prevention of river tsunamis is required to be implemented together with the protection at the sea shore and also plays an important role in tsunami-resilient community-building," this Committee (Chairperson: Shoji Fukuoka, Professor of Chuo University) provides urgent recommendations for handling the external force of tsunamis in river management, the concept of levee height in designing facilities and methods of promotion of tsunami-resilient community-building to contribute to early recovery/reconstruction measures in disaster-stricken rivers and to smooth implementation of the national-level countermeasures against river tsunamis

(August 2012).

A summary of recommendations is listed below.

●Basic principles of countermeasures against river tsunamis

・Protective measures for river tsunamis should be discussed periodically as in the case of floods.

・The tsunami specified in various parameters of facilities in tsunami river management should be treated as "tsunami related to facility design." "The maximum scale of tsunami" should be treated as a phenomenon exceeding the capacity of the facility. They should be treated included in the disaster reduction plans in conjunction with tsunami-resilient community-building.

●Countermeasures against river tsunamis for "tsunami facility design"

・By designating the geographic area defined by the maximum distance the tsunami could travel from the river mouth for facility design as the "tsunami reach zone," the designed high tsunami level should be decided as the water level to specify the height of river levees for tsunami protection.

・The height of river levees as the tsunami countermeasure should be determined by adding the height necessary for the designed high tsunami level.

●Response to "the largest-class tsunami"

・River managers, as participants to develop tsunami-resilient towns, should consider software and hardware measures in a comprehensive manner.

●For promotion of tsunami-resilient community-building and improvement of river management

・Promotion of technical development/study and research concerning countermeasures against river tsunamis, such as study and research to understand and respond to the hydraulic phenomenon associated with river tsunamis, improvements of precision of analysis of simulation models to estimate the numerical values for river tsunamis and inundation, data collection and study on hydraulic phenomenon around the river basin and changes in the river bed along the river channel caused by tsunamis

・Promotion of tsunami-resilient community-building, such as enhancement of coordination with urban sectors, study on evacuation plans for areas vulnerable to inundation by tsunamis, approaches to disaster prevention education, creation of hazard maps and enhancement of flood control

(3) Urgent Study Committee on Earthquake-proof Measures for River Levees

Under the recognition that damage to river levees due to the March 2011 Earthquake reminds us of the importance of ensuring anti-seismic features and provides us an important opportunity to review the anti-seismic measures, this Committee (Chairperson: Ikuo Towhata, Professor of University of Tokyo) gathered knowledge and intelligent concerning disasters from the Earthquake, discussed improvements of the anti-seismic measures and methods, and released a report on specific items and issues to be addressed as anti-seismic measures for river levees although there still remain many issues to be addressed in the future.

NILIM took part in the creation of documents and formulation of the report as a member of the Committee.

A summary of the final report is as follows.

●Characteristics of damage to levees

・Many cases of liquefaction of foundation caused the damage to levees, in addition to many liquefaction cases of levee bodies, which had previously not been taken seriously.

●Analysis of damaging process

・The damage to levees is thought to take the following three processes: (1) if a levee is built on soft clay soil, the surface of the soft ground layer at the lower part of the levee body will sink in due to consolidation settlement, during which process, the lower part of the levee body gets loose, (2) if the levee body built on a depressed area in the ground is made of sandy soil, penetrated water, such as rainfall, will be retained, forming a saturated area within the levee body, and (3) this area gets liquefied due to seismic motion, reducing the resilience/strength and causing the levee to slide and crack/collapse of the crest.

●Study on the methods of verification of seismic performance

・In addition to liquefaction of the foundation, settlement and deformation of the levee body due to liquefaction needs to be included as a verification target.
・The conventional verification method seems to be relevant for practical use for the verification on liquefaction of the foundation and there is no immediate need to change the method.
・As for verification of liquefaction of the levee body, it is now necessary to examine the materials used for the levee body, the water level in the levee body, the magnitude of settlement of the levee body due to consolidation settlement and the presence of settlement/deformation examined from the conditions of the foundation.

●Study on anti-seismic engineering

・As a measure against liquefaction of the foundation, it is necessary to establish a specific design method to withstand level 2 seismic motions, using the anti-seismic method with experience in construction, as a currently available method.
・The following are possible measures against liquefaction of the levee body: “measures to reduce the water level within the levee body,” “measures to increase the strength of the levee body,” and “measures to restrain the deformation of the levee body, while tolerating the occurrence of liquefaction.”
・As a measure to reduce the water level within the levee body, the drain method would be the main method for a while. It is expected that the drain method has the effect to mitigate settlement and deformation.
・In the case where the drain method cannot be used, it is necessary to consider mitigating settlement and deformation of the levee body through “the measures to mitigate the deformation of the levee body while tolerating the occurrence of liquefaction,” such as top weight, etc.

●Promotion of anti-seismic measures

・Since verification and measures have made little progress thus far, it is necessary to implement verification tests as soon as possible and take measures based on the results.
・Because it takes some time to complete the countermeasure construction, it is also important to prepare contingency plans, based on the disaster response simulation, etc.
・It may not be possible to protect from a large-scale or complex disaster by facilities alone, and it is necessary to explore responses to disaster which may hinder response by facilities, by, for example, simulating an earthquake disaster occurring at the same time as flooding.

(4) Research Committee on Anti-seismic Reinforcement Technology for River-mouth Weir and Floodgate based on the Lessons Learned from the Great East Japan Earthquake

This Committee (Chairperson: Tadashi Yamada, Professor of Chuo University) was established for the design and operation of weirs and floodgates capable of withstanding large-scale earthquakes and tsunamis, based on the results of study and analysis on weirs and floodgates damaged by the 3.11 Earthquake and Tsunami. The Committee then released a report (September 2011) that put together items to be addressed promptly, items necessary to be studied, and R&D in the future since technology has yet to be established. As flood season was approaching, the Committee also released urgent recommendations on items to be considered concerning damaged river-mouth weirs and floodgates (May 2011).

NILIM took part in the creation of documents and formulation of the report as a member of the Committee.

●Concept of future design and structure of weir/floodgate

・Learning from the experience of March 2011, it is necessary to clarify the specifications of river-mouth weirs and floodgates against the predicted tsunami in facility design and review the method of facility design.
・Even when the largest tsunami strikes, facilities should be structured to allow effective contingency management; for example, making the river-mouth weirs be in a prescribed state by opening and closing the gate and making the floodgates be able to shut the gates.
・Design and structure for the predicted tsunami in

facility design aim to minimize damage in protected land and need to be considered in a consolidated manner together with the operation.

・At facilities responsible for river runup tsunami operations, it is necessary to install facilities for remote control, automation, and non-power devices in order to secure the safety of operators and prompt and accurate operations.

●Concept for future river-mouth weirs/floodgates

・A floodgate having a function as a levee shall in principle be closed at the time of a river tsunami.

・Since a weir is a multi-purpose facility, in order to prevent occasional damage to drinking water supplies due to mixture with salty water upstream of the weir, no operation shall, in principle, be carried out, without leaving normal mode, in cases where the scale of the tsunami is expected to be small. When a large-scale tsunami is predicted, the weir shall be fully opened on an as-needed basis. However, with respect to individual facilities, an assessment and decision shall be made in a comprehensive manner based on predicted scenarios.

・It is necessary to consider the case not only of the estimated scale of tsunami, but also of an unexpectedly large-scale tsunami (beyond expectations) or of no tsunami despite warnings (inaccurate prediction).

・It is necessary to consider comprehensive operations, such as operation characteristics and the normal state of the gate, the estimated scale of tsunami, the type of warnings to be issued (tsunami warning, tsunami alarm, large-scale tsunami alarm) and estimated time of arrival, which are then specified in the operation manual as far as in advance as possible.

・In cases where machine operation is inappropriate, remote operation shall in principle be used in order to ensure the safety of operators, and this shall be specified in the operation manual.

(5) Research Committee on Reconstruction Technology for Levees of the Kitakami River, etc.

The Committee (Chairperson: Yasushi Sasaki, Professor emeritus of Hiroshima University), conducted studies on the effect of the 3.11 Earthquake and Tsunami, the shape (geographic feature) of levees (including foundation), soil layer composition, soil property and conditions of structures, such as seawalls, as well as on the state of damage, such as collapse, deformation and erosion of levees. The Committee then released a report on the mechanism of damage to levees by the tsunami based on the identified state of damage and the basic policies for the reconstruction of levees in line with the mechanism of damage by tsunamis (December 2011). As part of support for promoting prompt and accurate disaster recovery work, the Committee laid out policy proposals of reconstruction methods and presented a mid-term report on policies for river levee management and river management until the completion of the reconstruction work at the damage zones and sites (May 2011).

NILIM took part in the creation of documents and formulation of the report as a member of the Committee.

●Basic policies for reconstruction

・As the main cause of damage to levees due to the 3.11 Earthquake is liquefaction occurring in either or both of "sealed saturated zones" or/and "foundation soils," prevention of the recurrence of disaster shall be promoted, highlighting the reduction of deformation of levees due to liquefaction.

・Reducing the occurrence of liquefaction (removal of main cause of disaster)

Removal of the main cause is either to reduce the level of underground water in the liquefaction layer, which is the main cause of liquefaction, or to increase the density of or solidify the loose sandy soil layer.

・At the locations where damage was caused mainly by the liquefaction in sealed saturated zones, a method shall be selected that would achieve either of the above conditions, or a combination of both, depending on the conditions of the site (constraints of construction and reliability of drainage of underground water in the protected land, etc.) In the case of reducing the water level in the protected land, it is effective to install a drain device at the toe of the back slope.

・At the locations where damage was caused mainly by the liquefaction of foundation soils, reduction of the level of underground water is not realistic. Priority shall be given either to increasing the density of or solidifying the loose sandy soil layer.

・The following are the possible processes of damage to levees caused by tsunamis depending on the conditions of individual rivers.

・It is assumed that no large-scale damage, such as levee failure, was caused by the Earthquake in the tsunami-damaged zones. However, one cannot deny the possibility of the weakening of foundation soils and levees due to liquefaction, affecting the magnitude of damage by the subsequent tsunami.

・The damage to the levees at the back slope of “embankment” or “non-soil embankment” is assumed to have happened in the following process: (1) the back slope and near the toe of the slope (the back slope near the toe or the surface of the foundation adjacent to the toe of slope) were scoured by the overflown stream (the direction of crossing the embankment) or by the stream along the toe of the embankment slope, (2) the soil on the slope could no longer withstand the pressure, causing a local slope failure, (3) then progressive slope failure occurred with further scouring, and (4) finally, the soil section was washed away.

・Possible tsunami counter-measures include surface coating (seawalls, etc.) and ensuring of a levee profile that can maintain some profile shape even eroded and scoured; however, it is difficult to expand the profile in a large scale because it may affect the nearby environment. Therefore, the basic policy of the counter-measures shall be surface coating and securing (expansion) of a profile within a possible scope.

(6) Research Committee on Reconstruction Technologies for Levees in the Kanto Region

The Committee (Chairperson: Ikuo Towhata, Professor of University of Tokyo) conducted a survey on damage to levees, studied the mechanism for reconstruction work, gathered knowledge on future anti-seismic measures for river levees, discussed river management and effective flood control in preparation for the flood season and released a report (September 2011), in order to carry out accurate response in the flood season and smooth implementation of future anti-seismic measures.

NILIM took part in the creation of documents and formulation of the report as a member of the Committee.

●Reconstruction work

・Basic policies for reconstruction at the locations suffering from a large-scale disaster are to implement liquefaction counter-measures, with an aim to “restrict the damage to a mid-scale or lower even being hit by the same level of earthquake as 3.11.”

・liquefaction counter-measures for levee bodies shall in principle be the drain method. Besides the drain method, application of the soil stabilization method shall be discussed, with consideration to the location and scope of the liquefaction layer, underground water (water level in the protected land) in the liquefaction layer and economic feasibility, etc.

・The steel sheet piling method is basically used as countermeasures for both liquefaction of foundations and combined liquefaction of levees/foundations, but the soil stabilization method may be applied with consideration to the soil quality of the foundation, the presence or absence of cutbacks and economic feasibility, etc.

・ The liquefaction counter-measure in the surrounding area of structures shall be selected comparing the steel sheet piling method and the soil stabilization method with consideration to the conditions of the foundation and economic feasibility, etc.

●Response in flood season

・Invisible cracks and loose levees may occur due to an earthquake, which could cause levee failure due to seepage; therefore, it is critical to detect abnormalities in the levees at an early stage by patrolling and to implement appropriate and timely measures, including flood fighting methods.

・In addition to annual preparation for the flood season, the following actions shall be taken: (1) early dispatch of flood fighters and reinforcement of river patrol systems through review of the water level criteria, such as the water level at which flood fighters must wait on standby, and critical flood protection sites, (2) assessment of flood fighting methods and allocation of necessary materials and equipment based on the state of levee disaster and provisional measures, and (3) enforcement of information provision and information collection systems for the people by putting up bulletin boards on sites and through PR bulletins of the local governments.

・Although all possible measures have been taken in an unprecedented situation, necessary response should still be taken as the occasion demands, depending on the flood conditions and the results of monitoring.

●Future anti-seismic measures

(Measures to be implemented at the moment)

・For the reconstruction in the post-flood season, it is necessary to make prompt and proper implementation of appropriate methods, based on the analysis of the disaster mechanism conducted by the Committee.

・In the zones where the seismicity of levees has not been tested, such tests should be conducted as soon as possible and appropriate anti-seismic measures based on the Commission's discussions should be implemented in necessary areas.

(Issues to be addressed in the future)

・Discussions on the plan for stockpiling materials and equipment in times of peace, including development of storage sites in order to carry out early reconstruction

・ Discussions on the framework for rapid reconstruction, including formulation of a manual for river patrols until the completion of reconstruction work

・Discussions on measures to mitigate the scale of disaster with an assumption of the effects on the surrounding urban areas, a disaster covering a wide geographic area and damage before the flood season that are based on the disaster mechanism, etc.

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1) *Emergency Recommendations concerning River Tsunami Countermeasures,* Research Committee on River Tsunami Countermeasures http://www.mlit.go.jp/report/press/mizukokudo03_hh_000376.html

2) Urgent Study Committee on Earthquake-proof Measures of River Levees http://www.jice.or.jp/sonota/t1/201110240.html

3) Research Committee on Anti-seismic Reinforcement Technology for River-mouth Weir and Floodgate based on the Lessons Learned from the Great East Japan Earthquake http://www.jice.or.jp/sonota/t1/201106150.html

4) Research Committee on Reconstruction Technology for Levees of the Kitakami River, etc. http://www.thr.mlit.go.jp/Bumon/B00097/K00360/taiheiyouokijishinn/kenntoukai/index.htm

5) Research Committee on Reconstruction Technologies for Levees in the Kanto Region http://www.ktr.mlit.go.jp/bousai/bousai00000057.html

3.3.4 Water Resources

(1) Outline of damage

At dams managed under the River Act, special safety inspections were conducted by dam managers immediately after the Great East Japan Earthquake on March 11, 2011 (hereinafter referred to as the "3.11 earthquake"), in cases where earthquake motion of 25 gal or higher was recorded at the dam foundation or where earthquake motion of JMA seismic intensity of 4 or higher was observed at the nearest meteorological station (Table 3.3.4.1). The special safety inspections include a primary inspection and a secondary inspection. The former is a visual inspection, while the latter includes more detailed visual inspection and a safety inspection based on various data measured by monitoring devices.

As far as the dam body is concerned, damages to concrete gravity dams reported by the safety inspections include increased leakage, and damages to embankment dams are increased leakage (seepage) as well as settlement of the dam body, cracks on dam crests and on the upstream and downstream slopes of some earthfill dams and cracks on the waterproof facing of asphalt faced rockfill dams.

Although these damages are not regarded as serious enough to threaten the safety of the dams, at dams where some damages and increased leakage (seepage) were found, further monitoring has been in place and safety measures have been taken, such as reservoir drawdown and investigations and repair work on the damaged places.

Table 3.3.4.1 Number of dams where special safety inspections were conducted and the summary of the results

Manager	Total	Concrete dam	Embankment dam	Combined dam
MLIT / Japan Water Agency	46 (11)	31 (6)	10 (3)	5 (2)
Prefectural Governments	104 (8)	81 (6)	22 (2)	1 (0)
Water users	213 (27)	107 (7)	101 (19)	5 (1)
Total	363 (46)	219 (19)	133 (24)	11 (3)

* The figures in parentheses represent the number of dams where damages were reported, such as damage to the dam body and increased leakage.

(2) Outline of investigations

The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and the Public Works Research Institute (PWRI) conducted field investigations (detailed investigations), focusing on those dams in the Tohoku region where damages had been reported as a result of special safety inspections, such as deformation, increased leakage, or relatively large peak acceleration values, in order to confirm the state of damages reported in the special safety inspection results, to evaluate the safety of the dams, and to study countermeasures as needed. Several dams, where leakage increased in association with a rise of the reservoir water level caused by later rainfall or snowmelt, were added to the dams to be investigated, though no damage had originally been reported immediately after the 3.11 earthquake.

Table 3.3.4.2 and Figure 3.3.4.1 show the outline of field investigations and locations of dams for field investigations, respectively.

Table 3.3.4.2 Outline of field investigations

Investigator	Investigation date	Investigation site
MLIT Water Management Office, River Environment Division, River Bureau National Institute for Land and Infrastructure Management (NILIM) Water Resources Division, River Department Public Works Research Institute (PWRI) Hydraulic Engineering Research Group, Dam and Appurtenant Structures Research Team	April 7 (Thurs) – 10 (Sun)	Surikamigawa dam Ishibuchi dam Tase dam Gosho dam Kejonuma dam
Public Works Research Institute (PWRI) Hydraulic Engineering Research Group, Dam and Appurtenant Structures Research Team	April 23 (Sat) – 24 (Sun)	Kamuro dam Takasaka dam
MLIT Water Management Office, River Environment Division, River Bureau National Institute for Land and Infrastructure Management (NILIM) Water Resources Division, River Department	April 28 (Thurs)	
Public Works Research Institute (PWRI) Hydraulic Engineering Research Group, Dam and Appurtenant Structures Research Team	April 28 (Thurs)	Zao dam
	May 6 (Fri)	Fujiigawa dam Koyama dam
	May 22 (Sun)	Gassan dam

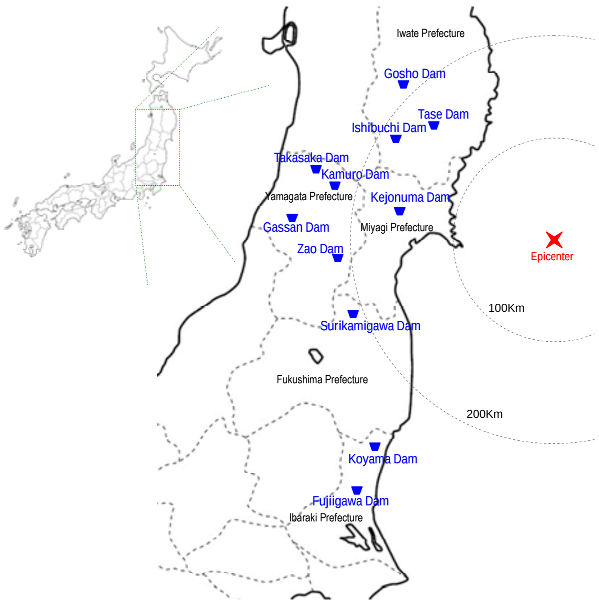


Figure 3.3.4.1 Locations of dams for field investigations

(3) Results of investigations and discussion

1) List of results of investigations on individual dams

Table 3.3.4.3 shows the specifications of investigated dams, major findings and outlines of the results of special safety inspections. Damage to the dam body and increased leakage (seepage) were observed in each dam, but no damages severe enough to threaten dam safety were found at any of these dams.

2) Results of inspections on individual dams

(a) Surikamigawa dam

Surikamigawa dam, shown in Figure 3.3.4.2, is an earth core rockfill dam with a cut-off wall (with a height of 105.0m) completed in 2006. The 3.11 earthquake caused an increase in leakage (total) from approximately 70 L/min to 100 L/min and also caused the following damages: settlement of the dam body (approximately 17 cm near the maximum cross section) and cracks on the pavement on the dam crest near both abutments, primarily in the stream

Table 3.3.4.3 Specifications of inspected dams, reported damages at the time of special safety inspections and results of detailed investigations

Dam	Manager	Year of completion	Dam type	Height (m)	Water level at the time of the earthquake (m) [Reservoir water level (m)]	Distance (m)		Seismic motion** (gal)		Reported damages at the time of special safety inspections	Volume of leakage (L/min)			Summary of the results of detailed investigations (concerning major damages, etc.)
						Epicentral distance	Shortest distance to a fault	Foundation	Crest		Prior to the earthquake	After the earthquake	At the time of investigation (date of investigation)	
Surikamigawa	Tohoku Regional Development Bureau	2006	R	105.0	286.35 [79.85]	216	138	110	474	Cracks on the dam crest	Approx. 70	Approx. 100	Approx. 85 [4/7]	· Settlement of dam body (maximum 17cm) · Cracks on the pavement of the dam crest near both abutments (later found to be minor, remaining within the protective layer, by the follow-up investigation) · Increased leakage (found to be caused by snowmelt)
Ishibuchi	Tohoku Regional Development Bureau	1953	CFRD	53.0	302.37 [32.37]	204	145	(184)	607	Cracks on the dam crest	River bed: Approx. 2000 Right bank tunnel: Approx. 440	River bed: Approx. 3000* Right bank tunnel: Approx. 700	River bed: Approx. 2000 Right bank tunnel: Approx. 710	· Settlement of dam body (maximum 1cm) · Cracks at the foundation of the crest parapet · Increase in leakage measured at the foundation (found to be caused by afflux of the water level due to adhering of algae)
Tase	Tohoku Regional Development Bureau	1954	G	81.5	197.34 [58.84]	192	121	-	-	Increased leakage	14	69	Approx. 40 [4/8]	· Exfoliation of parapet concrete on the crest and opening of cracks and level differences on crest pavement joints · Increased leakage (less than 10L/min each) from the scupper on the joint (near the maximum cross section) and muddy water (disappeared the day after)
Gosho	Tohoku Regional Development Bureau	1981	G+R	52.5	176.99 [52.99]	237	157	39	125	Increased leakage	Concrete dam/ approx. 20	Concrete dam/ approx. 70	Concrete dam/ approx. 60 [4/9]	· Increased leakage from the scupper on the joint (J4) at the concrete dam section · Settlement (very little) of the embankment body
Gassan***	Tohoku Regional Development Bureau	2001	G	123.0	222 [75]	265	204	11	14	-	6.2	32.8	189 [5/22]	· Leakage from the scupper on the joint (J14) (approx.25L/min, later stabilized) · Increased leakage from the scupper on the joint (J18, J17, etc.) at the time of water level increased since the end of April · Increased uplift pressure at the foundation scupper (BL18)
Kejonuma	Miyagi Prefecture	1995	E	24.0	25.97 [15.77]	176	121	269	495	Increased leakage	22	436	Approx. 40 [4/10]	· Settlement of dam body (maximum of 14cm) · Cracks at the joints around the left and right banks of the dam crest · Rapid increase in leakage (right bank) immediately after the earthquake (subsided later)
Kamuro***	Yamagata Prefecture	1993	G	60.6	375.9 [42.9]	231	174	18	52	-	Approx. 10	Approx. 40	Approx. 230 [4/24]	· Increased leakage from the scupper on the joint (2J3) along with the rise in the reservoir water level at the beginning of April (implemented detailed investigation and countermeasures later. Tends to be stabilized)
Takasaka***	Yamagata Prefecture	1967	G	57.0	184.27 [44.27]	254	197	26	32	-	Approx. 35	Approx. 15	Approx. 300 [4/24]	· Increased leakage from the scuppers on the joints (J9, J10) along with the rise in the reservoir water level at the beginning of April (implemented detailed investigation and countermeasures later. Tends to be stabilized)
Zao	Yamagata Prefecture	1970	HG	66.0	583.17 [45.17]	212	146	91	535	-	8.6	38.9	Approx. 50 [4/28]	· Increased leakage from the foundation scupper (7BL, etc.)
Fujiigawa	Ibaraki Prefecture	1976	G	37.5	44.96 [26.96]	289	92	174	636	-	9*	76*	32 [5/6]	· Increased leakage from the foundation scuppers at the maximum cross section (BL 4,5) · Leakage from the scupper on the joint (J4) * Leakage before and after the earthquake is given for reference (automatically measured value, which is later found to be larger than the actual value when compared with manually measured value)
Koyama	Ibaraki Prefecture	2005	G	65.0	291.86 [36.86]	244	81	334	1242	-	83.3	137.6	152.2 [5/6]	· Increased leakage from the scuppers on the joints (J5, J19, etc.) (silty sediments around the scuppers) · Leakage around the foundation scupper (BL21)

* G: Concrete gravity dam, HG: Hollow gravity concrete dam, R: Rockfill (earth core), CFRD: Concrete faced rockfill dam, E: Earthfill dam

** Peak value of the horizontal component (stream direction and dam axis direction). Value of Ishibushi dam (foundation) is for reference (recorded at the right terrace, not bedrock). Maximum value of Tase dam is unknown.

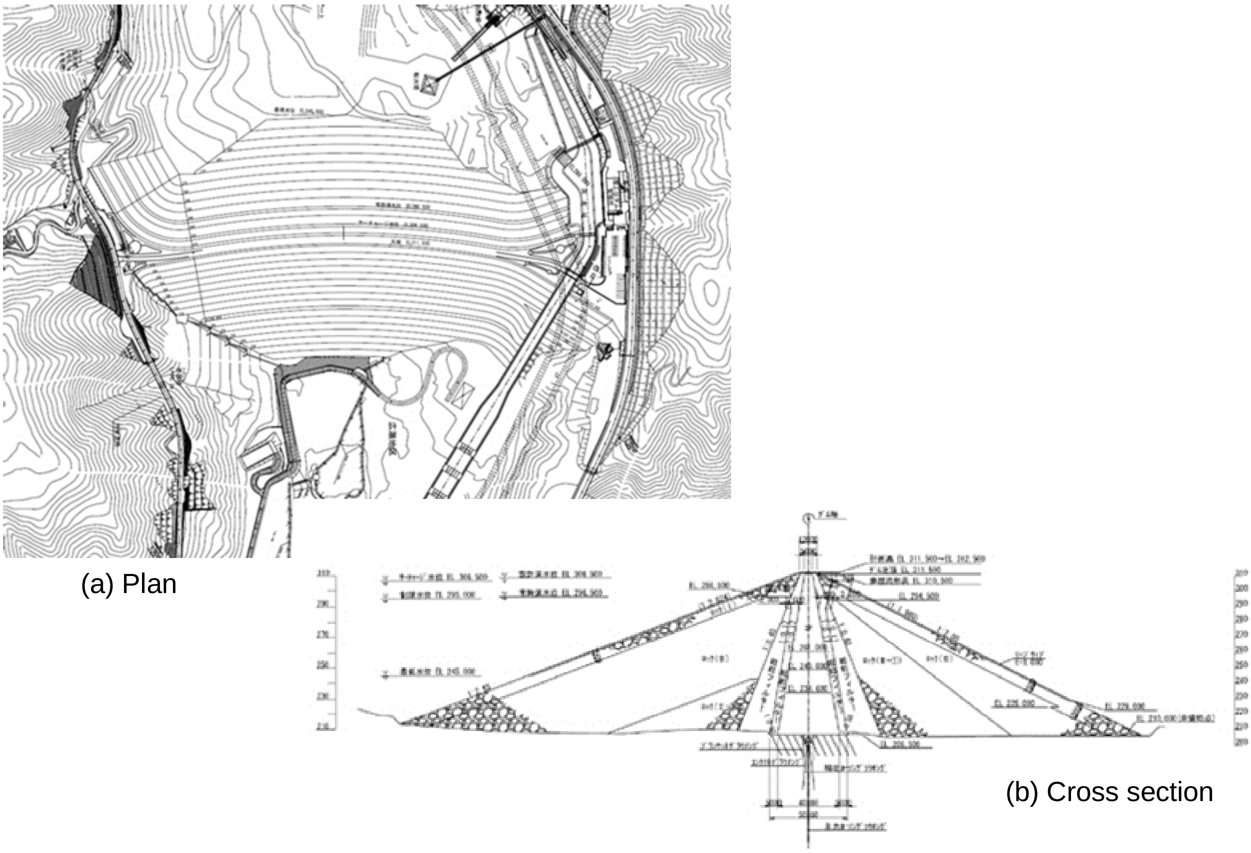
***No specific deformation was reported by the special safety inspections immediately after the earthquake, but detailed investigations were conducted because increased leakage was later observed as the reservoir water level rose.

direction (Photo 3.3.4.1, Photo 3.3.4.2).

As a result of the investigation, it was concluded that the safety of the dam was intact due to the following findings: the earthquake-induced leakage increase and settlement were small relative to the scale of the dam, the values of these changes were stabilized, the cracks in the crest pavement were narrow, and no change was found in the upstream and downstream surfaces. Still, the manager has continued measuring the depth of the cracks and monitoring the data on leakage to take every possible means to ensure safety. As a result of the follow-up investigations by the manager, the depth of the cracks was found to be shallow, staying within the protective layer of the dam crest.

(b) Ishibuchi dam

Ishibuchi dam (Figure 3.3.4.3) is a concrete faced



(a) Plan

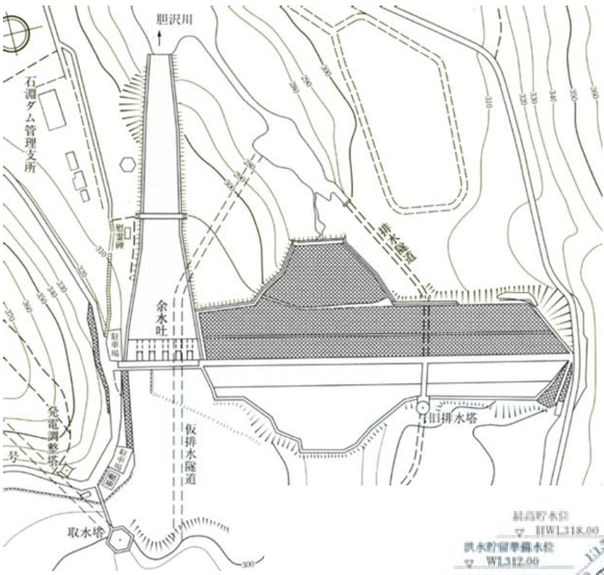
(b) Cross section

Figure 3.3.4.2 Surikamigawa dam

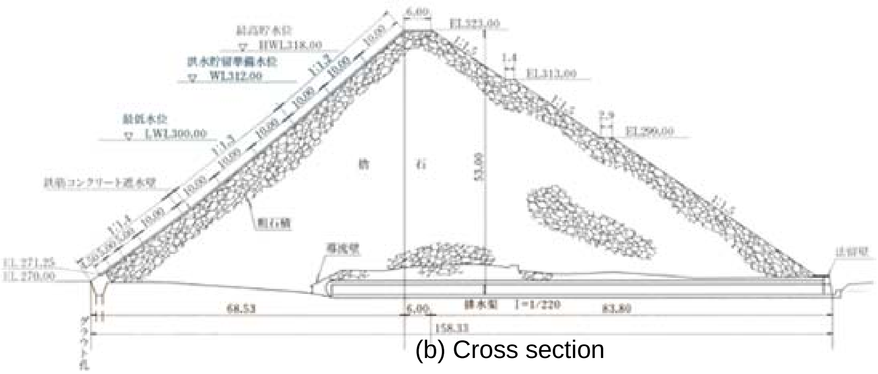
Photo: 3.3.4.1 A crack at the attaching portion of the left bank of the dam crest (Surikamigawa dam)

Photo 3.3.4.2 Close-up of a crack that appeared on the dam crest pavement (Surikamigawa dam)

rockfill dam (CFRD) with a cut-off wall (CFRD) (with a height of 53 m) completed in 1953. When the Iwate-Miyagi Inland Earthquake of 2008 (M7.2, inland active fault earthquake) hit the dam, a seismometer installed at the dam crest recorded a maximum acceleration of 1,461 gal (stream direction) and 2,070 gal (vertical direction). The dam was reported to have incurred the following damages due to the earthquake; at the crest of the dam, the pavement was buckled and cracked and gaps appeared on the boundary between the parapet and pavement (Photo 3.3.4.3). The 3.11 earthquake left much smaller damage than that by the 2008 earthquake, despite some settlement of the dam body and widening of gaps at the foundation of a crest parapet due to structures buried in the dam body (the piers of the tramway left buried in the dam body at the



(a) Plan



(b) Cross section

Figure 3.3.4.3 Ishibuchi dam

Photo 3.3.4.3 Crest of the Ishibuchi dam (earthquake of 2008)

Photo 3.3.4.4 Crest of the Ishibuchi dam (3.11 earthquake)

* a trace of pavement repaired was caused by earthquake of 2008

time of construction) (Photo 3.3.4.4). Since a rather large settlement occurred at the Ishibuchi dam (approximately 55 cm near the maximum cross-section) due to the 2008 earthquake, continuous observation of displacement has been conducted using GPS sensors at the dam crest and various sites of the upstream and downstream slopes in order to monitor the movement of the dam body (Figure 3.3.4.4), and data were also obtained when the 3.11 earthquake occurred. Among such data, Figure 3.3.4.5 shows the result of the observation point G-9 of the dam crest at the maximum cross section. From the Figure, it is clear that the maximum differential settlement of about 12mm was caused by the 3.11 earthquake and a smaller scale of settlement occurred at the time of an aftershock (at a maximum of M7.1) on April 7. From these data, it was found that there were no problems threatening the safety of the dam, because the earthquake-induced settlement was small and no damage was found on the cut-off wall surface at the upstream. An increase in the measured leakage (from approximately 2,000 L/min to about 3,000 L/min) reported from the special safety inspection was found to be caused by the blocking of the water level inside the channel due to adhering algae. Nonetheless, in order to take every possible measures to ensure safety, the manager has continued monitoring the data on leakage at this point and other points, and others and others.

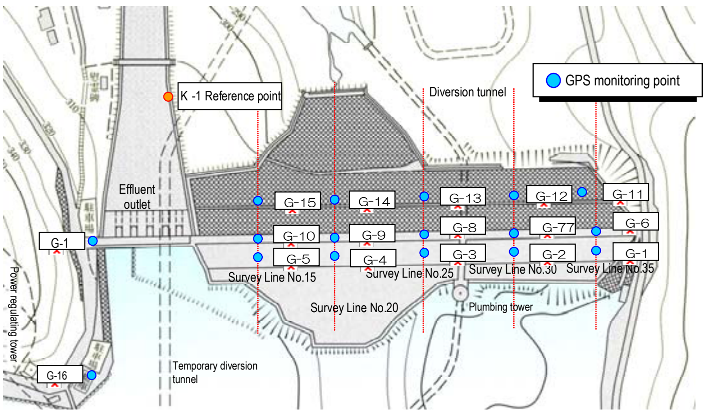
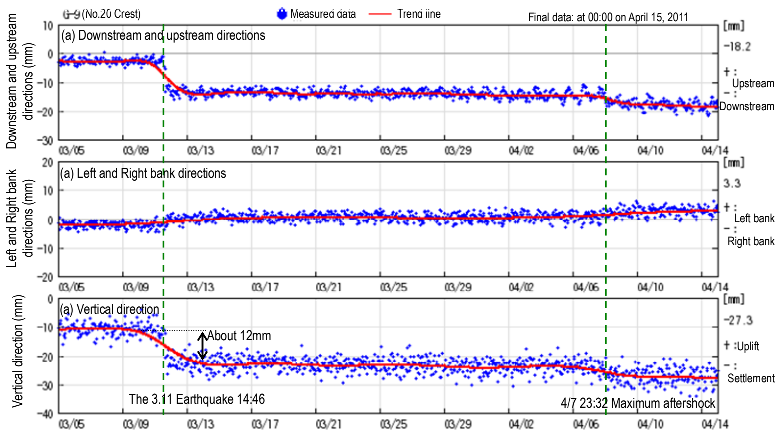


Figure 3.3.4.4 Displacement observation at the Ishibuchi dam (layout of GPS sensors)

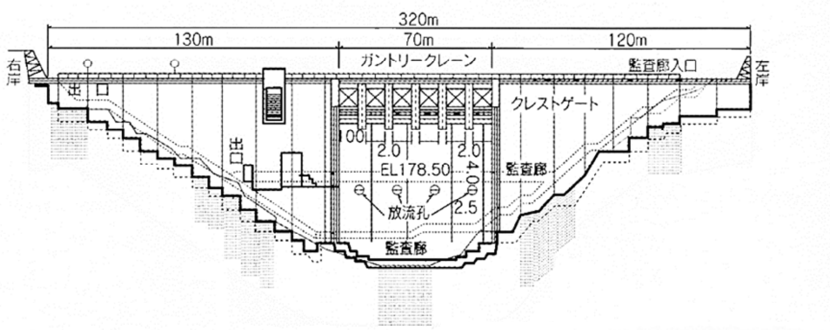


* Displacement sets zero at the time when GPSs were placed just after the Iwate-Miyagi Inland Earthquake in 2008.

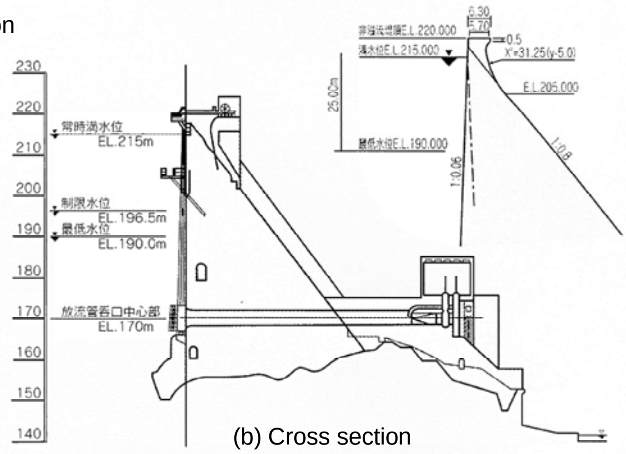
Figure 3.3.4.5 Changes in displacement of Ishibuchi dam body observed by the GPS

(c) Tase dam

Tase dam (Figure 3.3.4.6) is a concrete gravity dam (with a height of 81.5 m) completed in 1954. The 3.11 earthquake increased the total leakage from 14 L/min to 69 L/min (Figure 3.3.4.7), and caused exfoliation of parapet concrete at the crest and opening of cracks and level differences on the crest pavement (Photo 3.3.4.5, Photo 3.3.4.6). As a result of the detailed investigation, it was concluded that there were no problems threatening the safety of the dam from the fact that these damages were minor and leakage from each transverse joint was low at no more than about 10 L/min. However, since leakage from scuppers on the joint was observed, which had been nearly 0 L/min before the earthquake, the manager has continued monitoring the leakage with consideration to the relations with the reservoir water level in order to take every possible measure to ensure safety.



(a) Longitudinal section



(b) Cross section

Figure 3.3.4.6 Tase dam


Photo 3.3.4.5 Exfoliation of parapet concrete (Tase dam)


Photo 3.3.4.6 Level difference at joint of crest pavement (Tase dam)

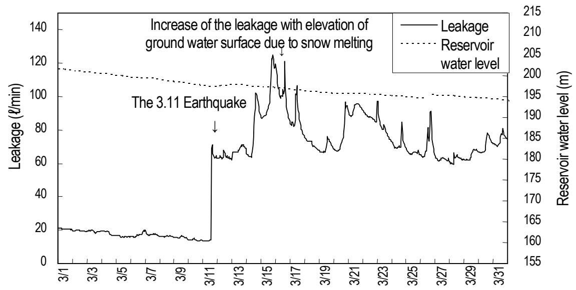


Figure 3.3.4.7 Leakage at Tase dam

(d) Gosho dam

Gosho dam (Figure 3.3.4.8) is a combined dam with a concrete gravity dam section, including spillway, and a rockfill dam section connected of a concrete part (completed in 1981 with a height of 52.5 m). The 3.11 earthquake caused an increase in leakage from approximately 20L/min to 70L/min. Major leakage occurred at the transverse joint (J-4) as shown in Photo 3.3.4.7. Leakage from this joint had previously been observed during the winter when the concrete contracted due to the low temperature with the maximum of 20L/min. After the 3.11 earthquake, the leakage increased from 20L/min to 35L/min. Leakage was also observed for the first time from the gallery on the downstream slope. Thus, the manager has continued monitoring, focusing on said locations (as of August 2012, leakage has been stabilized).

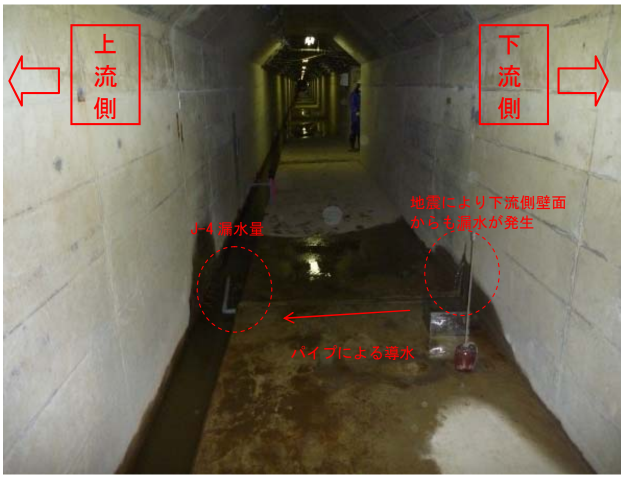
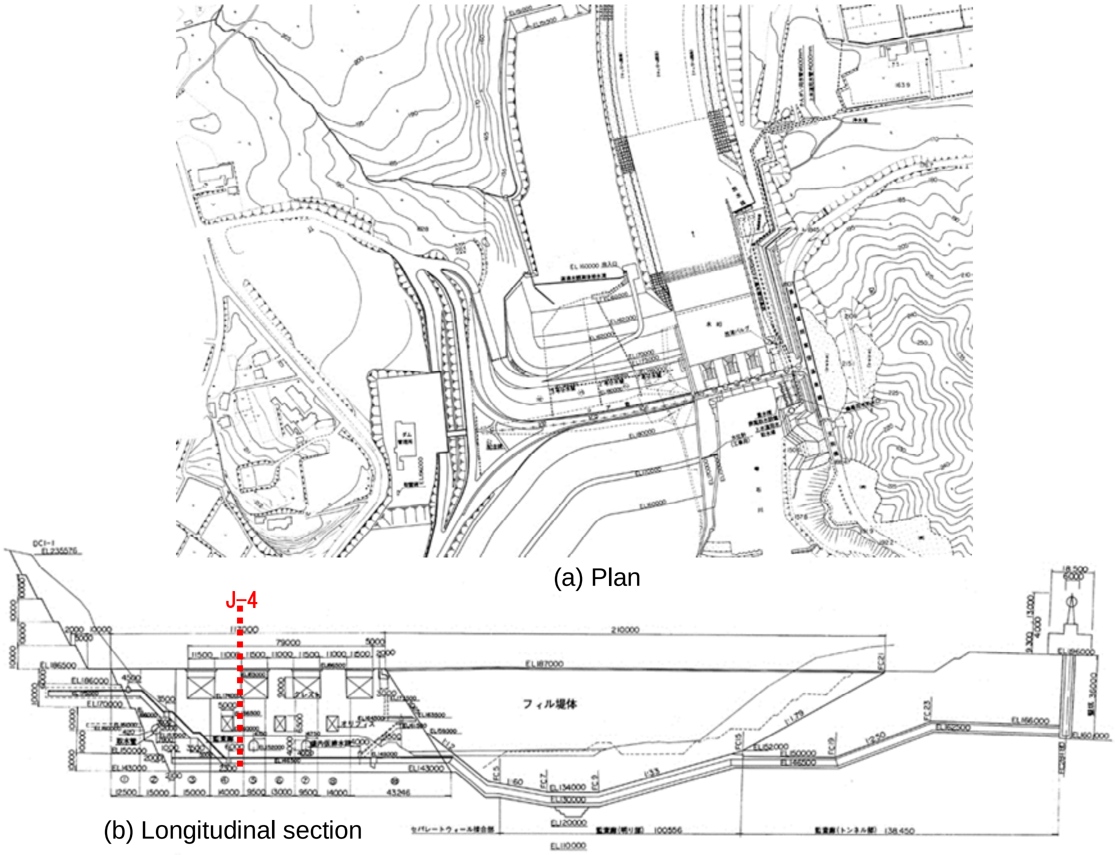


Photo 3.3.4.7 Leakage at the joint of the concrete gravity dam section (J-4) (Gosho dam, concrete gravity dam section)

(e) Kejonuma dam

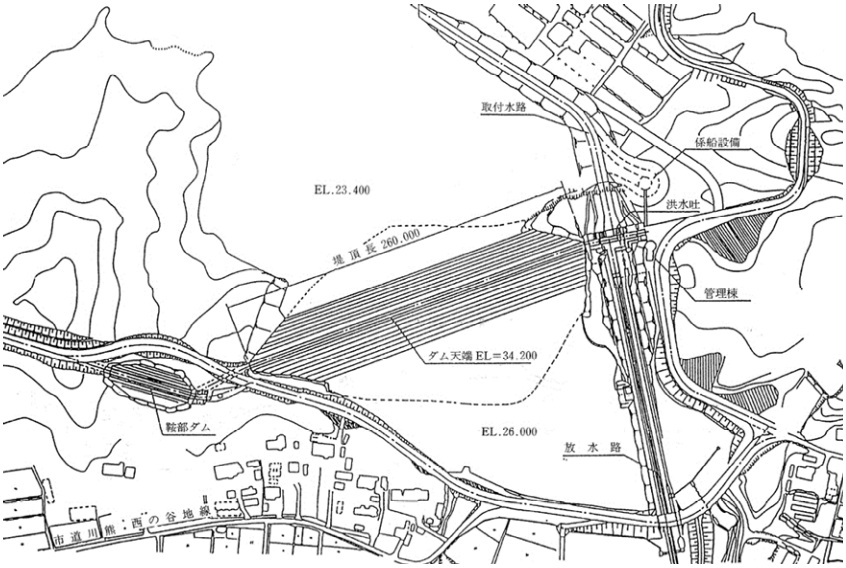


(a) Plan

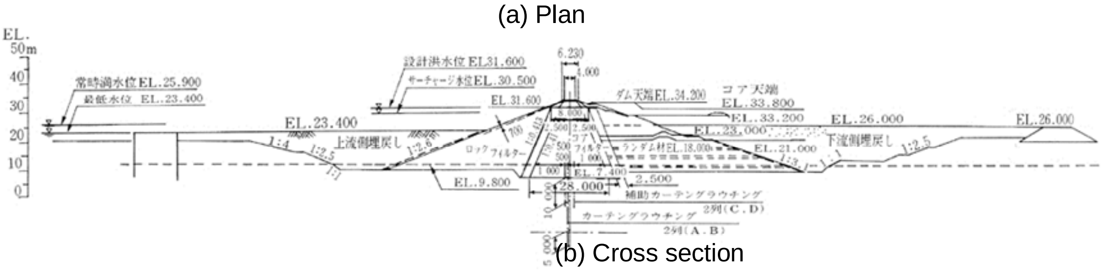
(b) Longitudinal section

Figure 3.3.4.8 Gosho dam

Kejonuma dam is an earthfill dam (with a height of 24.0m) completed in 1995. After the 3.11 earthquake, the total leakage (seepage) increased rapidly from 20L/min to 430L/min. At this dam, leakage is observed at different locations: namely, the left bank, center, right bank and borehole. A large increment of leakage is observed at the right bank of the dam, with the increment from 7L/min to 290L/min. The leakage



(a) Plan



(b) Cross section

Figure 3.3.4.9 Kejonuma dam

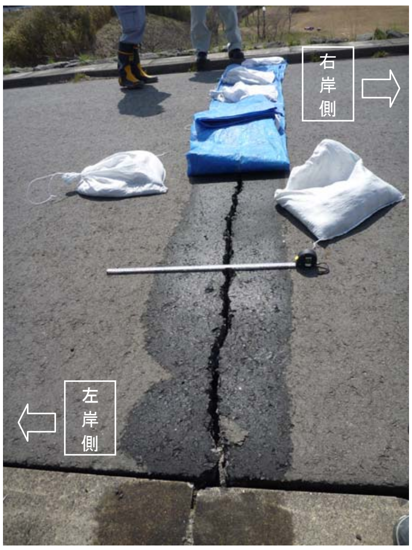


Photo 3.3.4.8 Cracks appeared upstream and downstream directions (Kejonuma dam)

Photo 3.3.4.9 Opening between curb at the crest center and pavement (Kejonuma dam)

subsided quite rapidly after that, and it has been stabilized at 50L/min since March 15 (Figure 3.3.4.10). The 3.11 earthquake caused a settlement of 13.9cm and deformation of 5.8cm towards the downstream direction near the center of the crest, where the maximum deformation was observed. At the crest of the dam body, several cracks were extended to the downstream and upstream directions, of which 2.5-3cm of cracks were observed on the left bank (Photo 3.3.4.8). There was an opening between the curb along the center to the left bank of the crest and the pavement (Photo 3.3.4.9). As for the investigation, there were no damages threatening the safety of the dam, however, continuous monitoring of leakage (seepage) is needed.

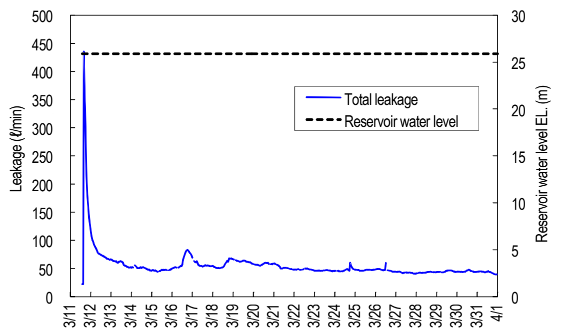


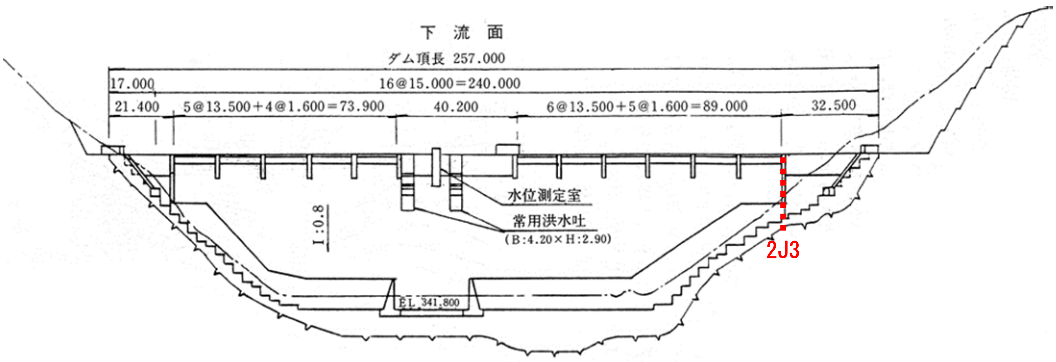
Figure 3.3.4.10 Leakage at Kejonuma dam

(f) Kamuro dam and Takasaka dam

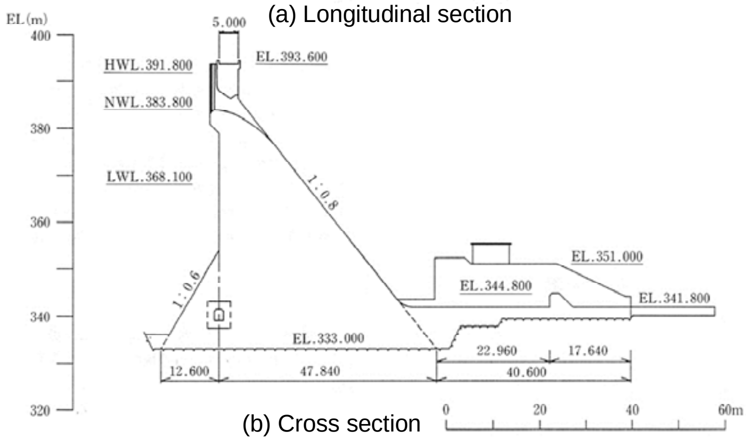
Kamuro dam (Figure 3.3.4.11) is a concrete gravity dam (with a height of 60.6m) completed in 1993, and Takasaka dam (Figure 3.3.4.12) is a concrete gravity dam (with a height of 57.0m) completed in 1967. Approximately one month after the 3.11 earthquake, leakage increased remarkably at both dams, corresponding to the rising reservoir water level due to snow melting and rainfall and the largest aftershock (M7.4) thus far on April 7. Although any correlation between the reported increase in leakage and the earthquake is unknown, detailed investigation was carried out upon a request made by the Yamagata Prefecture (local government), the manager of these dams, in order to examine the cause of the increase and possible countermeasures. The peak acceleration (horizontal component) of seismic motion observed at the foundation of these dams ranged from 15 gal to 25 gal, which is not particularly high. As a result of the investigation, the main damage to the Kamuro dam was notable leakage at the scupper of the transverse joint (2J3) (Photo 3.3.2.10), which was found higher than the maximum value observed at the same reservoir water level in the past (Figure 3.3.4.13). However, no noticeable change was observed in the leakage from the foundation scupper, nor was there uplift pressure at the foundation or displacement of the dam body. As for Takasaka dam, notable leakage from the scuppers of the transverse joints (J9) (Photo 3.3.4.11) and J10 was observed (Figure 3.3.4.14). No leakage from the foundation scupper or muddy water was observed.

Although it was concluded that no damage was observed that may threaten the safety of the dams, the manager has continued monitoring the leakage and gaps focusing on the transverse joints where a large amount of leakage was observed and conducted investigations on leakage paths for countermeasures.

Later, countermeasures were taken against the leakage from the transverse joints at both dams using a leak-stop agent based on the results of the investigation on leakage paths. Monitoring has continuously been conducted. The leakage tends to stabilize (the leakage has stabilized as of February 2012).

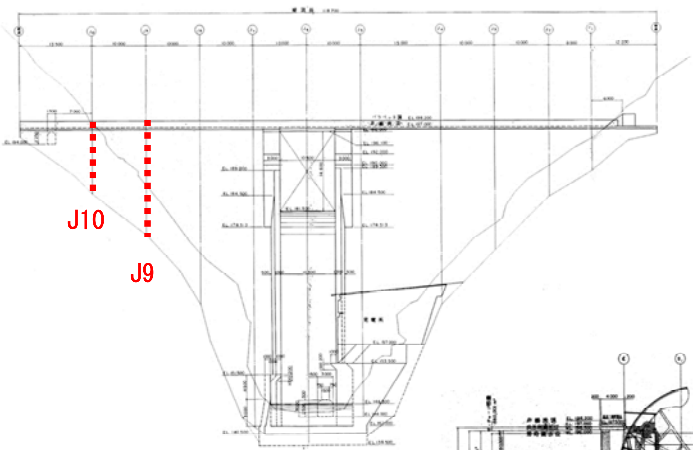


(a) Longitudinal section

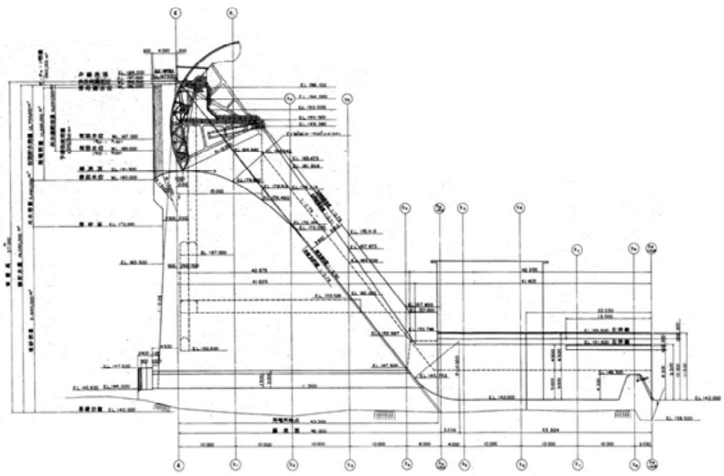


(b) Cross section

Figure 3.3.4.11 Kamuro dam



(a) Longitudinal section



(b) Cross section

Figure 3.3.4.12 Takasaka dam

Photo 3.3.4.10 Leakage from the transverse joint (2J3) (Kamuro dam)

Photo 3.3.4.11 Leakage from the transverse joint (J9) (Takasaka dam)

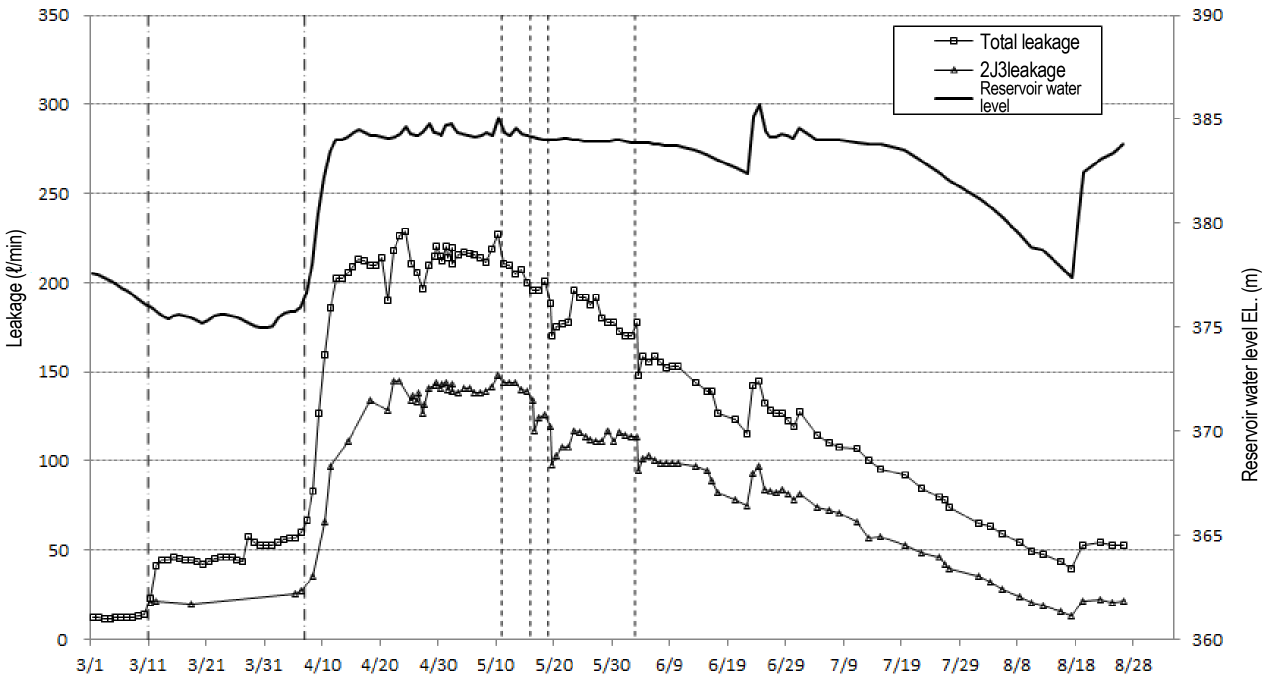


Figure 3.3.4.13 Time history of leakage at Kamuro dam

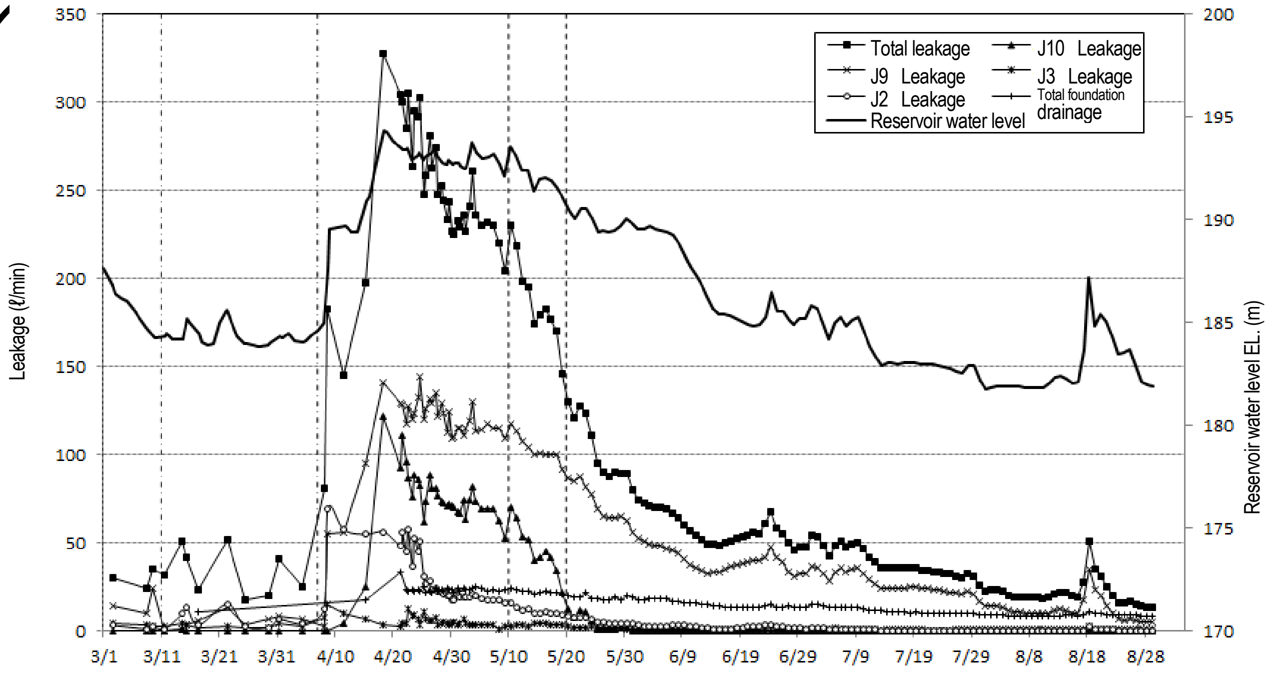


Figure 3.3.4.14 Time history of leakage at Takasaka dam

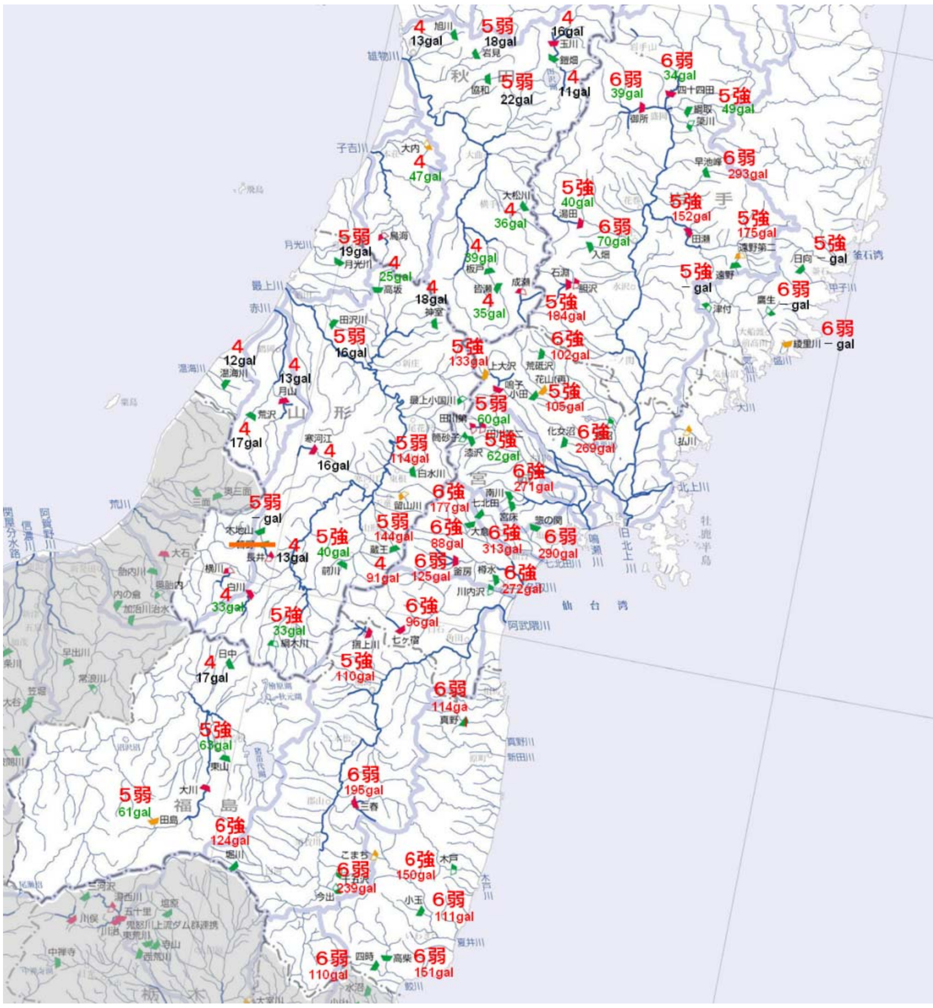


Figure 3.3.4.15 Distribution of seismic intensity around dams and peak acceleration at dams on the Great East Japan Earthquake

(4) Observed seismic motions

Table 3.3.4.4 Peak horizontal acceleration at dam foundation
(Records of 100gal or higher at dams managed by MLIT (under the jurisdiction of MLIT)

Dam	Manager (Prefecture)	Type	Height (m)	Maximum acceleration (Foundation) (gal)	Dam	Manager (Prefecture)	Type	Height (m)	Maximum acceleration (Foundation) (gal)
Miyatoko dam	Pref. Miyagi	G	48	313	Tomeyamagawa dam	Pref. Yamagata	G	46.0	144
Hayachine dam	Pref. Iwate	G	73.5	293	Jyuo dam	Pref. Ibaraki	G	48.6	139
Hananuki dam	Pref. Ibaraki	G	45.3	290	Koyama Dam	Pref. Ibaraki	G	65.0	334
Sohnoseki dam	Pref. Miyagi	G	23.5	290	Kamiosawa dam	Pref. Miyagi	E	19	133
Tarumizu dam	Pref. Miyagi	R	43	272	Kamafusa dam	Tohoku Regional Development Bureau (Miyagi)	G	45.5	125
Minamikawa dam	Pref. Miyagi	G	46	271	Horikawa dam	Pref. Fukushima	R	57	124
Kejonuma dam	Pref. Miyagi	E	24	269	Shiramizugawa dam	Pref. Yamagata	G	54.5	114
Komachi dam	Pref. Fukushima	G	37	239	Mano dam	Pref. Fukushima	G	69	114
Miharu dam	Tohoku Regional Development Bureau (Fukushima)	G	65	195	Shiobara dam	Pref. Tochigi	G	60.0	112
Ishibushi dam	Tohoku Regional Development Bureau (Iwate)	CFRD	53	184**	Kodama dam	Pref. Fukushima	G	102	111
Mizunuma dam	Pref. Ibaraki	G	33.7	183	Surikamigawa dam	Tohoku Regional Development Bureau (Fukushima)	R	105	110
Nanakita dam	Pref. Miyagi	R	74	177	Hanayama dam	Pref. Miyagi	G	47.8	110
Tohno dai-ni dam	Pref. Iwate	G	23.1	175	Yoji dam	Pref. Fukushima	R	83.5	110
Fujiigawa dam	Pref. Ibaraki	G	37.5	174	Oda dam	Pref. Miyagi	R	43.5	105
Takashiba dam	Pref. Fukushima	G	59.5	151	Aratozawa dam	Pref. Miyagi	R	74.4	102
Kido dam	Pref. Fukushima	G	93.5	150					

*G: Concrete gravity dam, R: Rockfill dam (earth core), CFRD: Concrete faced rockfill dam, E: Earthfill dam
**Value for Ishibuchi dam at the hill of the right bank (not bedrock)

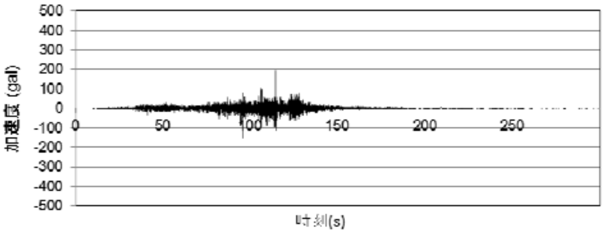
1) Peak acceleration

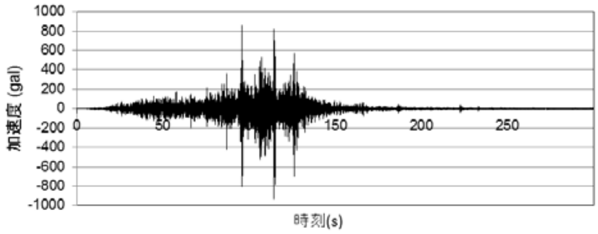
Figure 3.3.4.15 shows the peak acceleration recorded/reported by the seismometers installed at the foundation of the dams and inspection galleries in the low altitude area. The number of dams under the jurisdiction of MLIT which registered a horizontal acceleration of 100gal or higher was 23 dams (four dams under direct control of MLIT and 19 dams under the jurisdiction control of MLIT) (Table 3.3.4.4).

Although the magnitude of the 3.11 earthquake was extremely large, since each dam was located relatively far from the source fault of the earthquake, the peak acceleration was not particularly large compared with records observed at dams near the epicenter of the past inland active fault earthquakes.

3) Acceleration time history

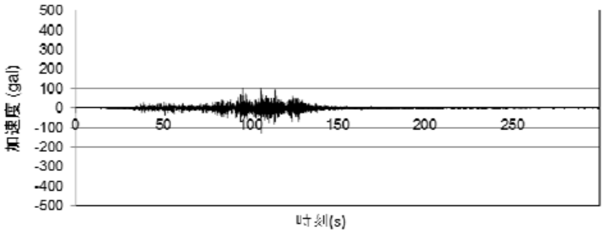
Acceleration time history observed at the Miharu dam (concrete gravity dam) and Surikamigawa dam (rockfill dam) are shown in Figure 3.3.4.16 and Figure 3.3.4.17, respectively. At Miharu dam, peak accelerations of 194.8 gal and 932.4 gal were recorded at the dam foundation and at the crest, respectively. Likewise, at Surikamigawa dam, peak accelerations of 110.3 gal and 473.9 gal were recorded at the dam foundation and at the crest, respectively. As Figure 3.3.4.16 and Figure 3.3.4.17 indicate, the duration of the seismic motion of the 3.11 earthquake is characteristically very long.

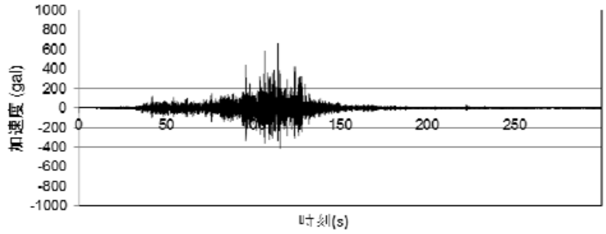




Upstream and downstream directions
(Maximum acceleration: 194.8gal)

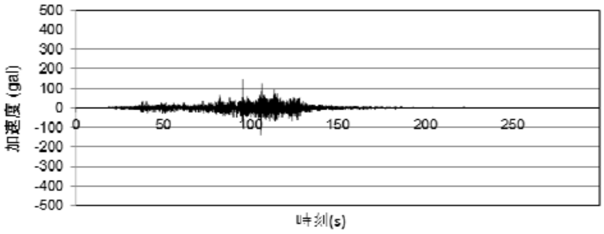
Upstream and downstream directions
(Maximum acceleration: 932.4gal)

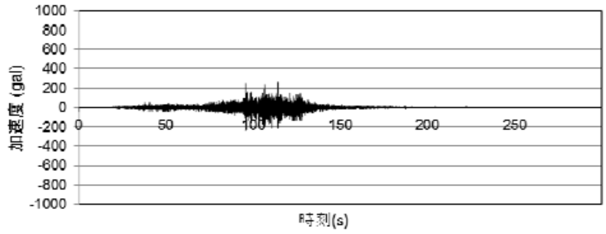




Dam axis direction
(Maximum acceleration: 130.8gal)

Dam axis direction
(Maximum acceleration: 661.2gal)





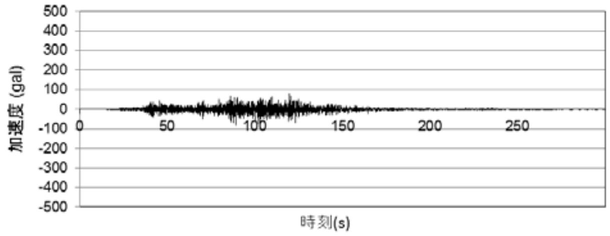
Vertical direction
(Maximum acceleration: 146.9gal)

Vertical direction
(Maximum acceleration: 262.5gal)

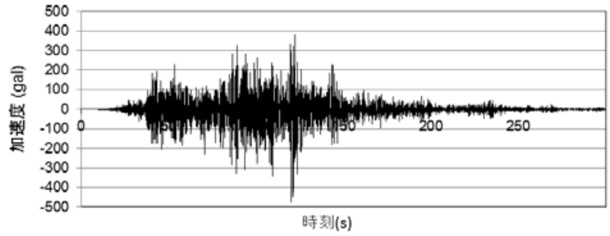
(a) Dam foundation

(b) Dam crest

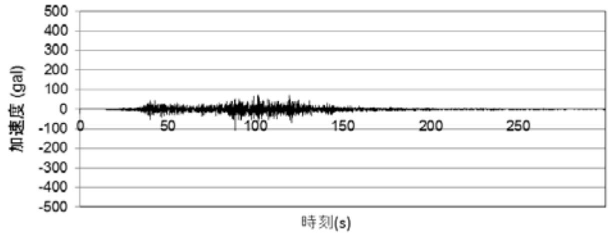
Figure 3.3.4.16 Acceleration time history observed at Miharu dam



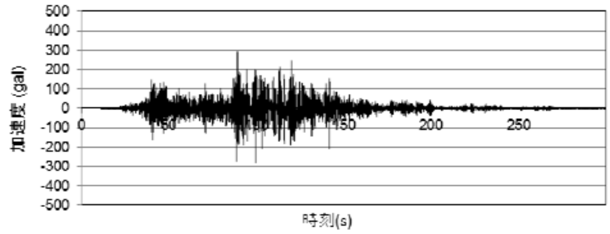
Upstream and downstream directions
(Maximum acceleration: 81.6gal)



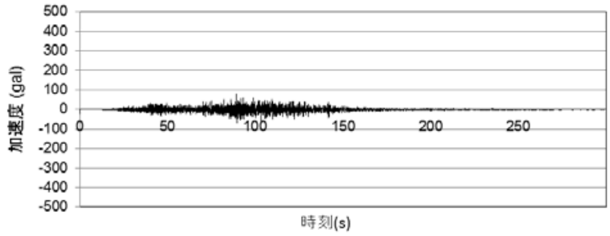
Upstream and downstream directions
(Maximum acceleration: 473.9gal)



Dam axis direction
(Maximum acceleration: 110.3gal)

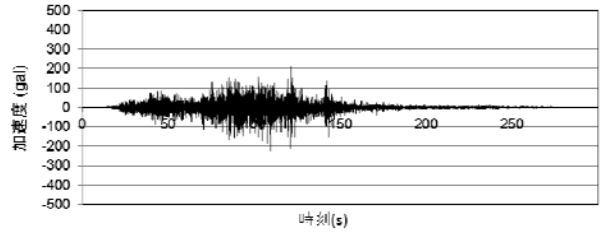


Dam axis direction
(Maximum acceleration: 294.1gal)



Vertical direction
(Maximum acceleration: 79.8gal)

(a) Dam foundation



Vertical direction
(Maximum acceleration: 224.8gal)

(b) Dam crest

Figure 3.3.4.17 Acceleration time history observed at Surikamigawa dam

(5) Conclusion

On the Great East Japan Earthquake of March 2011, special safety inspections were carried out at a number of dams in East Japan. As a result, no damage severe enough to threaten safety was found at any of the dams inspected. Although further investigation and analysis are needed to elucidate the factors contributing to this, it appears to be because almost all dams in Japan, except earthfill dams, are constructed on solid bedrock, and because the source fault of the earthquake was relatively far from the dams so the seismic motion was not felt as strongly as the seismic motion observed at dams close to the epicenters of the inland active fault earthquakes in the past.

An extremely long duration of seismic motion can be noted as a characteristic of the 3.11 earthquake. In this respect, further elaborated/detailed analysis and evaluation are warranted, together with more collection and analysis of records of seismic motion, so that findings would be reflected in the safety and management of dams and the ongoing evaluations of the seismic performance of dams.

References

1) Public Works Research Institute, National Institute for Land and Infrastructure Management: Quick Report on Damage to Infrastructures by the 2011 off the Pacific coast of Tohoku Earthquake, Technical Note of National Institute for Land and

Infrastructure Management, (no.646), Technical Note of Public Works Research Institute, (no.4202), pp.342-366, 2011

2) YAMAGUCHI, Yoshikazu: Evaluation of Seismic Behavior of Dams (Safety) at The Great East Japan Earthquake and Characteristics of the Observed Earthquake Ground Motions, Japan Dam Engineering Center, lecture on Measures to Strengthen Flood Control Facilities against Earthquake and Tsunami of the Great East Japan Earthquake" (at Water Resources Agency, Ministry of Economic Affairs, Republic of China), 2012

3.3.5 Shore and Coast

(1) Method of setting design tsunami water level

1) Background

The Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons from the "2011 off the Pacific Coast of Tohoku Earthquake" of the Central Disaster Prevention Council (hereinafter referred to as the Technical Investigation Committee) released a report[1). The report includes the following recommendations: Future tsunami countermeasures should be prepared based on the simulations for the following two levels of tsunamis as follows: First, for the simulations for preparing the integrated disaster prevention measures focusing on the protection of human life and residents' properties, the worst-case maximum level of tsunami (conventionally called "the level-two tsunami"), should be applied – although its occurrence frequency is low, it will cause disastrous damages once it occurs. Second, for the simulations for designing coastal protection facilities to prevent tsunamis from inundating inlands, the tsunamis conventionally called "the level-one tsunami" should be applied – although their heights are lower than the worst-case maximum level tsunami, they occur more frequently than the worst-case tsunamis and cause heavy damages. In addition, the Technical Investigation Committee recommended that, for such purposes in addition to the protection of human life as the protection of residents' properties, the preservation of regional economic activities, and the security of production sites, the coastal protection facilities should be designed and developed for the relatively more frequent tsunamis. The conventional facilities have functioned effectively for the prevention of damages that would be caused by the tsunamis with a height less than a certain value. Therefore, the recommendation is reasonable because, from the viewpoints of costs, environment, and coast utilization, it would be unrealistic to raise the design tsunami heights extremely to prepare for the worst-case maximum tsunami. In addition, the Technical Investigation Committee made comments on the necessity of preparing the methods for the determination of the height of the dike that will be reconstructed, because the reconstruction of damaged dikes is the very first step of recovery for the disaster affected areas, so such a method has to be prepared quickly so as to accelerate the recovery.

2) Official notice on setting design tsunami water level

On receiving the abovementioned report, the NILIM, in collaboration with the Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, surveyed and prepared the methods for determining the applicable design tsunami—typical and relatively frequent tsunamis—and the required dike height corresponding to such design tsunami height; the results of the survey were announced as an official notice[2)] dated July 8. Particularly, the NILIM, during the process of identifying the target coasts and investigating the past tsunami traces, collaborated with the Tohoku Regional Development Bureau. In addition, the NILIM, prior to the announcement of the abovementioned notice, collected comments from academic experts at the 2nd meeting of the "Committee for Technical Investigation on Coastal Countermeasures for Tsunamis."

The notice[2)] specified the procedure of determining the design tsunami water level and dike crown height as follows:

・Divide the coastline into subdivisions (sub-coasts) in each of which the tsunami force can be assumed uniform, according to "geographical conditions such as bay shapes or hillside connections" and "experienced tsunami heights of the past tsunamis recorded in historic documents or archival damage records and the tsunami heights obtained through simulations". (Figure 3.3.5.1)

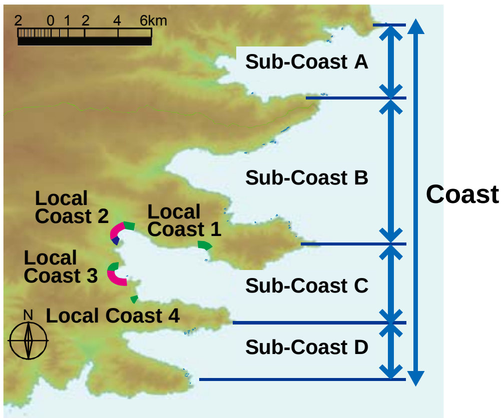


Figure 3.3.5.1 Example of the Subdivision of Coastline into Sub-coasts

・Select, as a target tsunami group, a group of typical tsunamis estimated to have occurred generally with a certain frequency (once in several decades or centuries) which can be used for setting the design tsunami water level through analyzing the past tsunami trace heights and taking into consideration the estimated tsunami water level caused by the concerned possible earthquakes (Figure 3.3.5.2).

When viewing figure 3.3.5.2, note the following:

Tsunami trace heights must be represented in T. P. value (height above the Tokyo Peil);

Tsunami trace investigations must be conducted according to the site investigation manual[3]) prepared by the Coastal Engineering Committee, Japan Society of Civil Engineers or the equivalent, or using the height measurements following the abovementioned manual. In the case where no other measurements are available than those obtained through other procedures than the measurements described above, choose reliable measurements such as those certified as site investigation measurements by the 2011 Tohoku Earthquake Tsunami Joint Survey Group[4]).

Collect tsunami traces as close to a coastline as possible.

In the case where a tsunami trace height is missing which needs to be compensated for, use a measurement presented in publications such as "Nihon Higai Tsunami Sou-Ran[5]) (in Japanese) (comprehensive list and description of tsunamis and damages in Japan) or the official investigation reports by the regional development bureaus, the local governments, and the Japan Meteorological Agency.

In the case where, although an earthquake occurrence was recorded in historical documents or archives, no tsunami trace height measurement is available, estimate the height as accurately as possible by simulations within practical limitations; note that in this case the inundated areas must be clearly grasped using the tsunami sediment investigation reports.

・Calculate a tsunami water level distribution for target tsunami group through simulations under the boundary condition that the progression of tsunami inundation stops at the dike locations. Based on the results of the simulations, discuss among the neighboring coast administration agencies. Finally, set the design tsunami water levels for the tsunamis listed in the target tsunami group. Principally, a sub-coast can have only one design tsunami water level. However, in the case where the design tsunami water level can be judged significantly differently along its coastline, it is allowable to subdivide the sub-coast to assign different design tsunami water levels to the subdivisions. Note that in such a case, reasons for dividing the sub-coast must be clearly stated.

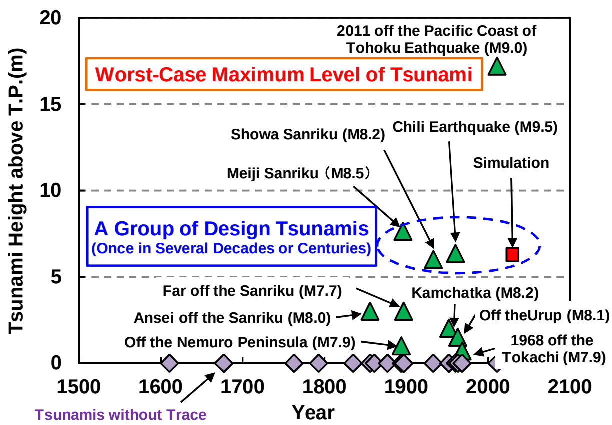


Figure 3.3.5.2 Example of Classification of Tsunami Heights Caused by the Past Earthquakes (in Sub-Coast A)

・Coastal managers are in charge of the determination of crown heights of dikes. The determination of a dike crown height should be in compliance with the conventional specification that have determined to satisfy the requirements for a dike to protect against tsunami or high-tide inundation or to reduce overtopping waves. A crown height must exceed the value of the design tsunami water level or "design high-tide level plus run-up height of the design wave" or "the sufficient height for effectively reducing the volume of water overtopped by the design wave at the design tidal level" considering the freeboard determined by the backland conditions. This determination should be made through a synthetic judgment by taking into considerations the diversified functions of the coast, environmental protection, economic efficiency, surrounding landscape, economic efficiency, maintenance convenience, construction convenience, and public usage.

3) Difference from the conventional method

The three prefectures having quake-hit areas in their lands—Iwate, Miyagi, and Fukushima, have finished work following the abovementioned procedure, and completed the setting of design tsunami water levels and planned dike crown heights. Note that the new setting procedure of design tsunami water level has three significant differences from the conventional method as follows:

First, earthquake occurrence frequency is clearly taken into consideration in the new method. While the conventional method uses, as a design quake, the maximum quake in the past or well-known quakes, the new method adopts the additional process of choosing the target tsunami group explicitly adopting the quake occurrence frequency—for example, once in several decades to several centuries.

Second, while, in some cases with the conventional method, tsunami trace heights were used for design tsunami water levels, the new method sets design tsunami water levels based on the results of simulations where dikes are taken into consideration—the progress in simulation technologies has enabled such techniques. This means that the new method explicitly takes into consideration water rises caused by dikes.

Third, the concept of sub-coasts is adopted; this enables setting design forces according to the geographical conditions, in contrast with the conventional method where, in some cases, coastal managers set design forces on a coast-by-coast basis.

(2) Analyses of dike damages

1) Background

In the Great East Japan Earthquake (hereinafter referred to as the Earthquake), many coast protection facilities suffered damages. The Central Disaster Prevention Council[1)], in order to cope with such situations, presented the following recommendation: "the government should promote the development of technologies that enable the construction of such structures that, even in a situation where a tsunami higher than the design tsunami height hits, resiliently maintain their functions, and develop facilities adopting such technologies." "To resiliently maintain their functions" in that context means to prolong as long as possible the time to destruction or collapse of dikes, to reduce as much as possible the likelihood of full destruction in order to preserve time for evacuation, or to reduce the damages a second tsunami would give, and to enable prompt recovery; this would help reduce the risk of second disasters or costs for recovery[6)]. Following this recommendation, the River Department, NILIM, has started analyses of three-surface armored coastal dikes (hereinafter referred to as coastal dikes) among the coastal protection facilities located in the prefectures from Aomori to Chiba, focusing on their damage situations and the relations between their structural characteristics and tsunami forces. The data used for analysis was collected by the Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism and the Coast Division, NILIM, with the cooperation of the concerned government ministries and the disaster-affected prefectures for the purpose of discussions at the "Committee for Technical Investigation on Coastal Countermeasures for Tsunamis."

Coastal dikes, generally except for the cases where sufficient construction spaces are unavailable, have a three-surface armored structure consisting of a body made of piled-up soil, a concrete-armored seaward slope, a concrete-armored crown, and a concrete-armored landward slope (Refer to Figure 3.3.5.3). The site investigations conducted shortly after the

Earthquake found many cases where the landward slope toe was scoured (Photo 3.3.5.1); this suggests that the loss of base due to scouring led to the washout of landward slope armoring soil, the washout of body soil, and the final collapse of coastal dikes (Figure 3.3.5.4).

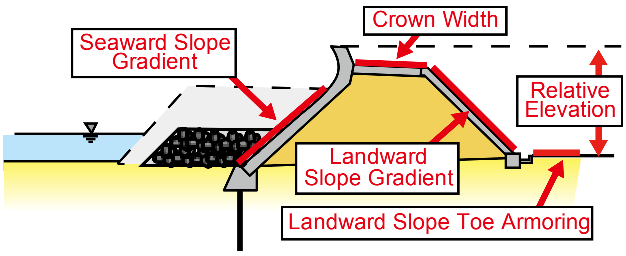


Figure 3.3.5.3 Basic Structure of Three-Surface Armored Coastal dike

2) Analysis procedure of dike damages

a) Collection of damage cases and their damage evaluation

In terms of the identification of damaged portions, coastal protection facilities need to be divided into subdivisions (shown in Figure 3.3.5.5 as "sections") so that each section has a single uniform structure, because, even if a facility is administered as a single administration unit, it would consist of different structures in some cases. During the investigation, facility structural parameters such as crown heights and slope gradients were obtained from facility data book, complete collapse length, number of complete collapses, number of units of complete collapse, partial collapse length, and overtopping water depth. These parameters were obtained by following manners.

The "number of units of complete collapse" is counted as follows: divide again a section of a facility of a uniform structure into small 100 m-units; then, count the number of units that suffered complete collapse;

The number of units of complete collapse was adopted as a supplemental index representing the severity of damage caused by a leading wave, for the reason that the complete collapse length can overestimate the severity in the case where backwashes caused additional damages;

The unit length of 100 m was adopted for the reason that the preliminary surveys on the complete collapse of 156 sites in total showed the following: the median value of the collapse lengths was 44.6 meters; 73.7 percent of the collapse lengths were less than 100 meters.

The grade of collapse—complete or partial—of the investigated facilities was judged as follows:

In the case where the dike armoring and base soil were completely lost, the dike was judged to be in a state of "complete collapse:"

In the case (as shown in photo 3.5.5.2) where the armoring soil was partially lost, or a part of the base soil remained even though the dike armoring was completely lost, the dike was judged to be in a state of "partial collapse."

The "overtopping water depth" was obtained by subtracting dike crown height after ground subsidence related to the Earthquake from the tsunami inundation height recorded in the preliminary report dated August 26, 2011,[4] prepared by the 2011 Tohoku Earthquake Tsunami Joint Survey Group.

Photo 3.3.5.1 Partially Collapsed Three-Surface Armored Coastal Dike and Scouring Situation at the Landward Slope Toe (Kabasaki Coast, Iwanuma City, Miyagi Prefecture)

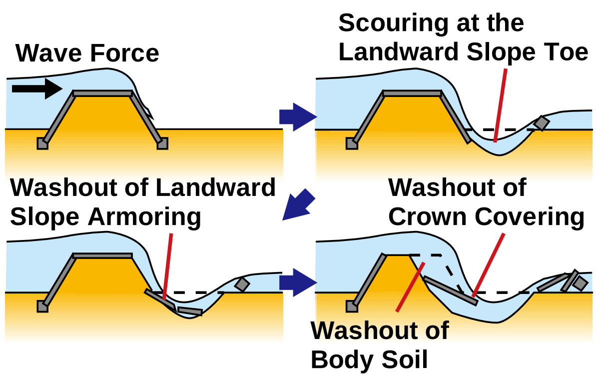


Figure 3.3.5.4 Collapsing Process starting at

Landward Slope Toe

b) Measurement of complete collapse length using satellite or aerial photos

Precise damage data were obtained by analyzing the aerial photos taken shortly after the Earthquake by the Geospatial Information Authority of Japan and Google Earth satellite images taken in April 2011. The reports and measurements by the coastal manager located in each affected prefecture were reinvestigated. And armoring width, complete or partial collapse length, the number of collapsed units and their grade (complete or partial) were measured in the case where the landward toe of the structure was covered. The partially and complete collapse lengths were re-measured by the authors in a unified way because the coastal managers used different criteria for the states of collapse (complete or partial).

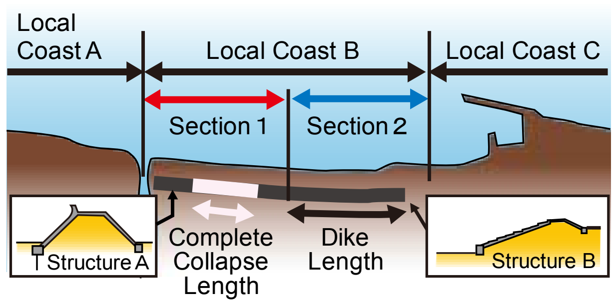


Figure 3.3.5.5 Schematic Diagram of the Determination of Sections

Photo 3.3.5.2 Completely Collapsed Coastal Dike (Ninokura Coast, Iwanuma City, Miyagi Prefecture)

c) Analysis on structure-based difference in damage

Focusing on the five dike structural characteristics–type of landward slope toe armoring, seaward slope gradient, relative elevation of dike crown from backland ground, and crown width, the differences among the damage states were analyzed as follows:

· Two-group comparisons

With regard to each characteristic element, the statistical relation of the overtopping water depth and the calculated collapse length ratio (the ratio of collapse length to the total facility length) was analyzed between the two groups, each of which has an almost equivalent number of members. Note that the data samples were arranged according to Table 3.3.5.1 so that the non-target characteristics have almost an equivalent number of members, except for the crown width which had an insufficient value distribution to be divided into two groups. Two-group comparisons were not applied to crown width, but only the multivariable analysis, described later, was applied.

Table 3.3.5.1 Group-Division Criteria

Target Characteristics	Non-target Characteristics				
	Landward Slope Toe Armoring	Seaward Slope Gradient	Landward Slope Gradient	Relative Elevation	Crown Width
Landward Slope Toe Armoring	N. A.	Less than 50 %	Less than 50 %	More than 3 m	All
Seaward Slope Gradient	None	N. A.	Less than 50 %	More than 3 m	All
Landward Slope Gradient	None	Less than 50 %	N. A.	More than 3 m	All
Relative Elevation	None	Less than 50 %	Less than 50 %	N. A.	All

· Multivariable logistic regression analysis

Multivariable analyses including all five structural characteristics were conducted in order to compensate for possible false conclusions by the two-group comparisons obtained when a sufficient number of sample data was unavailable as a result of division of data into uniform-sized groups.

For the analyses, the following assumptions were set:

A dike has a complete collapse probability varying with the overtopping fluid force determined by the dike structure;

For each 100 m-unit, a complete collapse occurs independently of adjacent units.

A complete collapse probability of a section is defined as the ratio of the number of completely collapsed units to the number of total units included in the section.

The distribution of the complete collapse probability

P_B is binomial because the event of collapse by outer forces has two-state values of "complete collapsed" and "not collapsed," expressed by the multiple logistic model (1),

$$P_B = \frac{1}{1 + e^{-(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n)}} \qquad (1)$$

Where n denotes the number of elements used in the analysis, variables X_1 to X_n denote explanatory variables representing the structural characteristic values, α denotes a constant, and β_1 to β_n denote coefficients.

The multiple logistic model, which is one of the multiple logistic analysis methods, frequently used in the medical field for the determination of disease causes, was applied to the probabilistic model-building of soil disaster occurrence by Kawagoe, et.al.[7] In the analysis, by the maximum likelihood estimation method, the coefficients in the expression (1) were determined, and the influence of each structural characteristic element was evaluated.

3) Result of damage analysis

a) General features

In order to understand overall damage data characteristics, Figure 3.3.5.7 (a) was drawn using the measurements of all of the dikes that suffered overtopping, where the collapse length ratios (ratio of the total collapse lengths to the total dike lengths) were shown in relation to the overtopping water depths. Note that the overtopping water depths were grouped into seven categories–less than 2 m, 2 to 4 m, 4 to 6 m, 6 to 8 m, 8 to 12 m, 12 to 16 m, and 16-20 m–and the calculation of the collapse length ratio was conducted within each category. Also note that the number of target sections was 225, the lengths of the sections were distributed between 3 m to 3,756 m, and the total length of all sub-coasts was 94.6 km.

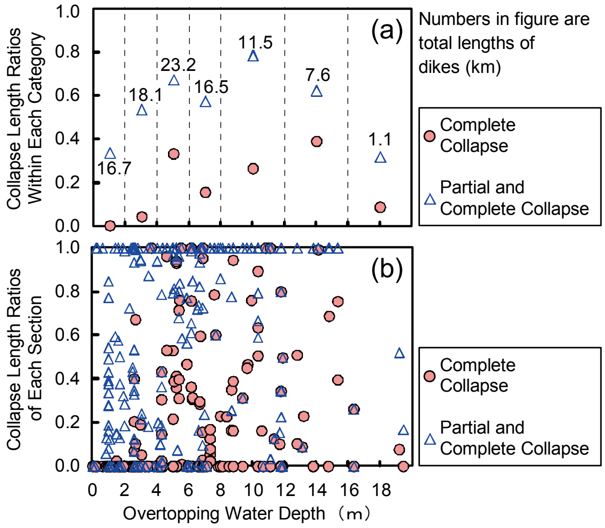


Figure 3.3.5.6 Relation of Collapse Length Ratio to Overtopping Water Depth

It was confirmed that, except for the water depth category of 16 to 20 m where a sufficient number of data was unavailable, the collapse length ratio generally increases as the overtopping water depth grows. However, Figure 3.3.5.6 (b), where the uncategorized data–raw data– is plotted, shows that the collapse length ratios are widely distributed even for a certain overtopping water depth; for example, while in a section having an overtopping water depth of 3 m, the complete collapse length ratio reached 100 percent–all the dikes in the section were completely collapsed–in other sections where the overtopping water depths were over 10 m, no dikes were collapsed. Such a phenomenon would be the result of the involvement of a variety of unknown factors such as the duration time of overtopping, geographical conditions of backlands, or micro-structures of facilities; in addition, the collapse itself is a stochastic event. Therefore, for grasping the general (averaged) trends, the data processing as shown in Figure 3.3.5.6 (a) is helpful. On the other hand, the fluctuation magnitude of data on damage severity is important information for disaster countermeasures planning; therefore, such a graph as shown in Figure 3.3.5.6 (b) will be helpful and should be referred to during practical operations.

b) Results of two-group comparisons for structural characteristics

·Landward slope toe armoring

The investigation of 63 sections with a total length of 35.4 km focusing on the landward slope toe armoring suggested that, for an overtopping water depth of less than 12 m, toe armoring worked well to lower the complete collapse length ratio, as shown in Figure 3.3.5.6 (a). Investigations on each section showed a similar tendency (Refer to Figure 3.3.5.7 (b)).

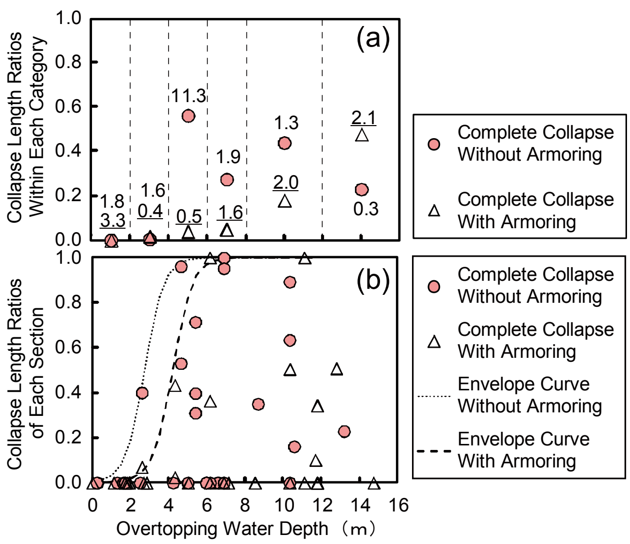


Figure 3.3.5.7 Relation of Landward Slope Toe Armoring to Damage Severity

Numbers in figure (a) are total lengths of dikes (km) without armoring at the landward slope toe, and underlined numbers are those of the other dikes.

·Seaward slope gradient

The investigation on 51 sections with a total length of 35.4 km suggested that, at an overtopping water depth of 2 to 12 meters, the collapse length ratio, in the cases of a seaward slope gradient gentler than 50 percent, was lower than that in the cases of a gradient steeper than 50 percent (Figure 3.3.5.8). However, focusing on the partial collapse cases–where dikes suffered damages but still stood–an inverse tendency as shown in Figure 3.3.5.9 was found where the collapse length ratio, in the cases of a gradient gentler than 50 percent, was higher.

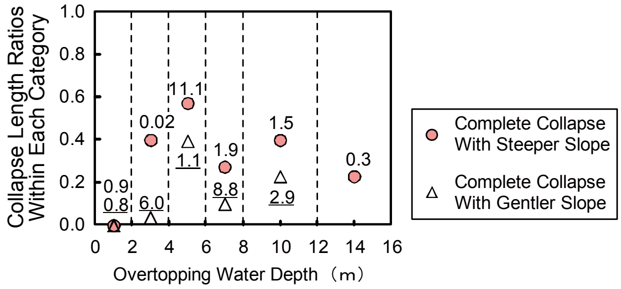


Figure 3.3.5.8 Relation of Seaward Slope Gradient to Damage Severity (complete collapse cases)

Numbers in figure (a) are total lengths of dikes (km) with seaward slope gradient steeper than 50 percent [Gradient 1 : n, n = 0.90 ± 0.40 (mean ± s.d.), N = 25], and underlined numbers are those of the other dikes [Gradient 1 : n, n = 2.52 ± 0.92 (mean ± s.d.), N = 26].

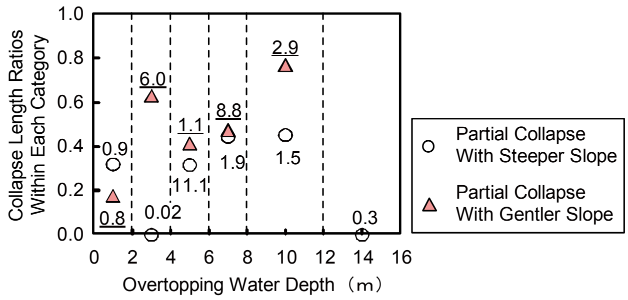


Figure 3.3.5.9 Relation of Seaward Slope Gradient to Damage Severity (partial collapse cases)

Numbers in figure (a) are total lengths of dikes (km) with seaward slope gradient steeper than 50 percent [Gradient 1 : n, n = 0.90 ± 0.40 (mean ± s.d.), N = 25], and underlined numbers are those of the other dikes [Gradient 1 : n, n = 2.52 ± 0.92 (mean ± s.d.), N = 26].

·Landward slope gradient

The investigation on 28 sections with a total length of 16.8 km, where only two groups–over-66.7-percent group and under-66.7-percent group–were compared because of the small number of available samples, showed that, at an overtopping water depth of 4 to 12 meters, the under-66.7-percent group had a lower complete collapse length ratio (Refer to Figure 3.3.5.10). However, the investigations focusing on partial collapse cases showed that the under-66.7-percent group had a higher collapse length ratio; a similar inverse tendency of collapse length ratio to the tendency found in the cases of seaward slope gradient was observed–the relation of the slope gradient to the collapse length ratio in the complete collapse cases shows an inverse tendency in comparison with the tendency in the partial collapse cases (Figure 3.3.5.11).

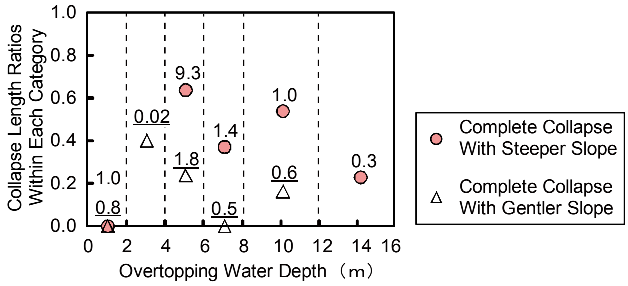


Figure 3.3.5.10 Relation of Landward Slope Gradient to Damage Severity (complete collapse cases)

Numbers in figure (a) are total lengths of dikes (km) with seaward slope gradient steeper than 66.7 percent [Gradient 1: n, n = 1.07 ± 0.09 (mean ± s.d.), N = 15], and underlined numbers are those of the other dikes [Gradient 1 : n, n = 1.55 ± 0.14 (mean ± s.d.), N = 11].

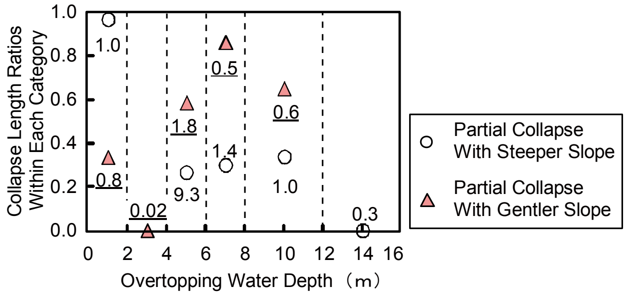


Figure 3.3.5.11 Relation of Landward Slope Gradient to Damage Severity (partial collapse cases)

Numbers in figure (a) are total lengths of dikes (km) with seaward slope gradient steeper than 66.7 percent [Gradient 1 : n, n = 1.07 ± 0.09 (mean ± s.d.), N = 15], and underlined numbers are those of the other dikes [Gradient 1 : n, n = 1.55 ± 0.14 (mean ± s.d.), N = 11].

·Relative elevation

The investigations on 49 sections with a total length of 7.9 km, focusing on the differences found in the relative elevation of the dike crown from backland ground, suggested as shown in Figure 3.3.5.12 that, at an overtopping water depth of 2 to 12 meters, the complete collapse length ratio in the cases of over-3-meter relative elevation was higher than the ratio in the cases of under-3-meter relative elevation.

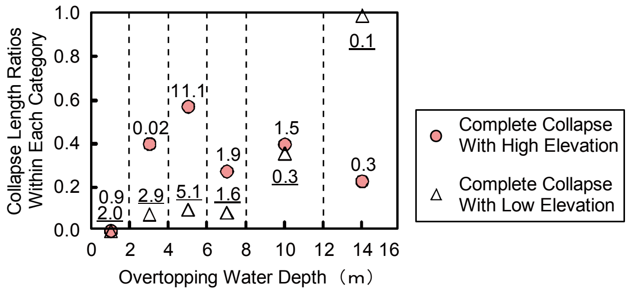


Figure 3.3.5.12 Relations of Relative Elevation from Backland Ground to Damage Severity

Numbers in figure (a) are total lengths of dikes (km) of relative elevation from backland ground over 3m [Relative elevation: 5.17 ± 1.79 (mean ± s.d.), N = 25], and underlined numbers are those of the other dikes [Relative elevation: 1.95 ± 0.71 (mean ± s.d.), N = 34].

c) Results of multivariable analysis

The multiple logistic regression analyses on the 170 sections with a total length of 79.3 km suggested that overtopping water depth, landward slope toe armoring width, seaward slope gradient, and landward slope gradient significantly affect the complete collapse probability (Table 3.3.5.2). Note that, although the relative elevation is not statistically estimated to be significant, its *p*-value is close to 0.05. The *α* coefficient is -0.568.

The odds ratio shown in Table 3.3.5.2 is the sensitivity of the complete collapse probability to an explanatory variable; for example, when the overtopping water depth has an odds ratio of 1.3, a one-meter increase in the overtopping water depth makes the probability increase to 1.3 times the original probability. A less-than-one explanatory variable's odds value means that the complete collapse probability decreases when the explanatory variable's value increases. As for the overtopping water depth, landward slope toe armoring width, seaward slope gradient, and landward slope gradient, the 95 percent confidence interval for the odds value (95 % CI) does not include 1 in it. Therefore, in terms of odds value, those five characteristic elements significantly affect the complete collapse probability.

Table 3.3.5.2 Result of Multiple Logistic Regression Analysis

Explanatory Variable (mean ± s. d.)	*β* coefficient	*p-value*	Standardized Regression Coefficient	Odds Ratio (95% CI)
Overtopping-water depth (5.8 ± 3.9 m)	0.261	<0.001	1.013	1.30 (1.23-1.37)
Landward-slope toe armoring width (1.6 ± 3.1 m)	-0.264	<0.001	-0.810	0.77 (0.68-0.85)
Seaward-slope gradient 1: n (1.7 ± 1.3)	-0.328	0.004	-0.436	0.72 (0.57-0.90)
Landward-slope gradient 1: n (1.5 ± 0.4)	-0.982	<0.001	-0.403	0.37 (0.23-0.61)
Relative elevation (3.5 ± 1.9 m)	0.096	0.075	0.183	1.10 (0.99-1.22)

Crown width m (3.6 ± 2.3 m)	0.019	0.830	0.044	1.02 (0.84-1.18)

The β coefficients for landward slope toe armoring width, seaward slope gradient, and landward slope gradient have negative values; this means that the wider the landward slope toe armoring width is, the gentler the seaward slope, or that a gentler landward slope leads to a lower complete collapse probability, consistent with the results of the two-group comparisons for each structural characteristic element.

The standard regression coefficient is a compensated β coefficient normalized by the standard deviation of the explanatory variable for the purpose of comparison of the explanatory variable's influence power. In terms of overtopping water depth, landward slope toe armoring width, seaward slope gradient, or landward slope gradient, the absolute value for each of them grows in that order. This means that landward slope toe armoring width has the most powerful influence on the complete collapse probability among the five structural characteristic elements.

4) Review and summary

a) Landward slope toe armoring: positive effect

The toe armoring width of 70 percent of the toe armoring treated in the two-group comparisons is narrower than 4 meters because all of the armored toes, without regard for their width, were included in the "armored toe group". Although such width is very narrow compared to the width of the scouring caused by overtopping water, the result of two group analysis suggested the effectiveness of toe armoring. The toe armoring is estimated to have pushed the scoured points far from the dike bodies. Therefore, toe armored dikes are stronger even if their toes are armored in a very limited way.

The results of the multivariable analysis indicated that landward slope toe armoring width is most effective among the structural elements. This result was consistent with the hypothesis that the scouring at the landward slope toe triggers the destruction of the dike. Countermeasures for scouring at the landward slope toe are required with higher priority in order to make dikes resilient against tsunami overtopping water.

b) Gradients of seaward slope and landward slope

With regards to slope gradients in the complete collapse cases, it is confirmed that a gentler gradient results in a lower collapse length ratio as for either of the seaward slope or landward slope. However, this tendency is reversed with regard to the partial collapse cases, a gentler gradient leads to a higher collapse length ratio. This suggests that a gentler gradient did not directly reduce the tsunami force. A gentler slope gradient is generally found in large-sized dikes; hence, the gentler slope effect could be a secondary one occurring by such a reason that a larger dike needs a longer time to completely collapse and remains in a partially destructed state.

With regard to slope armoring, the slopes with a gradient steeper than 50 percent are generally armored with a flat concrete coating or concrete slope frame, the slopes with a gradient gentler than 50 percent are generally armored with coastal protection blocks that are not required to resist the hydrodynamic force caused by tsunami overtopping water. Such blocks could easily be removed due to insufficient weight or unevenness and cause partial collapse of the dike. In addition, the behavior of overtopping water could be heavily influenced by the slope gradient. In the case of a seaward slope with a gradient steeper than a certain value, water splashing occurs, and in the case of an almost vertical landward slope, tsunami water overtops the dike crown and goes off to have almost no contact with the slope. The influence of the slope gradient on tsunami water's behavior is, as described above, so complex that the slope gradient should be determined after careful investigations through experiments and numerical simulations of overtopping water's behavior.

c) Relative elevation and crown width

Relative elevation, although estimated by the two-group comparisons to have positive influence on collapse probability, was not judged significant by the multivariable analyses. However, it is still a non-negligible element when the confident interval of its p-value or an odds ratio close to the significance level is taken into consideration, because the relative elevation could influence the magnitude of the energy of overtopping water colliding with the landward slope toe.

In terms of crown width, a sufficient variety of data for the estimation of its effect was not available. However, because a wider crown width leads to a bigger body soil allowance against washout, crown width should not be neglected even if no significant results are obtained by multivariable analyses.

d) Evaluation of resilience against overtopping water

Expression (1), when its variable coefficients are substituted by the coefficient obtained through the multivariable analyses, enables the numerical evaluation of different structures. Figure 3.3.5.13, as an example, shows how the complete collapse probability varies as the overtopping water depth grows for several landward slope toe armoring widths. This figure enables the evaluation of how much the widened landward slope toe armoring can reduce the complete collapse probability against a certain overtopping water depth. We can estimate how much the resilience will be increased.

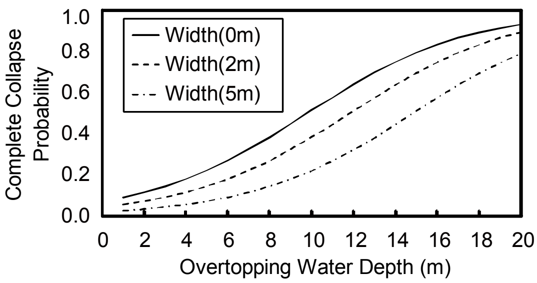


Figure 3.3.5.13 Complete Collapse Probability Curves for landward slope toe covering widths

Application of this model should be limited to the range of the original data of the explanatory variables, because the abovementioned model is derived based on the actual site data affected by a variety of structural conditions. In addition, the handling method of the explanatory variables in the model is not sufficiently validated. However, through a series of model experiments or accumulation of knowledge by numerical simulations, the model is expected to become a practically applicable model.

5) Summary

The analyses on the damages of three-surface armored coastal dikes caused by the Great East Japan Earthquake provided the following results and furthermore strategies for the enhancement of the resilience of facilities against tsunami overtopping water:

a) Tsunami overtopping water depth was confirmed to be the main factor of the complete collapse of dikes. However, large fluctuations were found in the relation between such depth and collapse severity according to coast conditions. It is necessary to grasp the trend in the relation of the maximum damage severity to the depth of inundation water by using an envelope curve for the purpose of disaster prevention.

b) Armoring of landward slope toes and gentler gradients of seaward slopes and landward slopes is confirmed to contribute to the reduction of the probability of complete collapse of dikes. Among them, the armoring of landward slope armoring is the most influential characteristic factor, and should be treated preferentially. On the other hand, the slope gradient of a seaward or landward slope should be carefully considered or treated because it was found to contribute quite inversely according to the collapse situation as complete or partial.

c) Relative elevation can be estimated by the two-group comparisons to contribute to the complete collapse probability. A higher elevation leads to a higher complete collapse probability. On the other hand, the multivariable analyses judged relative elevation to be a non-significant factor in the complete collapse probability.

The “Committee for Technical Investigation on Coastal Countermeasures for Tsunamis,” using available analytic methods within the temporal limitations, has published a report recommending the following three strategies for the construction of resilient structures: (1) Preventing scouring at the landward toe; (2) Preventing the loss of crown armoring, landward slope armoring, or seaward slope armoring, and the washout of body soil: (3) Preventing parapet wall fall-down. In addition, the analyses in this report reconfirmed the importance of landward slope toe protection.

In the structural design considerations of resilient coastal dikes described below, landward slope toe armoring and landward slope armoring will be preferentially discussed following the abovementioned findings.

(3) Study on structures for resilient coastal dikes

1) Background

The "Policies for Recovery of Coastal Levees Damaged by the 2011 Great East Japan Earthquake and Tsunamis"[6] prepared by the "Committee for Technical Investigation on Coastal Countermeasure for Tsunamis" listed the design strategies for resiliently functioning coastal dikes. Application of sufficient thickness of landward slope armoring and armoring on the landward slope toe were proposed to prevent landward slope washout and landward slope toe scouring. The armoring landward slope toe was proved effective by the previously mentioned damage analyses of dikes.

Reconstruction of the damaged dikes will generally be conducted by the affected prefectures, except for some portions of the Southern Coast of Sendai Bay, Miyagi which will be reconstructed by the central government—the Tohoku Regional Development Bureau is in charge of a coast of about 30 km. For such reconstructions, more specific knowledge will be required on technical methods for the realization of resilient structural design ideas previously mentioned. In such situations, the River Department, NILIM, in collaboration with the Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, and the Tohoku Regional Development Bureau, has been working on the study of structural design improvement and the points of concern regarding the installation through model-based experiments and mathematical analyses, and publicized the results in the NILIM Technical Bulletin[8) and 9)] dated May 14 and August 10, 2012.

2) Keys to attaining a structure resilient against overtopping water

The previously mentioned Technical Bulletins revealed the ideas and the key points for the improvement of resilience against scouring and the stability of trapezoidal-shaped dikes; they are the results of studies focusing on the scouring of landward slope toes and the stability of the landward slope armoring (Figure 3.3.5.14).

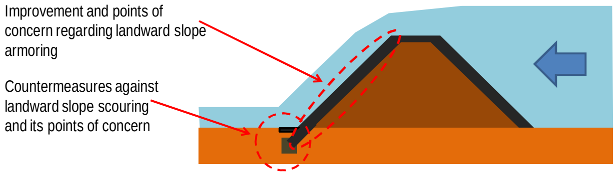


Figure 3.3.5.14 Diagram for the Illustration of Dike Portions of concern

Major points of concern are the following:

•High-speed currents around landward slope or landward slope toe

The tsunami, when overtopping a coastal dike, generates high-speed currents around the landward slope or landward slope toe; in the model-based experiments, a high-speed current of over 10 m/s (scale-converted to actual dike size). Therefore, countermeasures for the scouring and armoring loss at the landward slope toe should be prepared.

·Countermeasures against the scouring of landward slope toe

The model-based experiments revealed such a tendency of the scouring at the landward slope toe that the scouring goes deeper as the overtopping water depth grows. An important countermeasure against such scouring is to firmly protect the toe to have the overtopping water pop up surely so that the scouring point goes far from the dike body; such measure cuts off or retards the progression of the collapsing process—the scouring of the toe leads to the collapse of the dike body; as a result, the resilience of the dike body against the toe scouring is improved and the time to dike collapse will be extended.

Figure 3.3.5.15 illustrates a proposed structure for having the overtopping water pop up at the toe; the key point is to completely alter the flow direction of the water stream coming down along the landward slope to such a direction (e.g. horizontal) that the water flow will not collide with the ground. Note that the model experiments revealed that a relatively flat part which is short compared to the water stream thickness will not sufficiently alter the stream direction, and that, on the other hand, an improved ground soil around the base supports the base, and furthermore the improved part and the base work together in an integrated way as a protection gear altering the stream direction to the horizontal direction, makes the scouring point move far from the toe, and finally lowers the occurrence probability of collapse starting.

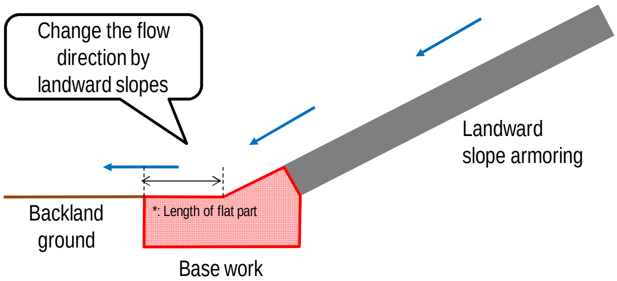


Figure 3.3.5.15 Proposed Improvement on Landward Slope Toe

· Instability of a structure that occurs in a stream due to structure surface unevenness

Bumps made on the landward slope armoring receive a strong stream force and make the armor instable. This suggests that an effective countermeasure is to remove unevenness on the armoring surface, or to adopt such a structure that the unevenness formulates no surfaces that directly receive the stream forces.

The following are the suspected causes of landward slope surface unevenness: loss of soil under landward slope armoring; earthquake motions; and long-term variations such as soil consolidation. However, because it is impossible to maintain a widely extended landward slope surface so flat that the surface can have minimum unevenness when hit by tsunamis, it would be reasonable to improve the surface structure so that, even when the dike body suffers deformations, surface unevenness is suppressed to a minimum, or, even when significant surface unevenness exists, such drag surfaces that directly receive water forces will not be formulated. Figure 3.3.5.16 shows an example: the surface is covered with blocks having rabbets at both ends; they mutually engage in such a way that the upper block prevents the lower block from extruding.

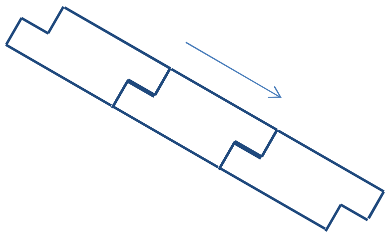


Figure 3.3.5.16 Improved Surface Cover Block

· Generation of lifting forces

Lifting forces are suspected to be generated by the following process:

A tsunami reaching a dike elevates the water level at the seaward side of the dike;

Along with the lift of the water level, the seepage face under the dike body begins to rise;

Air is trapped between the rising seepage face and the armoring. Such air entrapment occurs particularly in the case where the armoring has an impermeable or hermetically sealed structure for the washout prevention purpose, and in addition, even if the seepage face level is low, the pressure of the entrapped air grows because the seepage face moves higher in a short period along with the rising water level on the seaward side. Especially in the case where the original water level—before the tsunami reaches—was high in the ground, the seepage surface reaches the dike bottom relatively faster.

The pressure of the entrapped air rises high enough to prevent the seepage face from further rising, and finally the entrapped air generates a dangerous lifting forces on the armoring.

Such lifting forces make the dike unstable.

Therefore, as shown in the following, the key to the countermeasure against dike instability is to make the armoring have air permeability for the purpose of preventing the entrapped air pressure from reaching a dangerous level by permitting the entrapped air to escape when the seepage face rises.

· Landward side countermeasures against seepage water level

Dike structures should be improved so that the seepage water level is prevented from rising above a certain level, because if the seepage water level around the landward toe is elevated so high, the water going out can carry away the mud—the soil around the toe bottom, stirred up by water, turns into mud—causing damages to the toe. Such kind of a dangerous situation of soil washout, even if the water level remains high for a short period, can be seen according to the soil conditions in the dike body or the base, particularly when the overtopping water level goes down to the dike crown height—right after the water level reaches its maximum.

· Necessity of countermeasures against negative pressures

Negative pressures caused by the overtopping streams when tsunamis overtop the dike, greatly lower than the static pressure or even lower than the atmospheric pressure, can be generated around the landward side dike shoulder where the crown armoring contacts with the landward slope armoring. Countermeasure against such negative pressures are required.

(4) Seismic design of coastal dikes

The "Committee for Technical Investigation on Coastal Countermeasure for Tsunamis" recommended, in the "Policies for Recovery of Coastal Dikes Damaged by the 2011 Great East Japan Earthquake and Tsunamis,"[6)] as follows: coastal dikes should be designed so that the dike dose not suffer severe damage even during ground motions by an earthquake that cause the design tsunami with an intensity of over level-one, and that, after the quake, the dike still has such structural safety and crown height that the dike endures tsunamis hitting the dike after the quake.

For the purpose of supporting the recovery of affected areas, technical consultations such as seismic design reviews or advice on countermeasures have been provided in collaboration with the Soil Mechanics and Dynamics Research Team, Public Works Research Institute.

(5) Landscape assessment commission toward reconstruction of river or coastal structures

In the three disaster-affected prefectures—Iwate, Miyagi, and Fukushima—coastal dikes of 190 km out of 300 km in total were completely or partially collapsed; in Sanriku district, the dike crown height will be raised in accordance with the renewed design tsunami height for dike construction; therefore, in those areas, new dikes, instead of recovery, have to be constructed; however, such new dikes will have larger influences on the landscape than ever.

For the purpose of backing up the activities of assessing landscape changes accompanying the reconstructions of river or coastal structures conducted by the central government or the prefectural governments, the Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism established the "Landscape Assessment Commission toward Reconstruction of River or Coastal Structures" to discuss and specifically prepare methods to consider landscape for the reconstruction of river or coastal structures; those method standards were included in the "Guidebook for Landscape Consideration in the Reconstruction of River or Coastal Structures" and "Annex: Example of Landscape Consideration in Case Study Districts." The following is an example of basic consideration policies: on the dike line arrangement, "Although, because the reconstruction of the facilities stricken by the great earthquake will be conducted as one of the government-supported disaster recovery projects, the principle of reconstruction is the recovery at the original location, it is important to determine the location and line-shape to the possible extent so that the landscape will be visually improved, the effects on the ecosystem will be minimized, and the sustainability will be preserved"; on the surface finishing of slopes, mild rib patterns should be seen on the straight and long dikes (accentuation by rib pattern) to give a "sense of stability" or "sense of being supported."

Following the abovementioned policies, Miyagi

Prefecture and Tohoku Regional Development Bureau established the Environmental Assessment Committee for Recovery of River Mouths and Coastal Facilities in the Miyagi Coast to discuss, clarify, and describe the items of concern, and finally integrate the results into a guidebook. Iwate prefecture has a plan to establish a committee for the consideration of environment and landscape to discuss and prepare prefectural guidelines. The Coast Division, NILIM, has participated in such committees as a member.

<Reference: Landscape Assessment Commission toward Reconstruction of River or Coastal Structures>
(Timeline of discussions)
September 1, 2011: The 1st meeting
September 21, 2011: The 2nd meeting
October 14, 2011: The 3rd meeting

(Members)
Kunihiko Amano, Head, River Environment Division, Environment Department, National Institute for Land and Infrastructure Management
Yuichi Kayaba, Head, Aqua Restoration Research Center, Public Works Research Institute
Shinji Sato, Professor, Department of Civil Engineering, School of Engineering, The University of Tokyo
Yukihiro Shimatani, Professor, Kyushu University Gradual School (Chair)
Yoshio Suwa, Head, Coast Division, River Department, National Institute for Land and Infrastructure Management
Katsuya Hirano, Associate Professor, Tohoku University Graduate School
Ataru Matsumoto, Director, River Section, Civil Engineering Division, Land Development Department, Iwate Prefecture
Ryuichi Goto, Director, Rivers and Coasts Division, Civil Engineering Department, Miyagi Prefecture
Norio Miyazaki, Director, River Improvement & Maintenance Division, Public Works Department, Fukushima Prefecture

(Observers)
Kazuhiko Saijo, Basin & Flood Control Adjustment Official, Water Management & National Traffic Maintenance Department, Tohoku Regional Development Bureau

(Administration Office)
River Environment Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism
River Improvement and Management Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Disaster Management Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism

<Reference: Environmental Assessment Committee for Recovery of River Mouths and Coastal Facilities in the Miyagi Coast>
(Timeline of discussion)
Friday, November 25, 2011: 1st meeting
Thursday, February 9, 2012: 2nd meeting
Wednesday, March 7, 2012: 3rd meeting

(Members)
Masaki Sawamoto, Professor Emeritus, Tohoku University (Chair)
Yoshio Suwa, Head, Coast Division, River Department, National Institute for land and Infrastructure Management
Mitsuru Takasaki, Professor, School of Science and Engineering, Department of Biological Engineering, Ishinomaki Senshu University
Tomo-o Takatori, Former Deputy Director, Sendai Science Museum
Katsuo Takemaru, Director, Miyagi Branch, Wild Bird Society of Japan
Hitoshi Tanaka, Professor, Engineering, Tohoku University Graduate School
Toshihiko Naito, Doctor of Science, Miyagi plant
Katsuya Hirano, Associate Professor, Information Science, Tohoku University Graduate School
Akira Mano, Professor, Engineering, Tohoku

University Graduate School

(Observers)

Fisheries Infrastructure Department, Fisheries Agency

Private Forest Department, Tohoku Regional Forest Office, Forestry Agency

Northern Miyagi District Forest Office, Tohoku Regional Forest Office, Forestry Agency

Sendai District Forest Office, Tohoku Regional Forest Office, Forestry Agency

Maintenance Division, Tohoku Regional Agricultural Administration Office

Disaster Management Division, Water and Disaster Management Bureau, Ministry of Land Infrastructure, Transport and Tourism

Port and Airport Department, Tohoku Regional Development Bureau

(Administration Office)

River Section, Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism

Rivers and Coasts Division, Miyagi Prefecture

(6) Guide to tsunami inundation simulations

"Guide to Tsunami Inundation Simulations for Planning Recovery Measures from the 2011 Great East Japan Earthquake"[11), co-authored by the Coast Office, Water and Land Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, describing the standard procedures for promptly conducting simulations for the purpose of backing up the planning of recovery or rebirth of the affected areas based on the analyses on the tsunami damages caused by the Great East Japan Earthquake, after the reviews by academic experts at the 2nd "Committee for Technical Investigation for Coastal Countermeasures for Tsunamis" held in June, was released in July 2011. The guide includes the following recommendations:

· Principally, optimal geographic fault models (validated models applicable to wide area analyses), modified so that the actual simulation outputs match the actual tsunami traces, should be used in simulations;

· Principally, the high-accuracy measurement data obtained after the earthquake using instruments such as laser profilers should be used as the geographic models in the simulations.

· In simulations for predictions, damages of structures caused by ground motions or tsunamis are taken in account;

· Simulation outputs should include the horizontal distribution of maximum inundation depth and the off-the-coast directional distribution of maximum depth in a representative cross-section, in order to estimate the tsunami water inland invasion.

In addition, the Coast Division of the NILIM started consultation services on tsunami inundation simulations, and held briefing sessions on the abovementioned guide in 26 total affected cities, towns, and villages in July and August in 2011.

(7) Guidelines on designing the assumptions of tsunami inundation

The Law on the Development of Disaster-protected Communities requires prefectural governors to predefine the tsunami-inundation prospect consisting of the areas expected to suffer tsunami inundation and the inundation water depth. The "Guidelines on Designing the Assumptions of Tsunami Inundation"[6), co-authored by the Seacoast Office, Water and Land Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, after the reviews by academic experts, was released in February 2012. The guide includes the following recommendations:

· The tsunami inundation prospect should be formulated according to the following order: definition of the maximum-class tsunami; clarifying computational conditions; execution of tsunami simulations; extraction of inundated areas and inundation water depth;

· The maximum-class tsunami should be defined for each set of coasts by choosing a tsunami whose height is the highest among the past tsunamis that had hit the set of coasts—applying the actual observed height, simulated tsunamis—applying the heights found in simulation outputs, and the tsunamis that are predicted to likely occur in future—the predicted height;

· The geographical fault model—it determines the initial height of tsunami, could be formulated by using, as a reference if available, the geographical fault models validated by the authorities such as the Central Disaster Prevention Council or the Headquarters for Earthquake Research Promotion;

· Principally, the simulations for the definition of tsunami inundation prospect should be conducted under such an assumption that a maximum-class tsunami could always occur under an unfortunately bad condition and cause inundations with damages to facilities induced by earthquakes and tsunamis. Do not forget the lesson that "no upper limitation exists for the severity of a disaster." Do not forget that "saving life is the first and the ultimate goal";

· For clear estimations of the inland invasion of tsunami water, tsunami inundation simulations must output the maximum predictable inundated areas and water depths.

In addition, briefing sessions on the abovementioned guides were held targeting prefectural governments and construction consultants in February and March 2012. Also, since April 2012, Q&A and request-for-comment sessions have been held, participated in by the officials in charge from the prefectural governments concerned and the regional development bureaus concerned.

(8) Technical review concerning the regional development in tsunami disaster

The Ministry of Land, Infrastructure, Transport and Tourism discussed the regional development in tsunami disaster after the tsunami damages in the Great East Japan Earthquake, and established the act on regional development in tsunami disaster. This act promotes the following activities, based on the concept of "multi-leveled protection" consisting of a mixture of hardware-oriented protection measures and software-oriented measures: development of tsunami protection facilities; restriction of land development or construction; and preparation of tsunami warning and evacuation framework. Particularly, the methods of estimation of heading up of tsunami water on the fronts of buildings possibly used for shelters, the technical requirements of land-filling or cutting for making construction base grounds in the tsunami inundation risk areas, and the technical requirements of tsunami protection facilities were discussed as follows at the "Technical Review Committee on the Regional Development in Tsunami Disaster" [7]. This committee was chaired by Prof. Shoji Fukuoka, Chuo University, consisting of technical experts and administration officials, where the Coast Division, River Department, NILIM, jointly with the Seacoast Office, Water and Land Management Bureau, served as the administration office.

1) Evaluation of tsunami water heading up against buildings

Prefectural governors are required to publicly announce the reference water level (inundation water level including the heading up height of tsunami water) when setting the tsunami disaster warning areas or the special tsunami warning areas. Mayors of municipalities designate the facilities in the tsunami disaster warning areas as the authorized shelters that satisfy the requirements set by using the reference water levels. Furthermore, according to one of the permit requirements of the development of social welfare facilities, schools, and medical facilities, etc. in special tsunami disaster warning areas (hereinafter referred to as "special designated development"), those facilities are required to have floors higher than the reference water levels.

Such a reference water level is recommended to be equal to the maximum value of specific energy at the grid points obtained by tsunami inundation simulations; its validity has been confirmed during tsunami inundation simulations including virtual buildings, and examined by using the actual tsunami trace heights.

The abovementioned recommendations were incorporated into the "Basic Policies for Promotion of Regional Development in Tsunami Disaster" (January 16, 2012, Announcement No.51, Ministry of Land, Infrastructure, Transport and Tourism)

2) Technical requirements of land-filling or cutting

The technical discussion group, with regard to the special designated developments, worked out the following recommendations on the requirements of slopes resulting from land-filling or cutting so that their safety is secured against tsunami inland invasion:

・Slopes not protected by retaining walls should be armored with grass instead of mortar coating (this recommendation was derived from the estimation by the slope erosion depth by tsunami inundation simulations)

・Against the scouring of the slope toe, stability analysis assuming a circular slip should be executed by application of the maximum possible scouring depth, and either of the two protection measures, protection armoring or forming setbacks on the filled or cut, should be adopted.

・Because there is a risk of erosion of a slope's top-ends by overtopping tsunami water, countermeasures compatible with the requirements of low-water river revetment crowns should be applied.

The abovementioned recommendations were incorporated into "About the effectuation of the act on regional development in tsunami disaster (Chapter 9)" (July 31, 2012, Effectuation Notice by the Director of City Bureau, Director of Water and Land Management Bureau and Director of Housing Bureau).

3) Technical requirements of tsunami protection facilities

A tsunami protection facility is defined as follows: a facility for the purpose of saving human life in maximum-class tsunamis functioning as a protection against tsunami inundation inland invasion, including structures of land filling, revetments, breast walls, and lockage. The recommendations on technical requirements describe the functional performance and the durability capacity, and then the points of review of performance or capacity.

The recommendations were incorporated into the enforcement regulation of the act on regional development in tsunami disaster (December 26 2011, Ministry ordinance No. 99, Ministry of Land, Infrastructure, Transport and Tourism)

<References: Technical Discussion Group for the Development of Tsunami Protected Communities>

(Timeline of meetings)

November 8, 2011: 1st meeting
November 28, 2011: 2nd meeting
December 9, 2011: 3rd meeting
January 11, 2012: 4th meeting

(Members)

<Experts>

Shinji Sato, Professor, Department of Civil Engineering, Tokyo University Graduate School

Shoji Fukuoka, Professor, Research and Development Initiative, Cho University (Chair)

Koji Fujima, Professor, Department of Civil and Environmental Engineering, School of Systems Engineering, National Defense Academy

Mikio Futaki, Director, Tsukuba Construction Test Center for Better Living

<Administrative Officials>

Ataru Matsumoto, Director, River Section, Civil Engineering Division, Land Development Department, Iwate Prefecture

Ryuichi Goto, Director, Rivers and Coasts Division, Civil Engineering Department, Miyagi Prefecture

Takuo Chiba, Director, Building Grounds Division, Civil Engineering Department, Miyagi Prefecture

Toshikazu Asano, Director, River Planning Division, Public Works Department, Fukushima Prefecture

Kazuhiko Murata, Director, Urban Development Department, Hamamatsu City

<Administration Office>

Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism (Seacoast Office and River Planning Division)

City Bureau, Ministry of Land, Infrastructure, Transport and Tourism (Urban Development Control Office and City Planning Division)

River Department, National Institute for Land and Infrastructure Management (Coast Division)

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The materials such as the master list of coast protection facilities used in the analysis of dike damages were collected during the investigations by the "Committee for Technical Investigation on Coastal Countermeasures for Tsunami." The authors express thanks to Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba Prefectures, and the Tohoku Regional Development Bureau for their kindness in providing the reports of damage situation investigation. The authors also express thanks to Alpha Hydraulic Engineering Consultants, Co. Ltd., for their cooperation in the re-measurements of fishery areas.

The authors express thanks to the River Department, Iwate River and National Highway Office, Sendai National Highway Office of Tohoku Regional Development Bureau, and Land Development Department of Iwate Prefecture for their cooperation in the site investigations.

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3.3.6 Roads

(1) Initial Response (TEC-FORCE, etc.) and Surveys of the Extent of the Disaster

Immediately after the Great East Japan Earthquake struck, the Bridge and Structures Division of the Road Department and the Earthquake Disaster Prevention Division of the Research Center for Disaster Management at NILIM began to work in partnership with the Center for Advanced Engineering Structural Assessment and Research (CAESAR) at the Public Works Research Institute (PWRI), conducting surveys of bridges along national highways, prefectural roads, and municipal roads in the prefectures of Iwate, Miyagi, Fukushima, Tochigi, Ibaraki, Chiba, and Kanagawa. In conducting these surveys, as well as providing technical advice to road administrators concerning such matters as earthquake-resistance diagnosis of bridges and repair methods, the researchers gathered information to facilitate the verification of the seismic reinforcement measures and technical standards implemented hitherto. In terms of the extent of the damage to road infrastructure, according to a report by the Water and Disaster Management Bureau of the MLIT[1)], the number of points of damage to civil engineering infrastructure in the Tohoku and Kanto regions resulting from disasters during FY2011 (it should be noted that this includes damage resulting from disasters other than the Great East Japan Earthquake) was 372 in the case of road infrastructure on national highways managed by MLIT, 12,654 in the case of road infrastructure on roads managed by prefectural and municipal governments, and 542 in the case of bridges managed by prefectural and municipal governments. Moreover, in relation to traffic obstructions due road infrastructure being damaged as a result of the Great East Japan Earthquake, the Cabinet Office has reported that there were

(a) Numata Overpass

(b) Namiita Bridge

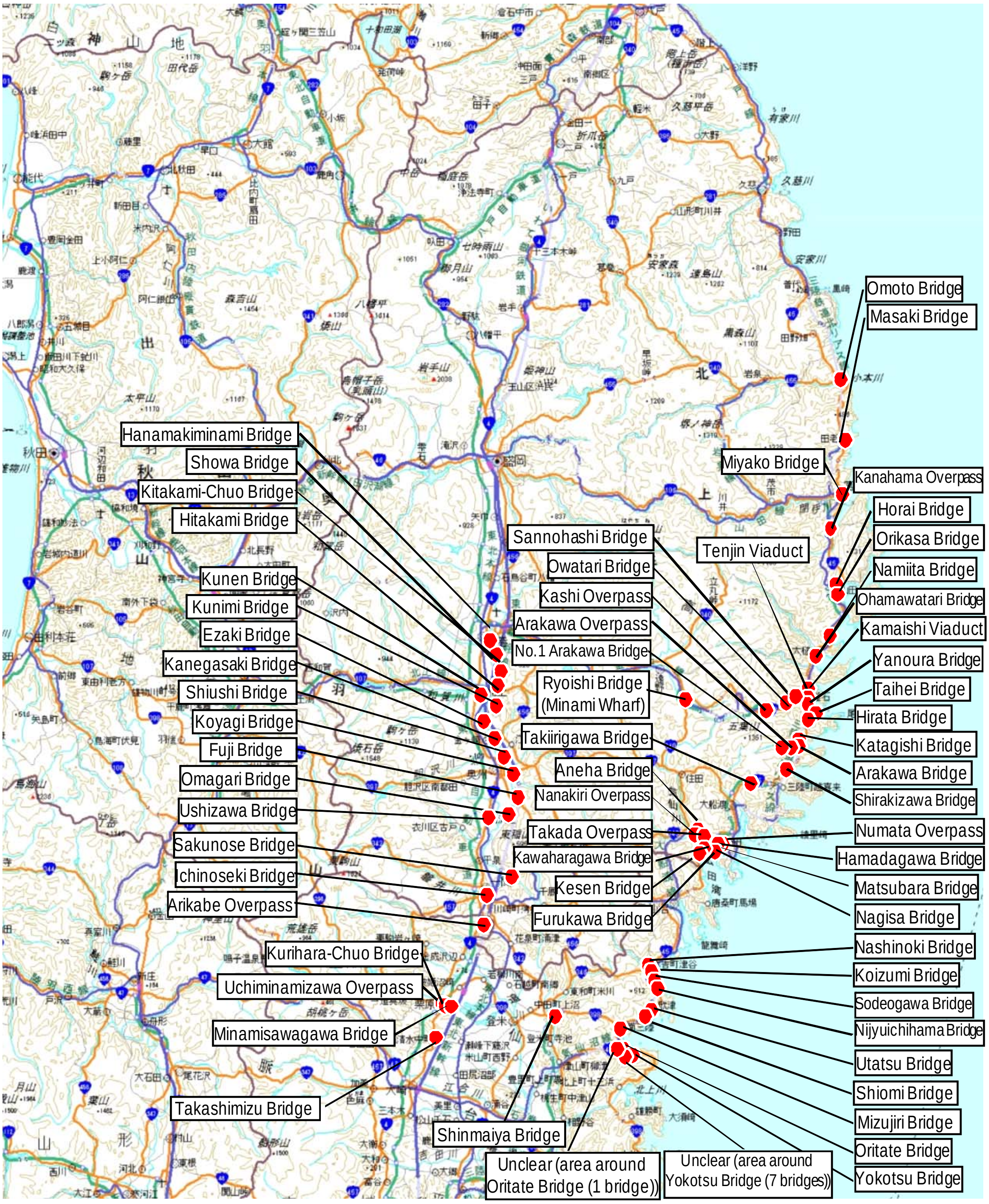
(c) Asahi Elevated Bridge

(d) Koizumi Bridge

Photo 3.3.6.1 Photographs of Surveys Being Conducted obstructions at 4,200 points due to road damage, and at 116 due to bridge damage[2)].

The objective of most of the surveys conducted at the time of the initial response was to provide technical support, mainly in response to requests from road administrators; the subsequent surveys were independent studies conducted for the purpose of developing technical standards in relation to tsunami and verifying earthquake-resistance standards. 218 bridges were surveyed (of which, 106 were surveyed by NILIM), with surveys taking a total of 280 man-days (of which, 59 man-days were contributed by NILIM, not including time traveling to and from the region). Figure 3.3.6.1 shows the bridges surveyed. This map also includes bridges surveyed independently by the PWRI.

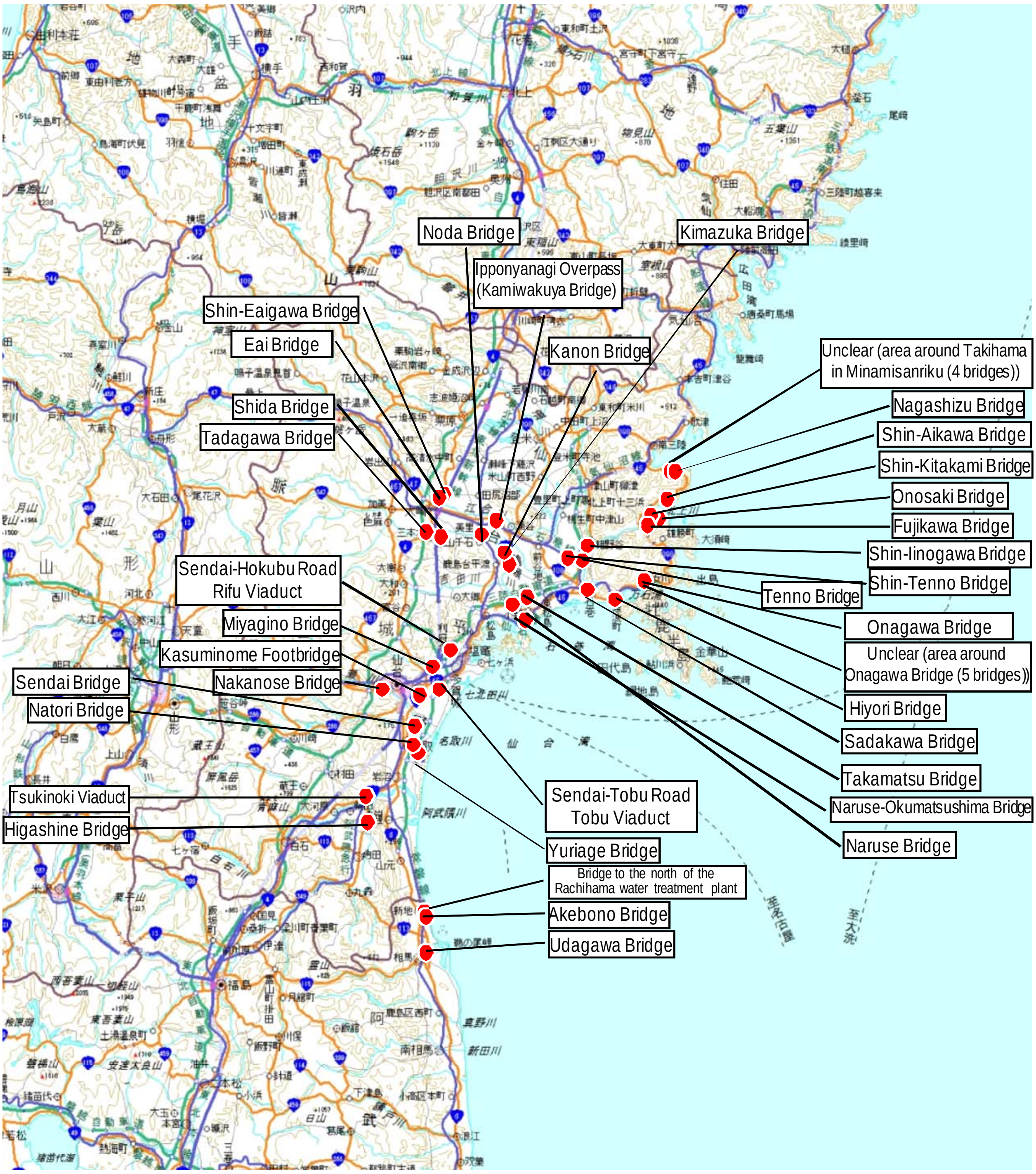
During the initial response, TEC-FORCE Unit 1 departed for the headquarters of the Tohoku Regional Development Bureau on the evening of March 11, 2011, the day of the disaster; the unit was sent at the Bureau's request, which was channeled to NILIM via the National Highway and Risk Management Division of the Road Bureau, MLIT. At this point, although information about the extent of the damage to civil engineering structures was non-existent, extensive damage was anticipated, based on reports such as earthquake early warnings. Accordingly, even while en route to the region concerned, it was unclear whether it would be possible to reach the Tohoku Regional Development Bureau headquarters, let



(Annotated version of background map data distributed by the Digital Japan Web System, Geospatial Information Authority of Japan)

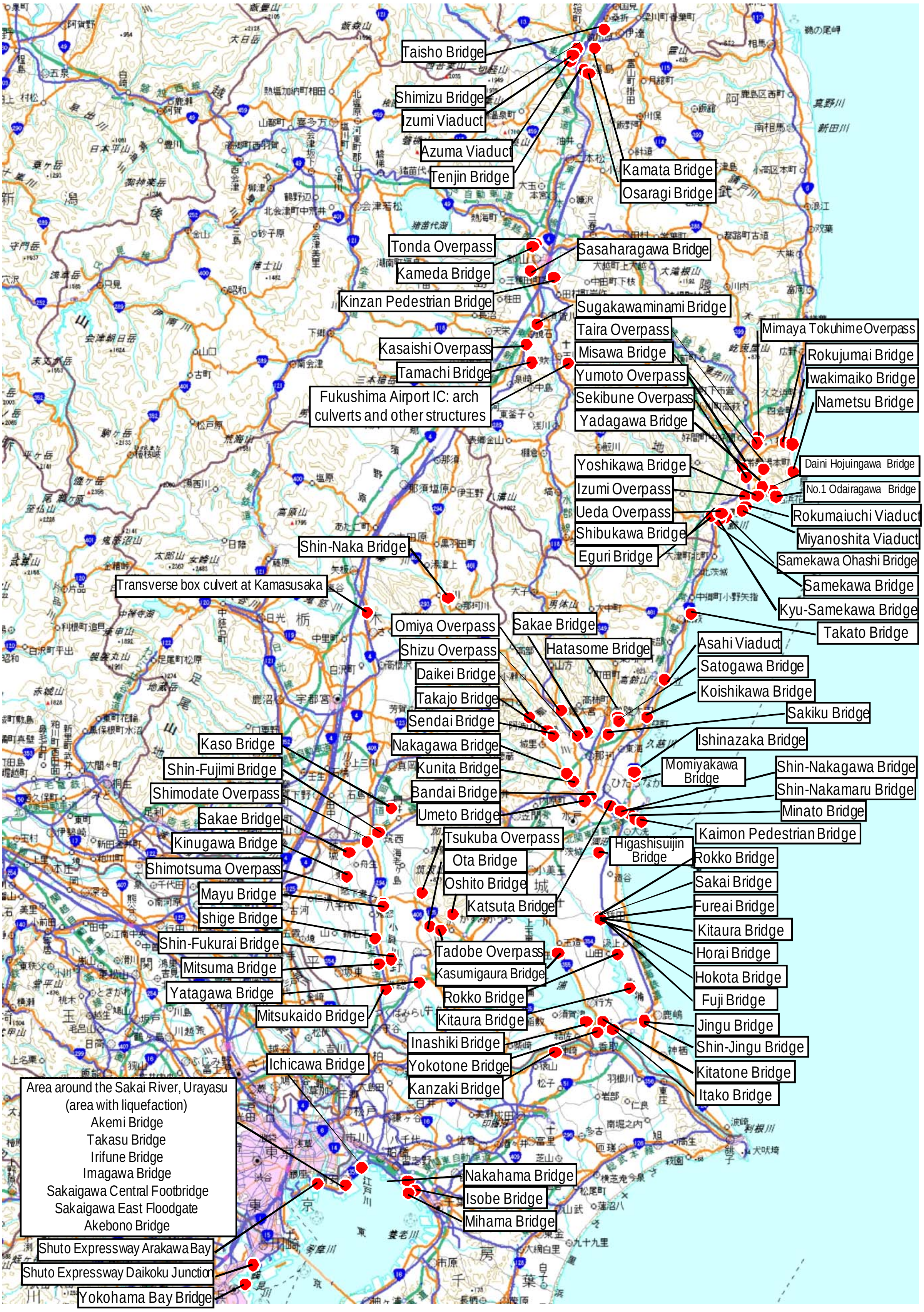
Figure 3.3.6.1 Location Map of Bridges Surveyed (1)

alone the areas actually affected by the disaster. However, due to the pressing need to provide support for the clearance of blocked roads and gain a prompt understanding of the extent of the damage to road structures, which play a vital role in rescue operations by facilitating emergency transport, as well as being crucial infrastructure supporting recovery and reconstruction activities, the team single-mindedly pressed on toward the disaster-stricken areas. They arrived at the headquarters of the Tohoku Regional Development Bureau late at night on the day of the disaster and, having assembled information about the extent of the damage that had arrived from each office, they commenced surveys in the disaster-stricken areas at dawn the following day.



(Annotated version of background map data distributed by the Digital Japan Web System, Geospatial Information Authority of Japan)

Figure 3.3.6.1 Location Map of Bridges Surveyed (2)



(Annotated version of background map data distributed by the Digital Japan Web System, Geospatial Information Authority of Japan)

Figure 3.3.6.1 Location Map of Bridges Surveyed (3)

As the extent of the disaster - particularly the extent of the damage caused by the tsunami - became clear, technical advice began to be required concerning the potential for temporary repair of bridges damaged by the tsunami and the use of temporary bridges in places where the bridge piers remained, as well as advice about the repair methods that could be used, so there were ongoing requests for TEC-FORCE's presence, which NILIM handled. In doing so, NILIM worked in collaboration with CAESAR, the assistance of which had been requested by the Tohoku Regional Development Bureau (not positioned as a TEC-FORCE request). NILIM's response (TEC-FORCE, technical consultations, etc.) in relation to road structures damaged by the Great East Japan Earthquake is shown in Table 3.3.6.1. In order to conduct field surveys of road bridges in response to requests from road administrators, 6 teams were dispatched to the Tohoku Regional Development Bureau, 1 team to Ibaraki Prefecture, 1 team to Iwate Prefecture, and 1 team to Chiba Prefecture. In addition, the activities conducted by TEC-FORCE

Table 3.3.6.1 List of Response Measures Implemented by NILIM (TEC-FORCE, Technical Consultations, etc.) Concerning Damage to Road Structures from the Great East Japan Earthquake (1)

Date	Response	Bridges Surveyed	Total Man-days
2011 March 11-12	TEC-FORCE (Tohoku Regional Development Bureau)	Miyagino Bridge, Naruse Bridge, Tenno Bridge, Shin-Tenno Bridge, Shin-Iinogawa Bridge, Tadagawa Bridge	2 man-days
March 14-15	TEC-FORCE (Tohoku Regional Development Bureau)	Namiita Bridge, Namiita Pedestrian Bridge, Ohamawatari Bridge, Orikasa Bridge, Horai Bridge, Horai Pedestrian Bridge, Miyako Bridge, Omoto Bridge, Masaki Bridge, Kanahama Overpass, Kameda Bridge	4 man-days
March 16-17	Field survey at the request of Ibaraki Prefecture	Takado Bridge, Satogawa Bridge, Hatasome Bridge, Omiya Overpass, Shizu Overpass	4 man-days
March 17-18	TEC-FORCE (Tohoku Regional Development Bureau)	Kesen Bridge, Numata Overpass, Kawaharagawa Bridge, Hamadagawa Bridge, Nanakiri Overpass, Takada Overpass, Aneha Bridge, Furukawa Bridge, Matsubara Bridge, Nagisa Bridge	6 man-days
March 29	TEC-FORCE (Tohoku Regional Development Bureau)	Osaragi Bridge	2 man-days
March 31	Ibaraki Prefecture Investigative Committee on Emergency Repair	Shizu Overpass, Satogawa Bridge, Hatasome Bridge, Kunita Bridge	1 man-day
April 6	Independent survey	Sendai-Tobu Viaduct	1 man-day
April 6	TEC-FORCE (Tohoku Regional Development Bureau)	Ezaki Bridge, Kanegasaki Bridge, Kunimi Bridge, Kunen Bridge	1 man-day
April 14-15	(i) TEC-FORCE (Tohoku Regional Development Bureau) (ii) Field survey at the request of Iwate Prefecture	(i) Mizujiri Bridge, Utatsu Bridge, Nijyuichihama Bridge, Sodeogawa Bridge, Koizumi Bridge, Shiomi Bridge, Kesen Bridge, Aneha Bridge, Kawaharagawa Bridge, Furukawa Bridge, Numata Overpass (ii) Koyagi Bridge	6 man-days
April 20	Field survey at the request of Chiba City	Mihama Bridge, Isobe Bridge, Nakahama Bridge	3 man-days
April 26	Independent survey	Shiushi Bridge, Koyagi Bridge, Fuji Bridge, Omagari Bridge	1 man-day
May 13	Technical consultation (Iwate Prefecture)	Koyagi Bridge	4 man-days
May 15	Independent survey	Yokohama Bay Bridge (R357)	2 man-days
June 1	Technical consultation (Ibaraki Prefecture)	Kunita Bridge	2 man-days
June 3	Independent survey	Koizumi Bridge, earthworks structures around the city of Kurihara	5 man-days
June 29	Tohoku Regional Development Bureau Investigative Committee (1st Meeting)	Ipponyanagi Overpass, Shin-Eiaigawa Bridge, Kashi Overpass, Ushizawa Bridge, Katagishi Bridge, Arikabe Overpass, Ichinoseki Bridge, Koizumi Bridge, Utatsu Bridge	1 man-day
August 10	Tohoku Regional Development Bureau Investigative Committee (2nd Meeting)	Samekawa Bridge, Naruse Okumatsushima Bridge, Tenno Bridge, Rokumaiuchi Elevated Bridge, Osaragi Bridge, Ueda Overpass, Kameda Bridge, Daini Hojuingawa Bridge, Udagawa Bridge, Miyako Bridge, Kinzan Pedestrian Bridge, Miyama Tokuhime Overpass, Izumi Viaduct, Okeba Bridge	1 man-day

Table 3.3.6.1 List of Response Measures Implemented by NILIM (TEC-FORCE, Technical Consultations, etc.) Concerning Damage to Road Structures from the Great East Japan Earthquake (2)

Date	Response	Bridges Surveyed	Total Man-days
August 25-26	Independent survey	Oritate Bridge, unclear (area around Oritate Bridge (1 bridge)), Yokotsu Bridge, unclear (area around Oritate Bridge (2 bridges)), Unclear (upstream of Yokotsu Bridge (5 bridges)), Unclear (area around Takihama in Minamisanriku (4 bridges)), Nagashizu Bridge, Shin-Kitakami Bridge, Onosaki Bridge, Onagawa Bridge, Unclear (area around Onagawa Bridge (5 bridges))	6 man-days
September 29	Tohoku Regional Development Bureau Investigative Committee (3rd Meeting)	Tadagawa Bridge, Natori Bridge, Ryoishi Bridge, Ichinoseki Bridge, Kameda Bridge, Azuma Elevated Bridge, Ipponyanagi Elevated Bridge, Arikabe Overpass, Shiomi Bridge	1 man-day
October 20-21	Independent survey	Tsukinoki Viaduct, Natori Bridge, Yuriage Bridge, Nakanose Bridge, Taisho Bridge, Osaragi Bridge, Kameda Bridge, Izumi Viaduct, Shimizu Bridge, Tenjin Bridge, Kamata Bridge	2 man-days
November 24	Technical consultation (Tohoku Regional Development Bureau)	Ichinoseki Bridge, Naruse Okumatsushima Bridge	2 man-days
2012 January 30	Technical consultation (Ibaraki Prefecture)	Asahi Viaduct	2 man-days

Note 1: The total man-days refers solely to NILIM staff.
Note 2: Excludes surveys, etc. conducted singlehandedly by the PWRI.
Note 3: The Tohoku Regional Development Bureau Investigative Committee is the Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake, described in (3) below.

often went on late into the night, so a 24-hour logistical support system was adopted by the research divisions, to provide information to the staff members dispatched to areas affected by the disaster and to serve as a point of contact for the Ministry and the disaster prevention coordinator in the Planning Division at NILIM.

Starting with the initial response, NILIM has conducted a number of rounds of independent surveys, with the objective of gaining an understanding of the extent of the damage and obtaining the data required to analyze the causes of the damage and determine the necessity of revising relevant technical standards. See the previous report[3] for details of the distinctive aspects of the damage.

(2) Emergency Inspection of Road Infrastructure (Conducted by Regional Development Bureaus)

One of the characteristics of the Great East Japan Earthquake is the fact that numerous large aftershocks continued for quite some time afterwards. As of October 16, 2012, aftershocks measuring magnitude 5.0 or higher had been recorded on 818 occasions[4]. Moreover, on April 7, 2011, an aftershock of a scale comparable to the main quake occurred, with a magnitude of 7.2 and a seismic intensity of 6-upper. Due in part to this fact, the National Highway and Risk Management Division of the Road Bureau issued an advisory to the Tohoku Regional Development Bureau and other bodies, entitled *Concerning Inspection of Road Infrastructure* (April 14, 2011; National Highway Risk Management Division Notice No.3). Furthermore, an administrative circular entitled *Concerning Emergency Inspection of Road Infrastructure* (April 20, 2011; Administrative Circular from the Deputy Director) was issued to serve as a point of reference when conducting these emergency inspections. Consisting of two parts, one subtitled *Bridges*, and the other *Soil Structure and Slopes*, this administrative circular specified matters relating to methods of inspection, the evaluation and recording of the results of emergency inspections, and major points on which to focus and things to bear in mind in conducting inspections. Working in partnership with CAESAR, the Bridge and Structures Division took charge of the task of writing the original draft for the *Bridges* part of this administrative circular. The PWRI was responsible for writing the original draft of the part entitled *Soil Structure and Slopes*. In response to this administrative circular, the Tohoku Regional Development Bureau immediately carried out emergency inspections.

NILIM received the results of the emergency inspections that the Bureau had conducted, and carried out correlation analysis concerning the extent of the damage and the various contributory factors. An example of the results of this analysis is shown in Figure 3.3.6.2. The damage rate in bridges that had sustained seismic motion of at least 6-lower on the seismic intensity scale used by the Japanese Meteorological Agency (JMA) was in excess of 50%.

Moreover, incorporating both issues that surfaced in conducting these emergency checks and insights gained from reflecting on similar emergency checks in the past, the *Manual on Emergency Checks and Surveys of Road Bridges in the Event of Disaster* (Draft) (February 2012, Road Department, Tohoku Regional Development Bureau; Bridge and Structures Division, National Institute for Land and Infrastructure Management) was compiled and sent to all Regional Development Bureaus for reference.

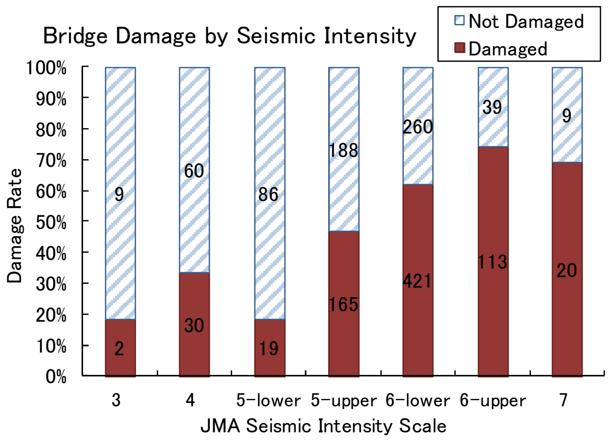


Figure 3.3.6.2 Example of the Outcomes of Analysis of the Results of Emergency Checks

(3) Outline of the Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake

The Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake was established under the auspices of the Road Department, Tohoku Regional Development Bureau, as a forum for deliberations concerning methods of repairing road bridges damaged by the Great East Japan Earthquake and points to bear in mind in doing so, as well as the potential for using the residual structures from bridges washed away by the tsunami. This Investigative Committee was established on the basis of the judgment that it would be more efficient to set up a formal organization when receiving technical support from NILIM and the Public Works Research Institute, rather than making requests in relation to each individual bridge.

The objectives, affairs under the jurisdiction of the committee, and members are shown in Table 3.3.6.2, while an overview of its meetings is provided in Table 3.3.6.3. Tireless efforts aimed at recovery and reconstruction are currently underway, based on the technical advice provided during meetings of this Investigative Committee.

Table 3.3.6.2 Outline of the Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake

Category	Content	
Objectives	An Investigative Committee shall be established to consider methods of repairing road bridges damaged by the Great East Japan Earthquake on March 11, 2011, from the perspective of extending the lives of these bridges, and points to bear in mind in doing so; in addition, the objective of its establishment is to conduct deliberations regarding the potential for using the residual structures from bridges washed away by the tsunami, and to contribute to technical advice required when conducting permanent bridge repairs in due course.	
Affairs Under the Jurisdiction of the Committee	The Investigative Committee shall provide guidance and advice concerning the following matters. (1) Matters pertaining to methods of repairing major damage to road bridges affected by the disaster, from the perspective of extending the lives of these bridges, and points to bear in mind in doing so. (2) Matters pertaining to the potential for using the residual structures from bridges washed away by the tsunami, namely the Numata Overpass, Kesen Bridge, Koizumi Bridge, and Utatsu Bridge. (3) Matters pertaining to approaches to bridge management, taking into account the lessons learned from the Great East Japan Earthquake.	
Member	Affiliation/Position	Name
	Head, Bridge and Structures Division, Road Department, NILIM	Takashi Tamakoshi
	Senior Researcher, CAESAR, PWRI	Shoichi Nakatani
	Senior Researcher, CAESAR, PWRI	Jun-ichi Hoshikuma
	Senior Researcher, CAESAR, PWRI	Yoshitomi Kimura
	Senior Researcher, CAESAR, PWRI	Masahiro Ishida
	Executive Officer for Road Information Management, Road Department, Tohoku Regional Development Bureau	Tomoyoshi Ito Note 1) Shoichi Akagawa Note 2)
	Executive Officer for Road Maintenance Planning, Road Department, Tohoku Regional Development Bureau	Shoichi Akagawa Note 1) Kazuo Sasaki Note 2)
	Director, Road Works Division, Road Department, Tohoku Regional Development Bureau	Yoshikatsu Shibata
	Director, Road Management Division, Road Department, Tohoku Regional Development Bureau	Shigeru Kiga
	Deputy Director, Sanriku National Highway Office, Tohoku Regional Development Bureau	Shigenori Kumagai
	Deputy Director, Sendai River and National Highway Office, Tohoku Regional Development Bureau	Eiji Okuyama
	Deputy Director, Tohoku Engineering Office, Tohoku Regional Development Bureau	Kazunori Sato Note 1) Hiroyasu Nagai Note 2)

Note 1) 1st Meeting

Note 2) 2nd Meeting onwards

Table 3.3.6.3 Meetings of the Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake

Date	Committee	Matters Considered
2011 June 29	1st Meeting	・The objectives and rules of the Investigative Committee on the Repair of Bridges Damaged by the Great East Japan Earthquake ・Reports on the extent of the damage to bridges resulting from the Great East Japan Earthquake ・Reports on the extent of the damage to bridges washed away by the tsunami
August 10	2nd Meeting	・Reports on the extent of the damage to bridges resulting from the Great East Japan Earthquake ・Technical issues in the field in relation to the repair of damaged bridges ・Reports on the extent of the damage to bridges washed away by the tsunami
September 29	3rd Meeting	・Technical issues in the field in relation to the repair of damaged bridges ・Common issues to bear in mind in design and inspection ・A unified approach to the design of repairs ・Key diagnostic points in relation to damaged bridges and examples of responses ・Reports on the extent of the damage to bridges resulting from the Great East Japan Earthquake ・Reports on the extent of the damage to bridges washed away by the tsunami

(4) Deliberations Aimed at Standardization

(i) *Technical Standards for Road Bridges and Elevated Roads* (*Specifications for Highway Bridges*)

The Bridges Committee of the Japan Road Association discusses the original drafts for revisions proposed by the Bridge and Structures Division, the Earthquake Disaster Prevention Division, and the PWRI in relation to the *Technical Standards for Bridges and Elevated Roads* (Circular Notice from the Director-General, City Bureau and Director-General, Road Bureau, MLIT; hereinafter referred to as "*Specifications for Highway Bridges*"), which detail the technical standards for road bridges.

As of March 11, 2011, when the Great East Japan Earthquake, deliberations were underway, focused on reflecting in the standards new findings and responses to various issues that had been built up since the 2001 revision; in addition, full-scale deliberations aimed at transitioning to a partial factor design method were also underway. It was amid this situation that the Great East Japan Earthquake occurred, with immense damage being caused to social capital as a result of a massive tsunami that struck coastal areas; there was serious damage to road bridges, with the superstructures of many being washed away, causing disruption to the road network. In light of this situation, it was decided to prioritize deliberations aimed at revising the *Specifications for Highway Bridges* as soon as possible, in order to enable the outcomes of various surveys and research considered since the last revision, as well as knowledge acquired from damage resulting from recent disasters, including the Great East Japan Earthquake, to be reflected in the repair of existing road bridges and the construction of new ones, Table 3.3.6.4 shows the progress of deliberations.

The original draft revision of the *Specifications for Highway Bridges* was discussed at the 81st Meeting

Table 3.3.6.4 Progress of Deliberations by the Bridges Committee of the Japan Road Association

Date	Committee	Matters Considered
2011 May 12	78th Meeting of the Bridges Committee	・Issues and matters for consideration relating to the *Specifications for Highway Bridges* in light of the Great East Japan Earthquake (1) Seismic motion (2) Design against liquefaction and fluidization (3) Design of components (4) Impact of tsunami (5) Seismic retrofit measures for existing bridges
July 27	79th Meeting of the Bridges Committee	・Issues and matters for consideration relating to the *Specifications for Highway Bridges* in light of the Great East Japan Earthquake (1) Evaluation of the impact of seismic motion of long duration (2) Evaluation of the impact of seismic motion in excess of the design spectrum (3) Consideration of the necessity of revising the method of evaluating liquefaction (4) Analysis of cases involving rupture of the rubber bearing (5) Consideration of the performance that should be ensured in the event of tsunami ・Opinions and queries regarding the draft revision of the *Specifications for Highway Bridges*
October 13	80th Meeting of the Bridges Committee	・Responses in the draft revision of the *Specifications for Highway Bridges* in light of the Great East Japan Earthquake (1) Matters to be considered in relation to tsunami (2) Draft revision of design ground motion (3) Appropriateness of the method of evaluating liquefaction (4) Revisions relating to clarification of the performance requirements for components (5) Responses to subsidence at the rear of abutments ・Opinions and queries regarding the draft revision of the *Specifications for Highway Bridges*
December 14	81st Meeting of the Bridges Committee	・Approval of the draft revision of the *Specifications for Highway Bridges*

Table 3.3.6.5 Content of Main Revisions to the *Specifications for Highway Bridges* in Light of the Great East Japan Earthquake

Section	Category	Content
I. Common	Maintainability	In light of the fact that there were cases in which bridges employed structures that made it difficult to ascertain the situation in the event of disaster, as well as cases in which it was not possible to ascertain the situation promptly from a position close to the point of damage, the reliability of maintenance was added to the matters to be considered in relation to design.
	Consideration for tsunami in planning	A stipulation was added to the matters to be considered in relation to bridge planning, to the effect that a bridge site and type should be selected that ensures consistency with the local disaster prevention plan and relevant road network plans.
	Records	As records concerning design and construction provide essential information for evaluating the situation after an earthquake and conducting rational deliberations regarding repairs, a stipulation was added, to the effect that such matters must be recorded appropriately and preserved in a way that enables those records to be used in maintenance throughout the service life of the bridge.
IV Substructure	Approach at the rear of abutments	In response to the pronounced differences in level that developed at the rear of abutments following the Great East Japan Earthquake and other disasters, provisions were added concerning the performance required in order to maintain the continuity of the road surface on the approach at the rear of abutments, as well as points to bear in mind in relation to the design and construction thereof.
	Pier design	In response to the reality of damage to the mountings of bearings and aseismatic connectors, the provisions concerning verification of the load acting on bridges from bearings and aseismatic connectors in the event of an earthquake were expanded.
V Seismic Design	Matters to be considered in relation to tsunami	A stipulation regarding local disaster prevention plans concerning tsunami was added to the matters to be considered in relation to the seismic design of bridges.
	Revision of Level 2 seismic motion (Type I) Revision of regional correction factors	Verification and revision of seismic motion and regional correction factors in light of the impact of the synchronization of hypocenters in a large-scale earthquake, as seen during the Great East Japan Earthquake.
	Matters pertaining to design around bearings	Clarification of the performance required of bearings, presentation of methods of verifying performance, and rationalization of the structure around bearings, in light of examples of damage around bearings resulting from the Great East Japan Earthquake.
	Matters pertaining to the design of mountings for bearings and aseismatic connectors	As well as clearly stipulating the design to be used for mountings, due to the fact that cases were identified in which the impact, such as damage to bearings, even extended to the mountings of aseismatic connectors, a provision was added concerning the points at which aseismatic connectors are to be installed.

of the Bridges Committee and the content approved; following further deliberations within MLIT, a circular notice from the Director-General, City Bureau and Director-General, Road Bureau was published on February 16, 2012, entitled *Concerning Revisions of the Technical Standards for Road Bridges and Elevated Roads*. Following on from this, *Specifications for Highway Bridges - With Annotated Commentary* (Japan Road Association), which included a commentary by the Bridges Committee on the provisions of the specifications for highway bridges in the circular notice, was published on March 26, 2012. Table 3.3.6.5 shows the main content of revisions made in light of the Great East Japan Earthquake. This revised version does leave issues outstanding in relation to the transition to the partial factor design method, so it adheres to a verification system based on a performance specification system and allowable stress design using the same method employed in the 2001 edition of *Specifications for Highway Bridges*.

(ii) *Guidelines on Highway Earthworks*

The Japan Road Association publishes the *Outline of Highway Earthworks* and six *Guidelines on Highway Earthworks*, which are the equivalent of technical standards concerning the structure of road earthworks. Of these, at the time of the Great East Japan Earthquake, deliberations were being carried out by the Road Earthworks Committee of the Japan Road Association, with a view to the revision of two of the *Guidelines on Highway Earthworks*: *Highway Earthworks: Guidelines on Retaining Walls* and *Highway Earthworks: Guidelines on Measures to Deal with Soft Ground*. The Road Department and the Research Coordinator for Earthquake Disaster Prevention from NILIM participate in these deliberations as committee members.

Table 3.3.6.6 Technical Standards Concerning Road Earthworks

Outline	*Outline of Highway Earthworks* (FY2009 edition)
Guidelines	*Highway Earthworks: Guidelines on Embankments* (FY2010 edition)
	Highway Earthworks: Guidelines on Cutting and Slope Stability (FY2009 edition)
	Highway Earthworks: Guidelines on Retaining Walls (FY2012 edition)
	Highway Earthworks: Guidelines on Culverts (FY2009 edition)
	Highway Earthworks: Guidelines on Measures to Deal with Soft Ground (FY2012 edition)
	Highway Earthworks: Guidelines on Temporary Structures (March 1999)

Table 3.3.6.7 provides a summary of the progress of deliberations conducted after the Great East Japan Earthquake. At the 1st Joint Meeting of the Road Earthworks Committee and the Guidelines on Highway Earthworks Investigative Subcommittee, which was held in June 2011, the establishment of a Disaster Working Group and the policy on the response by the Road Earthworks Committee were discussed. Subsequently, during the second meeting of the Disaster Working Group, the results of the field survey conducted by the PWRI were discussed, in relation to the factors contributing to the damage at nine locations where the damage was particularly severe and the response to this in the guidelines. In light of the outcomes of this discussion, draft revisions to *Highway Earthworks: Guidelines on Retaining Walls* and *Highway Earthworks: Guidelines on Measures to Deal with Soft Ground* were discussed at the 2nd Joint Meeting of the Road Earthworks Committee and the Guidelines on Highway Earthworks Investigative Subcommittee, which was held in January 2012; the content of the revisions was approved and they were published by the Japan Road Association on July 30, 2012.

Table 3.3.6.8 shows the main content of revisions made in light of the Great East Japan Earthquake. In revising these standards, the factors contributing to the damage were classified into Category I-IV, based on the results of the survey of factors contributing to the damage at nine locations where the damage was particularly severe; then, in relation to each of the contributory factors, the deficiencies and excesses of the provisions and commentary in the existing guidelines were summarized and the content of the revisions considered (Table 3.3.6.9). The Committee concluded from its deliberations that the existing edition of *Highway Earthworks: Guidelines on Embankments* (FY2010 edition) already dealt with the issues in question.

Table 3.3.6.7 Progress of Deliberations by the Road Earthworks Committee of the Japan Road Association

Date	Committee	Matters Considered
2011 October 27	1st Joint Meeting of the Road Earthworks Committee and the Guidelines on Highway Earthworks Investigative Subcommittee	・Establishment of the Disaster Working Group ・Policy on basic surveys of the damage ・Policy on the response by the Road Earthworks Committee
November 11	1st Meeting of the Disaster Working Group	・Policy on the survey of factors contributing to the damage at locations where the damage was severe ・Opinions and queries regarding responses in the Specifications for Highway Bridges concerning the subsidence of approaches at the rear of abutments
December 14	2nd Meeting of the Disaster Working Group	・Opinions and queries regarding responses in the Specifications for Highway Bridges concerning the subsidence of approaches at the rear of abutments ・Results of the survey of factors contributing to the damage ・Policy on responses in the *Guidelines on Retaining Walls* and *Guidelines on Measures to Deal with Soft Ground*
2012 January 19	2nd Joint Meeting of the Road Earthworks Committee and the Guidelines on Highway Earthworks Investigative Subcommittee	・Opinions and queries regarding responses in the Specifications for Highway Bridges concerning the subsidence of approaches at the rear of abutments ・Draft revisions of the *Guidelines on Retaining Walls* ・Draft revisions of the *Guidelines on Measures to Deal with Soft Ground*

Table 3.3.6.8 Content of Main Revisions to the *Guidelines on Highway Earthworks* in Light of the Great East Japan Earthquake

Guideline	Content of Main Revisions
Highway Earthworks: Guidelines on Measures to Deal with Soft Ground (FY2012 edition)	・A stipulation was added concerning liquefaction at points where there was pronounced subsidence of embankments due to high groundwater levels and points where depressions in the original ground surface had been filled. ・The description of construction methods that are effective in curbing deformation due to liquefaction was enhanced.
Highway Earthworks: Guidelines on Retaining Walls (FY2012 edition)	・The provision regarding cases in which concrete foundations for base supports that have become tilted are being replaced was enhanced.

Table 3.3.6.9 Policy on Responses in Light of the Results of the Survey of Factors Contributing to the Damage

Category	Results of the Survey of Contributory Factors	Policy on Response in the Guidelines
I	The water level within the embankment was high at points where runoff water from embankments and the road surface gathers due to catchment topography, and the gliding force at the time of the earthquake was greater than the slip resistance, leading to the collapse of the embankment.	This issue has already been responded to in the *Guidelines on Embankments* (FY2010 edition), by strengthening the stipulation regarding drainage in relation to the installation of a foundation drainage layer and horizontal drainage layers on the berm.
II	At embankments where the foot of the mound is beside the edge of a body of water, such as a pond, even in cases in which the foundation drainage layer reduced the water level within the embankment, the water level reached the height of the foundation subgrade or exceeded it, causing the foundation subgrade to undergo liquefaction.	The following response shall be adopted in the *Guidelines on Measures to Deal with Soft Ground* (FY2012 edition). ・A warning shall be provided concerning places where there is a possibility of liquefaction, such as in cases where the foundation subgrade is sandy soil located adjacent to a body of water, such as a pond.
III	At depressions in the foundation subgrade, there was liquefaction in the thick sand mat layer located below the groundwater level, causing a major collapse.	This issue has already been responded to in the *Guidelines on Embankments* (FY2010 edition), by stipulating the installation of a foundation drainage layer. A stipulation shall be added to the *Guidelines on Measures to Deal with Soft Ground* (FY2012 edition), concerning methods of dealing with places where there is pronounced consolidation settlement and places where there is a large depression or other significant unevenness in the foundation subgrade.
IV	The embankment was built in 1965 on sloping ground with a low-density sand layer, and no particular consideration was given to the design of embankments on sloping ground or retaining walls in the guidelines at that time. Consequently, subsidence has occurred in the embankment and cracks have appeared at the crest of the retaining wall, due to subsidence and slippage.	The *Guidelines on Embankments* (FY2010 edition) already contain a provision regarding responses to unstable sloping ground. The *Guidelines on Retaining Walls* (March 1999) already contain a provision regarding consideration for the stability of retaining walls on sloping ground. The *Guidelines on Retaining Walls* (FY2012 edition) shall contain a further provision regarding cases in which concrete foundations for base supports that have become tilted are being replaced.

(5) Collaboration with the Japan Society of Civil Engineers (JSCE)

In the immediate aftermath of the disaster, the JSCE established the Special Committee on the Great East Japan Earthquake, with the objective of swiftly compiling the outcomes of surveys and research activities relating to the Great East Japan Earthquake; in addition, it established committees that conducted activities focused on individual fields, including disaster phenomena such as tsunami and ground liquefaction, response measures relating to facilities and structures, and approaches to local reconstruction plans and local disaster prevention plans. Representatives of the Bridge and Structures Division at NILIM participated as members of the two committees shown in Table 3.3.6.10. At each committee meeting, the results of field surveys conducted by NILIM were provided, along with information based on the status of deliberations; in addition, at the committee's request, the Tohoku Regional Development Bureau provided information such as schematic drawings of road bridges managed by the Bureau.

Table 3.3.6.10 shows the progress of activities by the two committees. Both committees held briefings, Committee (i) on January 27, 2012, and Committee (ii) on June 26, 2012, at which they presented the results of their deliberations.

Table 3.3.6.10 Progress of Activities by Committees Established by the Japan Society of Civil Engineers

(i) Steel Structure Committee / Special Committee on Surveys of Steel Structures Following the Great East Japan Earthquake

Category	Content		
Purpose of Establishment	This committee was established to ascertain the extent of the damage to steel structures due to the Great East Japan Earthquake and analyze the factors contributing to the damage based on field surveys and past survey reports, and to discuss matters and issues that should be reflected in the design, construction, and erection of steel structures, based on the results of these analyses.		
Progress of Committee Activities	Date	Committee	Matters Considered
	2011 May 10	1st Meeting	・Objectives of the Committee's activities, content of surveys, policy on surveys, etc.
	May 31	2nd Meeting	・Policy on field surveys ・Report on the extent of the damage to road structures on expressways
	October 5	3rd Meeting	・Report on the results of field surveys ・Policy on the compilation of the outcomes of surveys and deliberations
	November 25	4th Meeting	・Compilation of the outcomes of surveys and deliberations
	December 21	5th Meeting	・Compilation of the outcomes of surveys and deliberations
	January 27	Presentation of Report	・*Extent of the Damage to Steel-frame Structures and the Analysis Thereof Report of the Special Committee on Surveys of Steel Structures Following the Great East Japan Earthquake*

(ii) Investigative Committee on Evaluation of Wave Force Inflicted on Bridges by Tsunami (as of October 2012)

Category	Content		
Purpose of Establishment	This committee was established with the objective of clarifying the extent of damage to bridges damaged by the tsunami and conducting deliberations regarding methods of evaluating the wave power acting on bridge structures as a result of tsunami, in order to incorporate specific provisions regarding tsunami load in *Standard Specification for Concrete Structures: Design*, so that this knowledge can be utilized in design in the future.		
Committee Progress of Activities	Date	Committee	Matters Considered
	2011 August 8	1st Full Committee Meeting	・Report on the extent of the damage to road bridges
	November 4	2nd Full Committee Meeting	・Results of surveys of the damage to prestressed concrete bridges, etc. ・Development of a database of field survey results ・Tsunami simulations
	2012 February 2	1st Joint Working Group	・Assignment of topics relating to the status of deliberations by each member
	February 14	3rd Full Committee Meeting	・Results of the analysis of the damage to bridges ・Introduction to the status of deliberations in the field of coastal engineering
	May 18	4th Full Committee Meeting	・Results of the analysis of the damage to bridges ・Results of numerical calculations of tsunami wave power acting on bridge beams
	June 26	Interim Briefing	・Introduction to the results of deliberations in each field

References

1) MLIT Water and Disaster Management Bureau: *Outline of the Report on Damage to Public Works Facilities Under the Jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism Resulting from Disasters in 2011* http://www.mlit.go.jp/river/toukei_chousa/bousai/saigai/kiroku/pdf/h23_houkoku.pdf
2) Cabinet Office: Concerning the Great East Japan Earthquake http://www.kantei.go.jp/saigai/pdf/201208281700jisin.pdf
3) *Quick Report on Damage to Infrastructures by the 2011 off the Pacific coast of Tohoku Earthquake*, Technical Note of National Institute for Land and Infrastructure Management No.626; Technical Note of Public Works Research Institute No.4202, July 2011 http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0646.htm
4) Japan Meteorological Agency website: Number of Aftershocks with a Magnitude of at Least 5.0 http://www.seisvol.kishou.go.jp/eq/2011_03_11_tohoku/aftershock/

3.3.7 Ports and Harbors (including coastal protection facilities in ports)

3.3.7.1 Port Facilities

(1) Damage Surveys

The National Institute for Land and Infrastructure Management dispatched damage survey teams as shown below, for investigating the damage caused to port facilities. All of these surveys were done in cooperation with the Port and Airport Research Institute. The damage surveys were divided into the Tsunami Team, that investigated the tsunami intrusion situation and situation of damages caused by tsunami, and the Earthquake Team that investigated the situation of damages caused by earthquakes.

(1) March 15-19, 2011 One person dispatched to Ishinomaki Port and Sendai Shiogama Port (Earthquake Team)
(2) March 16-19, 2011 One person dispatched to Kamaishi Port and Ofunato Port (Tsunami Team)
(3) March 16-19, 2011 Two people dispatched to Hachinohe Port and Kuji Port (Tsunami Team)
(4) March 27-30, 2011 One person dispatched to Kamaishi Port and Miyako Port (Tsunami Team)
(5) April 5-8, 2011 Two people dispatched to Soma Port and Onahama Port (Tsunami Team, Earthquake Team)
(6) April 5-6, 2011 One person dispatched to Kashima Port and Ibaraki Port (Tsunami Team)
(7) April 12-14, 2011 One person dispatched to Kashima Port and Ibaraki Port (Earthquake Team)

Damages to the port facilities were broadly classified into damages to breakwaters caused by tsunami, and damages to wharves caused by seismic movement. Damages caused to breakwaters by tsunami between Aomori and Fukushima prefectures was remarkable in ports that recorded very huge tsunami waves. In some ports such as Hachinohe Port, Kamaishi Port, and Ofunato Port, there was displacement / overturning / collapse of breakwater caissons, and also massive scouring due to flows (Photo 3.3.7.1)

Damage to the wharves was remarkable at the ports in Fukushima and Ibaraki prefectures. There was very little damage to wharves of northern Miyagi ports, because most of the ports in Miyagi prefecture have thin sedimentary layers compared to the ports of Fukushima and Ibaraki prefectures, which may have prevented strong amplification of the earthquakes. Damage to the wharves was in the form of bulging of head line towards the normal seaward side (Photo 3.3.7.2), as well as sloping of the walls and collapse of the rear apron (Photo 3.3.7.3), etc.

There was remarkable damage to the wharves at Soma and Ibaraki ports, due to seismic movements. Particularly at Soma Port, the wharf collapsed at many places. Apparently, first the seismic movements caused the wharf to bulge towards the sea side, and while the rear apron part was sunken, a rip current of the tsunami caused a huge water level difference, leading to the washout (Photo 3.3.7.4). There are very few examples of such extreme damage caused by the compound action of seismic movements and tsunami.

Photo 3.3.7.1 Soma port breakwater devastation state

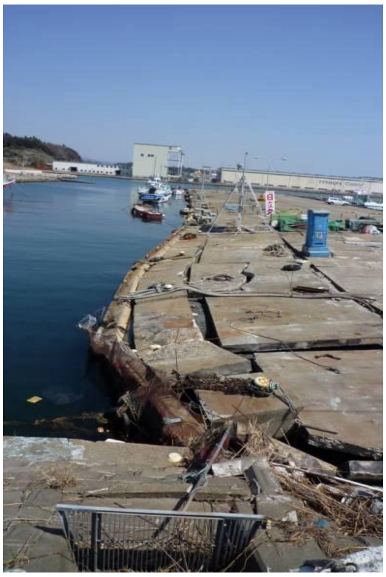


Photo 3.3.7.2 Bulging of wharf head line at Ibaraki Port (Hitachi Minato-ku)

Photo 3.3.7.3 Sunken wharf apron at Onahama Port

Photo 3.3.7.4 Collapsed wharf at Soma Port

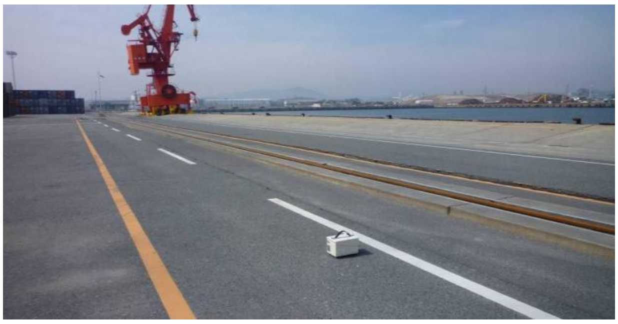
(2) Disaster analysis

A feature of this earthquake damage was that the breakwaters suffered extensive damage at the harbors that reported high tsunami waves as mentioned above, while the scale of damage to wharves in the same harbor varied greatly depending on the district in some cases. This was thought to be because the amplification characteristics (site amplification characteristics) in sedimentary layers from the seismic basement up to the ground surface were different, even at sites that were almost at the same distance from the epicenter. To validate this theory, micro-tremor recording was done at the sites during normal times, including at Onahama, Soma, Kashima, and Ibaraki Ports, where wharves were damaged by seismic movements.

The results at Onahama Port and Kashima Port are given below. At Onahama Port, Pier no. 3 suffered extensive damage, while there was no damage to Pier Otsurugi (Photo 3.3.7.5) The micro-tremors H/V spectrum (ratio of horizontal and perpendicular components of microtremor spectral amplitude during normal times) of both the sites are shown in Fig. 3.3.7.1. The peak frequency of micro-tremor H/V spectrum corresponds to the frequency greatly amplified by the earthquake. If the peak frequency of less than 2Hz can cause significant transformation of the wharf, an earthquake can easily cause damage. The peak recorded at Pier 3 was less than 2 Hz, while it was more than 2 Hz at Pier Otsurugi, which corresponds well with the scale of the damage to these sites.

At Kashima Port, there was a huge contrast between the damage caused to Berths A~B and berths C~D berths at Nankokyo Pier. As shown in Photo 3-3.7.6, the paved surface around berths A~B collapsed, while there was no damage to the adjoining berths C~D. The micro-tremor H/V spectrum for both sites is shown in Fig. 3.3.7.2. The peak of H/V spectrum is not clear in berth D part, while the amplitude is not much above 1. This kind of micro-tremor H/V spectrum in normal times is characteristic of very favorable ground conditions, such as bedrock sites. On the other hand, the micro-tremor H/V spectrum in normal times of berth A part showed a clear peak of approximately 1.5 Hz, which corresponds to the huge damage.

(a) Pier no. 3



(b) Otsurugi Pier

Photos 3.3.7.5 Damage situation of wharf apron at Onahama Port

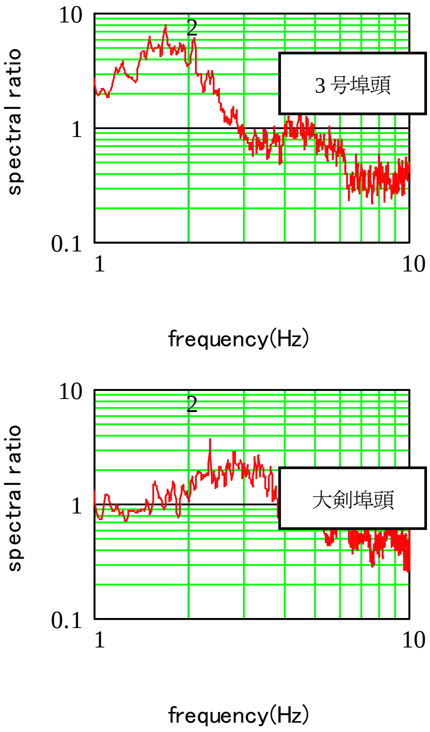


Figure 3.3.7.1 Onahama Port micro-tremor H/V spectrum during normal times

(a) Berth A

(b) Berth D

Photo 3.3.7.6 Damage situation of wharf apron at Kashima port

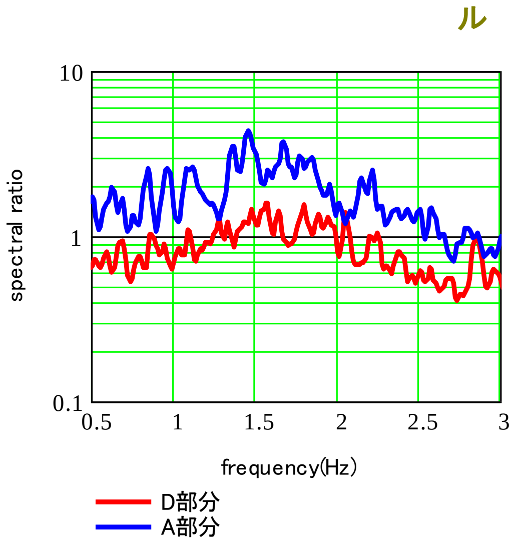


Figure 3.3.7.2 Kashima Port micro-tremor H/V spectrum during normal times

(3) Restoration measure response

As a restoration measure response, advise was provided in response to a request received from the site at Onahama Port. Specifically, the caisson-type wharf at Onahama port was inclined, so the angle of inclination was checked and it was compared with a wharf that had restricted service due to damage caused by a previous earthquake. As for the base of cargo handling crane, the crane base at the land side could use a bearing pile, but the design documents confirmed that some piles were not reaching up to the base support, therefore, it was recommended to make a solid base in case of a need for urgent restoration. It was also suggested to move the sea side base landward, as the transformation of wharf causes the crane rail span to expand.

Moreover, it was decided to generate design seismic movements at the port as time history waveforms reflecting site amplification characteristics, so new level 1 seismic movements were established for ports for which the site amplitude characteristics had not been properly evaluated, in order to contribute to the restoration design. Therefore, aftershocks were observed in several harbors, and the aftershock records and site amplification characteristics were thoroughly evaluated and level 1 seismic movements were established. Fig. 3.3.7.3 shows an example of level 1 seismic movements at Pier No. 1 of Soma Port.

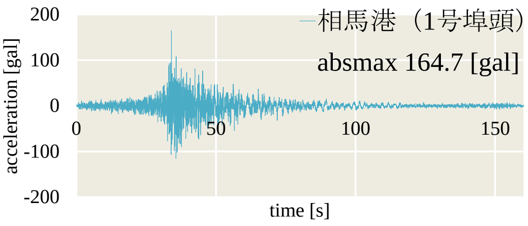


Figure 3.3.7.3 Soma Port level 1 seismic movements

(4) Damage of tsunami-induced debris: cargo containers and others

NILIM dispatched 1 staff member to Hachinohe Port on May 8-9, 2011, to conduct a disaster survey on the driftage of ships, in coordination with staff of Port and Airport Research Institute. They investigated damage of the windbreak fence behind the slipway, which suffered less than other fences around this area, as well as damage of the ships which drifted ashore in this area.

Moreover, NILIM dispatched 1 staff member on June 13, 2012 to the Hitachinaka Port Area of Ibaraki Port, for an interview survey of the tsunami evacuation, and for a field investigation on the driftage of cargo containers. These surveys helped in understanding the tsunami evacuation and the driftage of cargo containers in terminal area. Details of the surveys are referred to in the exiting paper.[1)]

(Summary of Surveys)

(1) May 8-9, 2011: 1 staff member dispatched to conduct disaster surveys at Hachinohe Port

(2) June 13, 2012: 1 staff member dispatched to conduct disaster surveys at Minato-district, Hitachinaka, Ibaraki Port

(a) Damage of fence (North pier section of Minato-district, Hitachinaka Port Area, Ibaraki Port, drifted containers were removed)

(Crown height of walls T.P. + 2.20m, Observed tsunami height T.P. + 4.32m)

Photo 3.3.7.7 Damage of tsunami-induced debris (cargo containers)

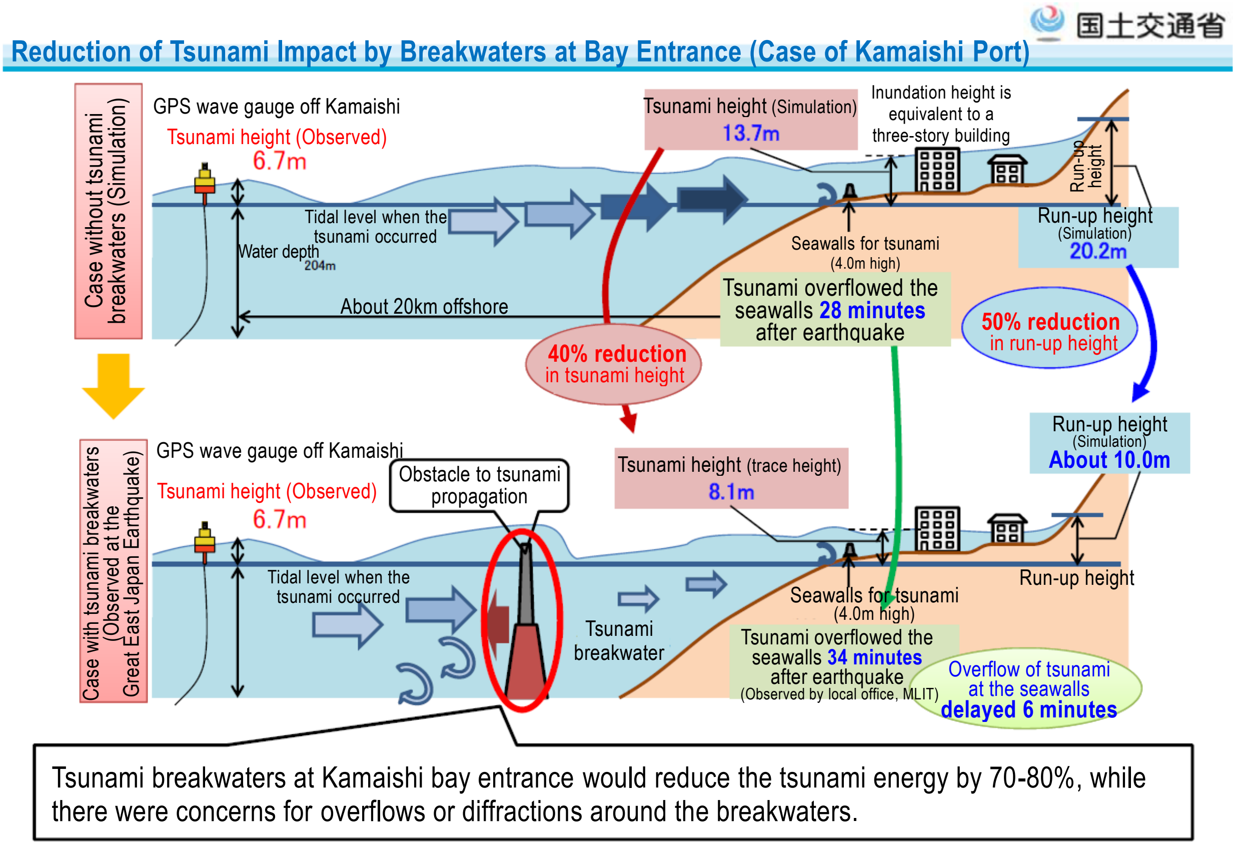
(5) Restoration measures (council, study committee, etc.)

Council and study committees established by the Ministry of Land, Infrastructure, Transport and Tourism deliberated restoration measures, using the data of preceding disaster surveys and related analysis of the Great East Japan Earthquake and subsequent Tsunami, provided by NILIM and the Port and Airport Research Institute.

1) Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council

The Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council was established on May 2, 2011 to report on “Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors” to the Minister. By June 2012 the group had held 6 meetings, and on June 13, 2012 it submitted the report on “Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors”.[2)]

Prior to this report, in July 2011 the group urgently published the “Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (Interim report),”[3)] including the principle of future tsunami assumptions to develop the restoration measures for ports and their hinterlands. The group investigated the failure mechanism of port facilities, such as seawalls and breakwaters, for tsunami, and proposed new comprehensive measures for tsunami, such as the restoration policy for damaged ports in cooperation with urban areas and industries in hinterlands. For the restoration and reconstruction of damaged ports and hinterlands, future hazard assumptions required two levels of tsunami: frequently occurring tsunami and largest-possible tsunami. These assumptions required the measures to be based on the concepts of "disaster prevention" and "disaster reduction," respectively.



Note: Translated tentatively to English by the author based on materials from the Transport Policy Council

Figure 3.3.7.4 Reduction of tsunami impact by breakwaters at bay entrance (case of Kamaishi port) (Material of the 5th Disaster Prevention Group Meeting, Port and Harbor Subcommittee, Transport Policy Council)[5)]

A tsunami breakwater was installed at the bay entrance to reduce the water level rise due to tsunami in inner area, and to prevent injury to human life and property in inner area from tsunami, using revetments, embankments, etc. Fig. 3.3.7.4 shows the reduction of tsunami impact by breakwater at bay entrance at Kamaishi Port, using the hindcast analysis by the Port and Airport Research Institute.[4), 5)] Propagation of tsunami to seawalls was delayed, because the current velocity was decreased with decrease of the wave height by tsunami breakwater. It was effective in gaining time for evacuation of residents. Wave force of tsunami was also decreased with decrease of the current velocity. A tsunami breakwater should have a resilient structure, because it will be difficult to repair it quickly if destroyed, it will reduce the impact of subsequent tsunami, and it will maintain calmness in ports temporarily until the restoration will be completed.

Therefore, NILIM provided various information on effects of tsunami breakwaters, and on damage and failure mechanisms of seawalls in ports shown in Fig. 3.3.7.5,[6)] in association with the Port and

Airport Research Institute. Moreover, NILIM suggested the concept of resilient structures to reduce the damage for largest class tsunami, after specifying the objective of disaster reduction and disaster prevention against the corresponding assumed tsunami, in accordance with the scale and frequency of occurrence, as shown in Fig. 3.3.7.6.[7)]

Based on this, the group prepared a report on basic concepts of comprehensive measures in ports for earthquakes and tsunamis. The report indicated the following 5 viewpoints on restoration measures in ports for the Great East Japan Earthquake and Tsunami: (1) Necessity to specify the objectives for disaster prevention and disaster reduction respectively, and to develop evacuation measures, (2) Clarification of tsunami disaster reduction effects of breakwaters, (3) Necessity to ensure earthquake and tsunami resistance for logistics that support the regional economy, (4) Necessity to respond sequentially over time, from initial response until restoration, and (5) Necessity to build a strong logistics network for disasters.

Accordingly, the group reported basic concepts to specify the objectives for disaster prevention and disaster reduction, through the specification of the corresponding assumed tsunami in accordance with the scale and frequency of occurrence of tsunami, as well as through the review of management and operation systems for floodgates and land locks. Regarding the basic concepts, the group proposed the following measures for earthquake and tsunami in ports, in accordance with the objective of disaster prevention/reduction: protection of hinterland with seawalls, evacuation measures in port, strong and multiple information systems for evacuation: management system based on safety first: as well as automation and remote operations to manage/operate floodgate and land lock.

<Reference: Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council>

(Request for advice to the council)

No. 130: Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (May 2, 2011)

(Process of deliberation)

May 16, 2011: 1st Disaster Prevention Group Meeting

- Analysis of the characteristics of this tsunami, damage of tsunami prevention facilities in ports, and their failure mechanisms

June 3, 2011: 2nd Disaster Prevention Group Meeting

- Assumption of 2 levels of comprehensive measures for tsunami (disaster prevention and disaster reduction)
- Deliberation on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (interim report (draft))"

July 6, 2011: 3rd Disaster Prevention Group Meeting

- Conclusion on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (interim report)"

July 6, 2011 Report on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (interim report)"

February 29, 2012 4th Disaster Prevention Group Meeting

- Picking up the points to discuss "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors"

May 8, 2012: 5th Disaster Prevention Group Meeting

- Deliberation on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (draft)"

June 13, 2012: 6th Disaster Prevention Group Meeting

- Conclusion on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (report)"

June 13, 2012 Report on "Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors (report)" to the Minister

(Members of Disaster Prevention Group (as of

June 13, 2012))

Hitoshi IEDA, Professor, Graduate School of the University of Tokyo

〇Masahiko ISOBE, Professor, Graduate School of the University of Tokyo

Fumihiko IMAMURA, Professor, Graduate School of Tohoku University

Masakazu UCHINO, The Mainichi Newspapers

Kunio OTOSHI, Professor, Kochi University

Takeshi OKI, The Japan Iron and Steel Federation

Toshitaka KATADA, Professor, Graduate School of Engineering, Gunma University

◎Katsuhiko KURODA, Professor Emeritus, Kobe University

Kiyoshi KOBAYASHI, Dean, Graduate School of Management, Kyoto University

Kenji TAWA, Petroleum Association of Japan

Makoto TOYOMA, The Federation of Electric Power Companies of Japan

Motoya HAYATA, Japan Feed Trade Association

Norio MAKI, Associate Professor, Kyoto University

※ ◎: Chairman, 〇: Acting Chairman

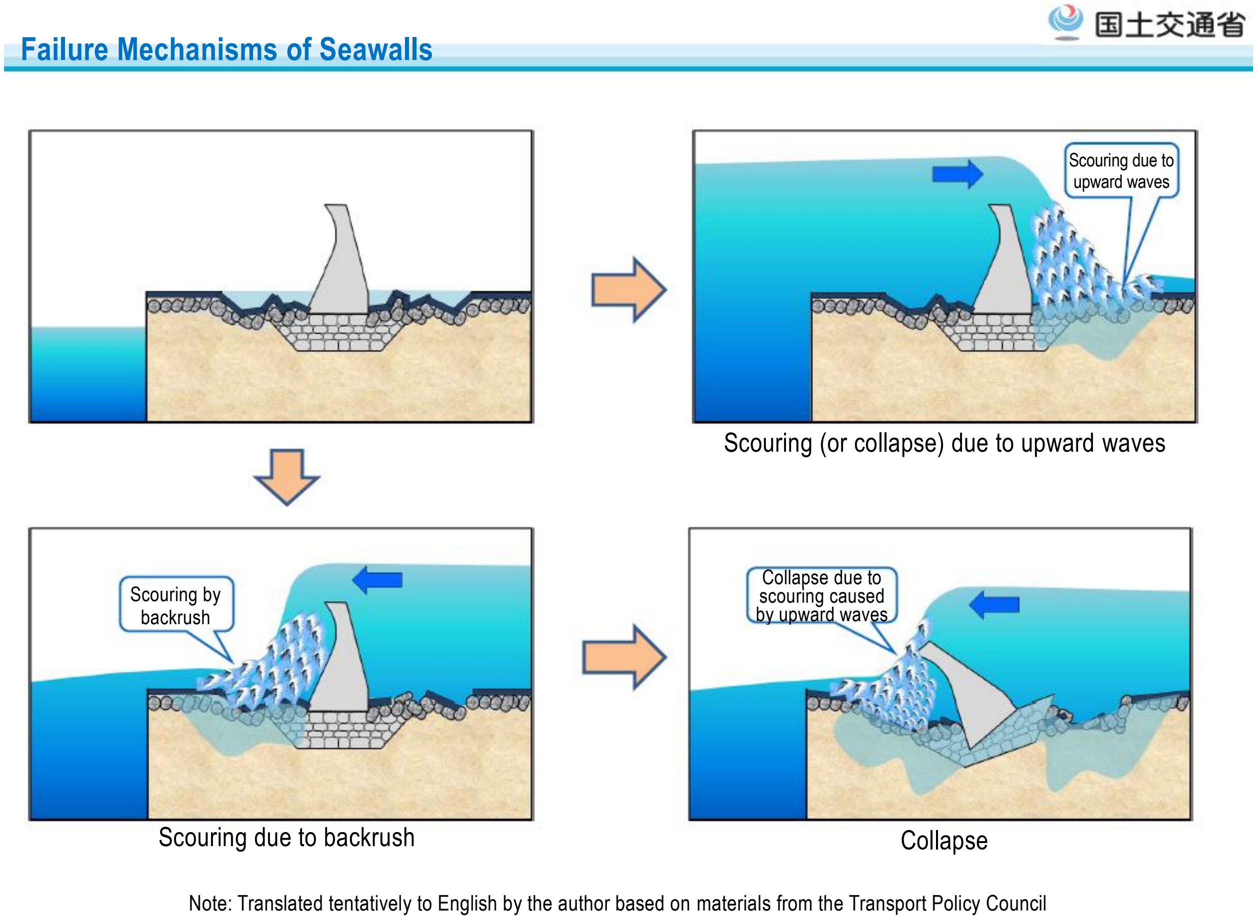
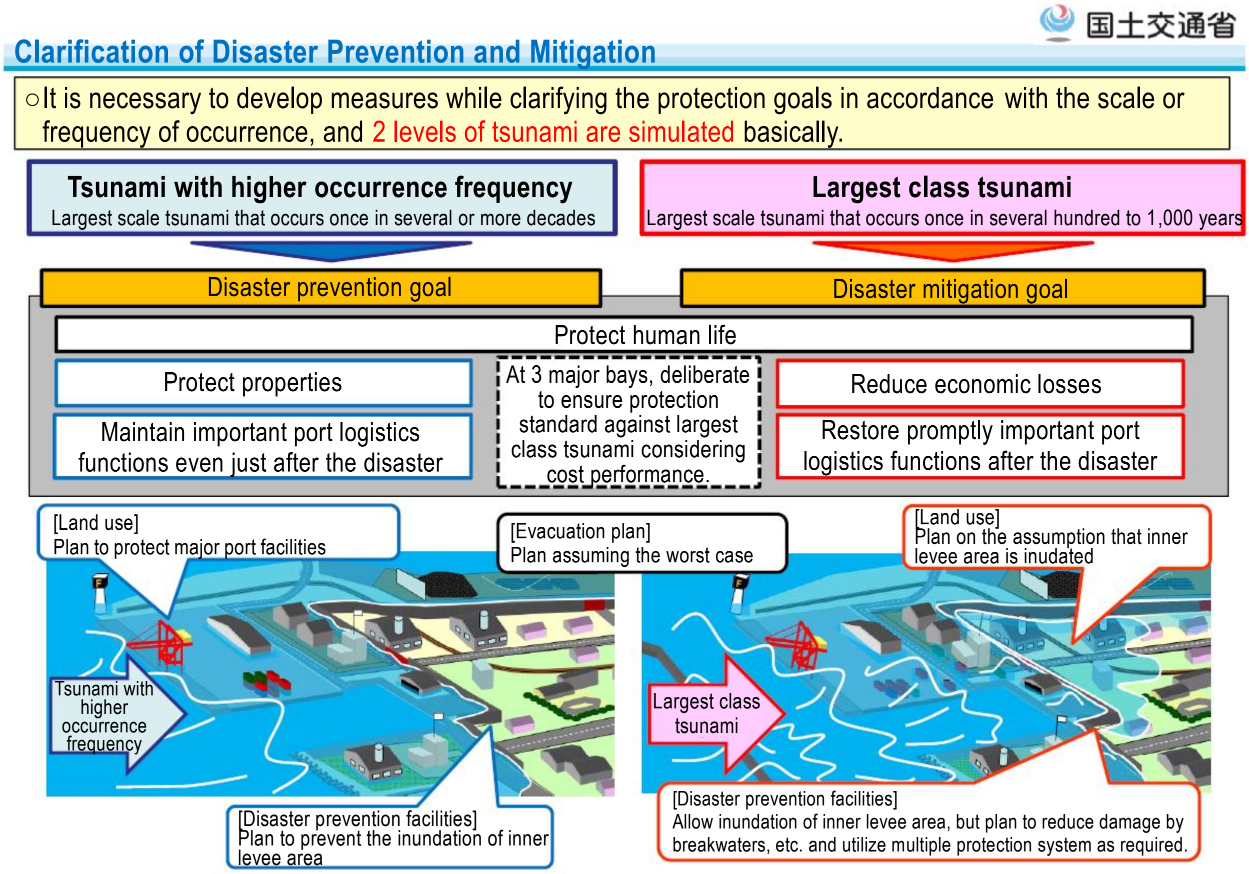


Figure 3.3.7.5 Failure mechanism of seawalls (Material of the 3rd Disaster Prevention Group Meeting, Port and Harbor Subcommittee, Transport Policy Council)[6)]

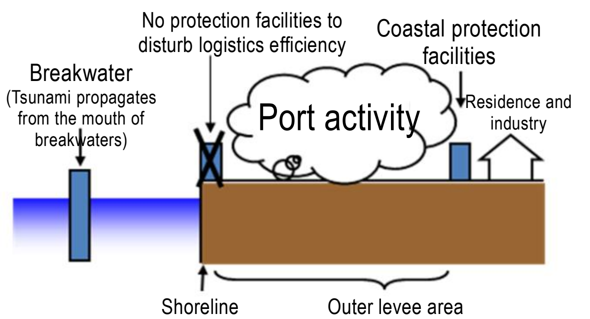


Note: Translated tentatively to English by the author based on materials from the Transport Policy Council

Figure 3.3.7.6 Developing countermeasures to prevent damage for frequently occurring tsunamis and to reduce damage for largest class tsunamis (Material of the 6th Disaster Prevention Group Meeting, Port and Harbor Subcommittee, Transport Policy Council)[7)]

2) Study committee on design Guidelines of seawalls and breakwaters in port for tsunami

The study committee on design guidelines of seawalls and breakwaters in port for tsunami had held 3 meetings during December 2011 to March 2012, to prepare the draft guidelines. A seawall is defined as a structure installed to protect the hinterland from damage due to tsunamis or storm surges. There must be installed many kinds of facilities facing the coastline in a port, so it is difficult to install protection facilities for tsunami, such as revetments and embankments on a coastline. Therefore, as shown in Fig. 3.3.7.7, seawalls are commonly installed in ports. And functioning with seawalls, an offshore breakwater is installed to reduce the water level in the port. It is a general idea to protect life and properties on the hinterland in a port.



Note: Translated tentatively to English by the author based on materials from the Transport Policy Council

Figure 3.3.7.7 Concept of protection measures for tsunamis and storm surges in ports

After the Great East Japan Earthquake and Tsunami, the Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council proposed that future hazard assumptions required two levels of tsunami: frequently occurring tsunami and largest-possible tsunami. These assumptions required measures based on the concepts of “disaster prevention” to protect life and properties on hinterland, and “disaster reduction” to at least protect life with comprehensive measures.

However, there wasn’t enough knowledge available for the designers of practical protection facilities to determine the details of design conditions and procedures for frequently occurring tsunami, and to establish a concept for tsunami resilient structures. The Central Disaster Prevention Council planned to review the assumptions of “Tokai, Tonankai and Nankaido earthquakes,” and, in the future, the council might require introducing a performance design concept for largest-possible tsunami to breakwaters, as well as to high priority facilities such as seawalls, to protect hazardous materials. These issues also faced a lack of knowledge for practical design.

Therefore, the study committee would prepare the guidelines for designers to carry out practical design of breakwaters and seawalls in ports. The study committee discussed the following 5 issues: (1) Scope of guideline, (2) Basic concept of assumed earthquake and tsunami, (3) Basic concept of required performance regarding the objective of corresponding facilities, (4) Concept of standard design condition, examples of performance design simulation and its verification standards, and (5) Concept of tsunami resilient structures.

The study committee improved the existing wave force formula regarding breakwaters for tsunami, while considering overtopping and undulating bores. Firstly, tsunamis are classified as to whether they formulate a undulating bore or not. Propagating the long wave of tsunami into shallow waters, the wave will divide into multiple waves with short periods, and an undulating bore will be created in front of the tsunami. The impact wave force due to bore has extremely large values, which can be clearly underestimated if using the existing formula proposed by Tanimoto. In general, the undulating bore will be created if the sea bottom slope is very loose. The bore will not be created if the ratio of wave height against water depth will be low, or if the sea bottom slope will be relatively steep. Therefore, the exiting formula was improved to adjust the increase of impact wave force due to undulating bore of tsunami.

Moreover, it is also important to ensure the stability of base mound of breakwaters for tsunami, because the stability of main body is damaged due to severe scouring of the base mound. Therefore, hydraulic model experiments were carried out, to investigate the failure mechanism due to the scouring of base mound, and countermeasures against scouring.

To ensure the stability of base mound of breakwaters for tsunami, the study committee investigated the following 3 points: (1) Required mass of covering material for base mound to resist the flow induced by tsunami at the bay entrance (including head part of breakwaters), (2) Required mass of covering material to resist the flow induced by tsunami along the breakwater, and (3) Required mass of covering material for rear side of base mounds to resist the overtopping flow through breakwaters induced by tsunami. The required mass of covering materials at each point was evaluated from velocity of the flow calculated in (1) and (2), respectively. The existing equation proposed by Isbash was applied, to calculate the required mass of covering stones and blocks to resist the flow, introduced in the present technical standards and commentaries for port and harbor facilities. This equation sometimes provides an extremely overestimated required mass, depending on the velocity of flow. In such a case, the required mass of the covering material should be evaluated through hydraulic model experiments, etc.

Regarding the investigation of the study committee, it is proceeding to prepare guidelines, while reviewing the concept of required performance, reviewing the comprehensive measures for tsunami in port reported by Transport Policy Council, investigating the concept of tsunami resilient structures shown in Fig. 3.3.7.8,[7)] investigating the coefficient of water level difference to estimate wave force acting on breakwaters for tsunami, as well as reviewing the concept of performance design for seawalls and its procedures.

<Reference: Study committee on design guidelines of seawalls and breakwaters in port for tsunami>

(Investigation items)

(1) Scope of the guideline
(2) Basic concept of the assumed earthquake and tsunami
(3) Basic concept of required performance regarding to the objective of corresponding facilities
(4) Concept of standard design conditions, and examples of performance design simulation and its verification standards
(5) Concept of tsunami resilient structures

(Progress of investigation)

Dec 12, 2011 1st meeting of study committee

- Direction to revise the technical standards and commentaries for port and harbor facilities, Main items to be included in guidelines, Future schedule of investigation, etc.

Jan 31, 2012 2nd meeting of study committee

- Verification on the performance of breakwaters for tsunami, Report on the disaster reduction effect of breakwaters for tsunami, Tentative report on the hydraulic model experiments and future schedule, etc.

March 9, 2012 3rd meeting of study committee

- Report on the progress of hydraulic model experiments, Investigation of the draft guideline.

(Members)

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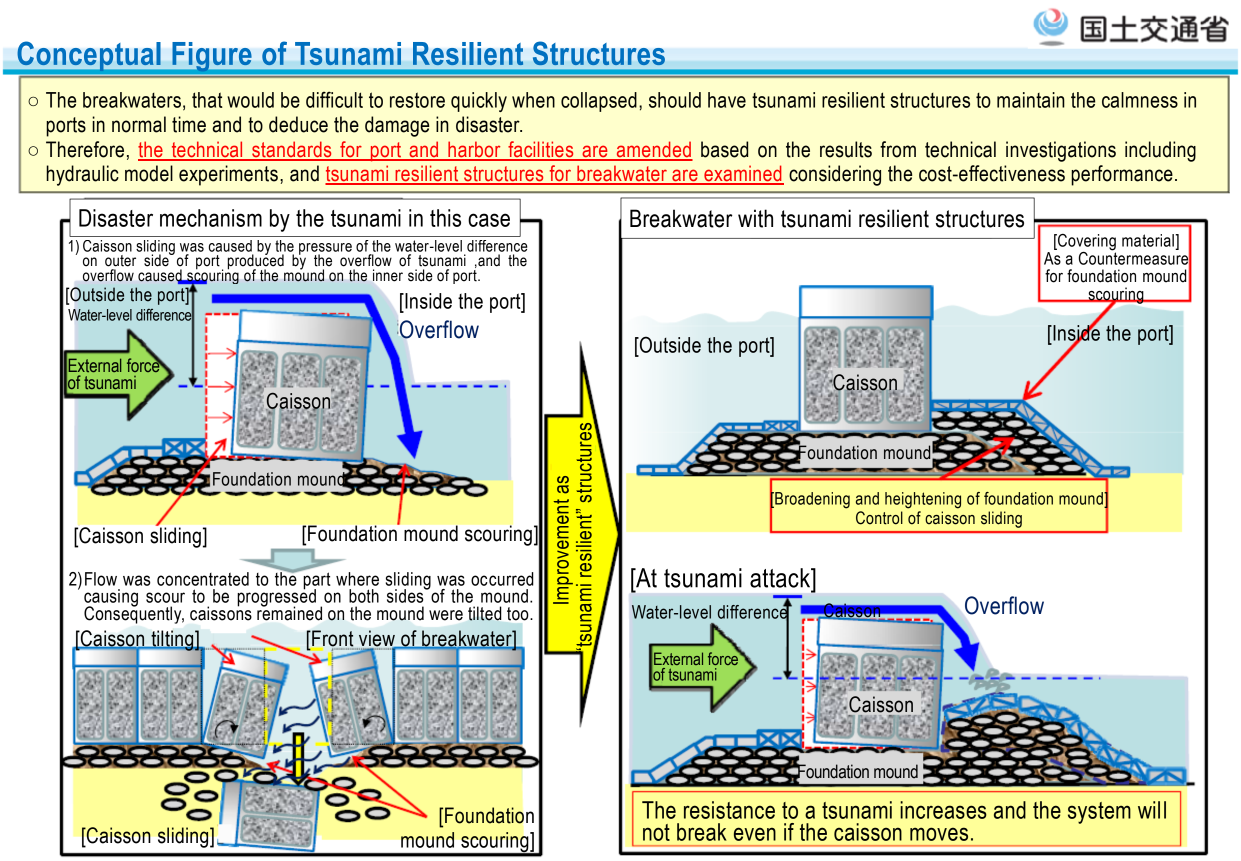
Eiji KOHAMA, Team Leader of Earthquake and Structural Dynamics Group, Earthquake Disaster Prevention Engineering Field

※ ◎ indicates Committee Chairman,
names in parentheses ( ) are predecessors



Note: Translated tentatively to English by the author based on materials from the Transport Policy Council

Figure 3.3.7.8 Example of tsunami resilient structures (Material of the 6th Disaster Prevention Group Meeting, Port and Harbor Subcommittee, Transport Policy Council[7])

Acknowledgements

In conducting disaster surveys, we received the full support of the Tohoku Regional Bureau and Kanto Regional Bureau. In preparing the report, the members of the Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council provided us their earnest and fruitful advices during the deliberations. In preparing the draft guidelines, the members of study committee on design guidelines of seawalls and breakwaters in port for tsunami provided us their earnest and fruitful advices during the discussions. We would like to take this opportunity to express our deep appreciation for their great assistance.

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6) Transport Policy Council, MLIT: Material of the 3rd Disaster Prevention Group Meeting, Port and Harbor Subcommittee, 2011 (in Japanese).
7) Transport Policy Council, MLIT: Material of the 6th Disaster Prevention Group Meeting, Port and Harbor Subcommittee, 2012 (in Japanese).

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http://www.ysk.nilim.go.jp/oshirase/uc.html
http://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/index.html
2) Ministry of Land, Infrastructure, Transport and Tourism website: Information related to Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council (in Japanese)
http://www.mlit.go.jp/policy/shingikai/s303_kouwanbousai01.html

3.3.7.2 Coastal protection facilities in ports

(1) Damage survey, on-site response

1) Activities of TEC-FORCE[1)]

The disaster surveys described in 3.3.7.1 (1) include the surveys on coastal protection facilities in ports, as well as on port facilities. The Coastal, Marine and Disaster Prevention Department and the Port and Harbor Department, NILIM, dispatched 8 staff members for 7 series of surveys during March 16-30 (including 4 staff members for 3 series of surveys, from the Coastal, Marine and Disaster Prevention Department), to investigate the tsunami traces and the damages to the coastal protection facilities in ports, as well as to the port facilities. All the investigations were carried out in cooperation with staff of the Port and Airport Research Institute.

(a) Collapsed seawalls in Ichikawa district, Hachinohe Port
(Crown height of walls T.P. + 5.4m, Observed tsunami inundation height T.P. + 8.38m)
Photo 3.3.7.8 View of disaster survey on coastal protection facilities

Photo 3.3.7.8 shows a collapsed revetment in Ichikawa district, Hachinohe Port. The details of disaster surveys were posted on the web site as a prompt report, as well put into the report[1)] of urgent survey with Port and Airport Research Institute.

(Summary of Surveys: Portions by the Coastal, Marine and Disaster Prevention Department, NILIM)

(1) March 16-19, 2011 1 staff member dispatched to conduct disaster surveys at Kamaishi Port and Ofunato Port

(2) March 16-19, 2011 2 staff members dispatched to conduct disaster surveys at Hachinohe Port and Kuji Port

(3) March 27-30, 2011 1 staff member dispatched to conduct disaster surveys at Kamaishi Port and Miyako Port

(Release of Prompt Report)

(1) March 24, 2011 Damages for Tsunami at Kamaishi Port and Ofunato Port

(2) March 24, 2011 Damages for Tsunami at Hachinohe Port and Kuji Port

(3) March 31, 2011 Damages for Tsunami at Kamaishi Port and Miyako Port

2) Damages of coastal protection facilities[2)]

The Coastal, Marine and Disaster Prevention Department dispatched 6 staff members for 3 series of surveys during June 16 to September 1. They conducted disaster surveys on coastal protection facilities, to investigate the damage of facilities, and to understand the causes of failures. The details of disaster surveys were included in the technical notes[2)] of NILIM.

The seawall type of coastal protection facilities are more commonly installed in port areas and fishing port areas, compared to levees or revetments. Thus, the field survey on coastal protection facilities was focused on the seawalls in port areas, to investigate the details of damages, and to understand the causes of failures. Photo 3.3.7.9 shows some examples of tsunami damage to coastal facilities.

(Summary of Surveys)

(1) June 16-17, 2011 2 staff members dispatched to conduct disaster surveys on coastal protection facilities at Ofunato Port.

(2) July 19-20, 2011 2 staff members dispatched to conduct disaster surveys on coastal protection facilities at Kesennuma Port

(3) Aug 30-Sept 1, 2011 2 staff members dispatched to conduct disaster surveys on coastal

protection facilities at Ogatsu Port, Onagawa Port, Oginohama Port, Ishinomaki Port, and Matsushima Port

(Release of Prompt Reports)
(1) June 27, 2011 Damages of coastal protection facilities at Ofunato Port
(2) Aug 15, 2011 Damages of coastal protection facilities at Kesennuma Port
(3) Oct 31, 2011 Damages of coastal protection facilities at Ogatsu Port, Onagawa Port, Oginohama Port, Ishinomaki Port, and Matsushima Port

These surveys revealed the damage of seawalls and revetments in coastal protection facilities at 20 areas in 7 ports along the coast of Iwate and Miyagi prefectures.

(a) Seawalls collapsed to landside (Chayamae district, coastal protection area in Ofunato Port) (Crown height of walls T.P. + 3.40m, Observed tsunami trace height T.P. + 8.07m)

(b) Seawalls collapsed to seaside (Nagahama district, coastal protection area in Ofunato Port) (Crown height of walls T.P. + 3.00m, Observed tsunami trace height T.P. + 10.02m)

(c) Scouring observed on seaside (Suga district, coastal protection area in Kamaishi port) (Crown height of walls T.P. + 4.00m, Observed tsunami trace height T.P. + 8.64m)

Photos 3.3.7.9 Tsunami damage to coastal protection facilities

As for the damage of seawalls, “collapse of main body” appeared with following failure patterns: 1-(1) development of cracks, 1-(2) damage due to collision of driftage, and 1-(3) removal of top part from joint of main body. Extent of damage was least in (1) and largest in (3). “Scouring and displacement of main body” appeared with the following failure patterns: 2-(1) slight scouring of paved ground in front and behind the main body, 2-(2) extensive wash away of ground due to current, 2-(3) collapse of main body due to wave force and subsequent scouring, 2-(4) ground subsidence of entire area, requiring embankment. “Dysfunctional operations” appeared with the following failure pattern: 3-(1) incomplete operation of flap-board valve. Additionally, in a past disaster survey, the seawalls at Kuji Port showed 3-(2) obstruction of passage through land lock.

(2) Damage analysis and restoration measures response

A council and study committee established by the Ministry of Land, Infrastructure, Transport and Tourism deliberated restoration measures, using the data of preceding disaster surveys and related information on the Great East Japan Earthquake and subsequent Tsunami, provided by NILIM and the Port and Airport Research Institute.

1) Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council

The Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council was established on May 2, 2011 to report “Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors” to the Minister. By June 2012 the group had held 6 meetings, and on June 13, 2012 it submitted the report on “Comprehensive Measures for Earthquake and Tsunami in Ports and Harbors.” NILIM provided various information to support the group meetings, in association with the Port and Airport Research Institute.

As shown in Fig. 3.3.1(5) 2), seawalls are commonly installed in ports. And functioning with seawalls, an offshore breakwater is installed to reduce the water level rise in the port. It is a general idea to protect life and properties on hinterland in port. Coastal protection facilities in ports are expected to have same function for disaster prevention. Therefore, the outcomes for seawalls should be applied to those for coastal protection facilities, such as failure mechanisms, concept of tsunami resilient structures for largest-possible tsunami, etc.

2) Study committee on measures for tsunami in coastal area

The study committee on measures for tsunami in coastal area held 4 meetings from April to November 2011, and reported “Basic Concepts on Restoration of Coastal Facilities Damaged by the 2011 off the Pacific Coast of Tohoku Earthquake and Tsunami”[4)] in November 2011, as recommendations.

As mentioned in 1) above, seawalls are more commonly installed in ports, compared with revetments, embankments, etc. And functioning with seawalls, an offshore breakwater is installed to reduce the water level rise in the port. It is a general idea to protect life and properties on hinterland in port. Therefore, NILIM organized the damage of seawalls and related information, and revealed the issues for their restoration. This information was reflected in the recommendation. In cooperation with other bodies, NILIM investigated the failure mechanisms for seawalls, and suggested the measures for their restoration.

Acknowledgments

In conducting disaster surveys, we received the full support of the Tohoku Regional Bureau. Especially, Mr. Norihiko NAGAO, deputy-director of Kamaishi Port Office, and Mr. Motokazu AYUKAI, assistant manager of the Port and Airport Division, were kind enough to help us to conduct disaster surveys on seawalls in the field. In preparing the report, the members of the Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council provided us with their earnest and fruitful advices during the deliberations. In preparing the recommendation, the members of the study committee on measures for tsunami in coastal provided us with their earnest and fruitful advices during the discussions. We would like to take this opportunity to express our deep appreciation for their great assistance.

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1) Shigeo TAKAHASHI, Kazuhiko TODA,

Yoshiaki KIKUCHI, Takahiro SUGANO, Yoshiaki KURIYAMA, Hiroyuki YAMAZAKI, Takashi NAGAO, Ken-ichiro SHIMOSAKO, Takashi NEGI, Jinkatsu SUGENO, Takashi TOMITA, Hiroyasu KAWAI, Yasuhiro NAKAGAWA, Atsushi NOZU, Osamu OKAMOTO, Kojiro SUZUKI, Yoshiyuki MORIKAWA, Taro ARIKAWA, Mitsuyasu IWANAMI, Taka-aki MIZUTANI, Eiji KOHAMA, Toru YAMAJI, Kentaro KUMAGAI, Daisuke TATSUMI, Makoto WASHIZAKI, Takuya IZUMIYAMA, Katsumi SEKI, Gyeong-Seon YEOM, Masahiro TAKENOBU, Hiroaki KASHIMA, Masayuki BANNO, Yusuke FUKUNAGA, Jyun-ichiro SAKUNAKA and Yuji WATANABE: Urgent Survey for 2011 Great East Japan Earthquake and Tsunami Disaster in Ports and Coasts, Technical Note of PARI, No. 1231, 200p, 2011 (in Japanese).

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2) Ministry of Land, Infrastructure, Transport and Tourism website: Information related to Disaster Prevention Group, Port and Harbor Subcommittee, Transport Policy Council (in Japanese)
http://www.mlit.go.jp/policy/shingikai/s303_kouwanbousai01.html

3.3.8 Airport

(1) Overview of Damage

During the Great East Japan Earthquake, tremors measuring 6 on the Japanese seismic intensity scale were observed in the cities of Natori and Iwamura, where Sendai Airport is located.

Immediately after the earthquake, staff from the Sendai Airport Office began urgent inspection of the airport facilities. But a tsunami warning (6 m in height) was issued for the coastal areas of Miyagi Prefecture, so the urgent inspection was halted and the staff evacuated to the office building. Subsequently, the forecast height of the tsunami was revised to "at least 10m in height", and the tsunami actually arrived at Sendai Airport about 70 minutes after the earthquake.

Photograph 3.3.8.1 shows the situation at the airport at around 14:00 on March 12, the day after the earthquake. At this point, although the pavement surface of Runway B, which is at a higher elevation, has already been exposed, the runway strip and the area around Runway A are submerged. It is thought that it remained submerged for a long time because the area around Runway A is at a lower elevation than the other areas of the airport.

During the period March 21-27, NILIM, the Civil Aviation Bureau and the Port and Airport Research Institute conducted a survey focused mainly on the asphalt and concrete pavement of the runway, taxiway, apron, etc in order to check and assess the damage to the pavement, as well as identifying the areas that needed to be repaired before reopening of the airport. Figure 3.3.8.1 shows the site plan of the airport and the damage status. The following provides details of the damage to the runway, taxiway, and apron.

Photo 3.3.8.1 Situation at Sendai Airport around 14:00 on March 12, 2011
(photograph by the Geospatial Information Authority of Japan)

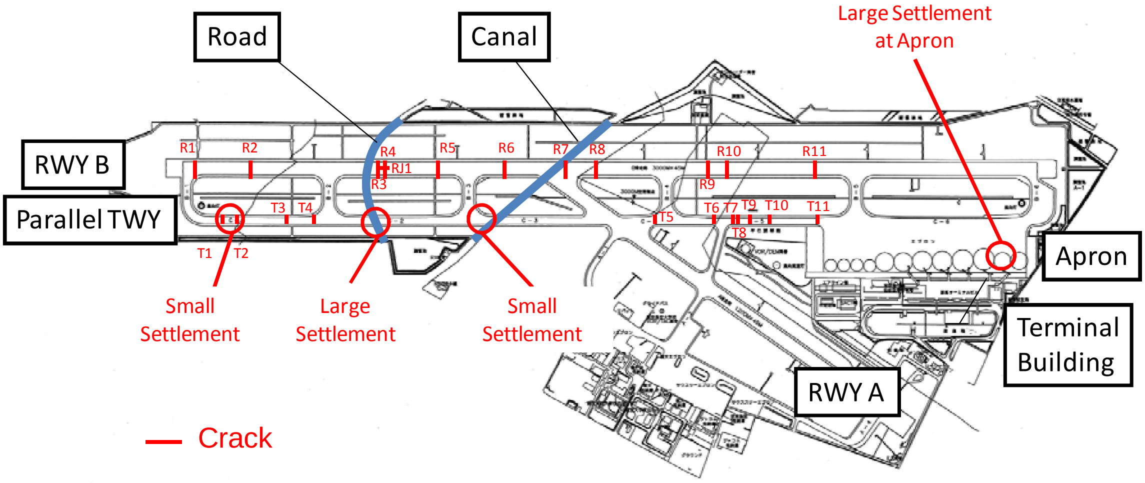

Figure 3.3.8.1 Status of Damage to Pavement

(2) Damage to the Runway

Both of the runways at the airport are made of asphalt pavement. However, Runway A was being used as a temporary space for storing vehicles that had been washed up at the airport as a result of the tsunami. Accordingly, a survey of Runway B was carried out, with a view to reopening the airport.

As a result of visual inspection of Runway B, it was confirmed that there was a total of 12 cracks, as shown in Figure 3.3.8.1. Almost all of the cracks ran in a transverse direction across the whole width of the runway. The cracks were around 5mm at their widest and the faulting of the crack was also around 5mm at most; no cracks were found that appeared likely to impede the passage of aircraft. As a result of core drilling at three points along the cracks, it was confirmed that in all of the cores, the crack penetrated the whole thickness of the asphalt concrete layer (surface course, binder course, and asphalt stabilized base).

The road and canal run underground north to south below the airport. With regard to the two points where the road and canal intersect with Runway B, liquefaction had been forecast even before the earthquake occurred, so soil stabilization had already been carried out. Therefore, there were no areas where the evenness of the runway had deteriorated.

(3) Damage to the Taxiway

As a result of visual inspection of the parallel taxiway and other taxiways, it was confirmed that there was a total of 11 cracks in the parallel taxiway, as shown in Figure 3.3.8.1. Almost all of the cracks ran in a transverse direction across the whole width of the taxiway. The cracks were around 3mm at their widest, but no faulting was found at any of the cracks.

As shown in Figure 3.3.8.2, localized settlement due to liquefaction was found (i) at Taxiway C1, at the westernmost point of the parallel taxiway; (ii) at the point where the underground road intersects with the parallel taxiway (hereinafter referred to as the road intersection); and (iii) at the point where the underground canal intersects with the parallel taxiway (hereinafter referred to as the canal intersection). The occurrence of liquefaction at these points had been forecast even before the earthquake occurred, so soil stabilization was in the process of being carried out. But localized settlement occurred at points where stabilization had not yet been carried out at the time of the earthquake.

Photograph 3.3.8.2 shows the situation in regard to localized settlement at the road intersection. At this point, the settlement that occurred followed the edge of the box culvert for the road. Although the shape of the settlement was not measured, the width of the settlement was around 5m on both sides of the box culvert, while the depth of the settlement was a few dozen centimeters at the shoulder of parallel taxiway.

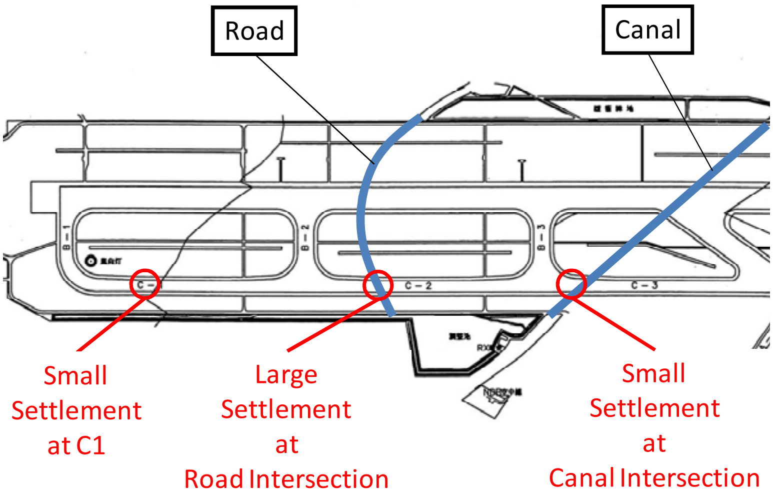

Figure 3.3.8.2 Positions of Areas of Settlement due to Liquefaction on the Parallel Taxiway

(a) Shoulder (forefront) and taxiway

(b) Shoulder (left) and taxiway

Photo 3.3.8.2 Status of Localized Settlement at the Road Intersection

(4) Damage to the Apron

The apron is made of jointed plain concrete pavement. The designed bearing capacity factor of the granular base is $70MN/m^3$, while the thickness of the concrete slabs is 42cm. The initial declivities of the apron had been a gradient of 0.5% in the direction of the terminal side and the Runway B side, with the joint between the 15th and 16th row of slabs in Figure 3.3.8.3 forming the boundary.

As a result of visual inspection of the apron, numerous cracks and settlement were found at aircraft stands #1, #2, and #3 on the eastern side of the apron. The positions of the cracks and the height of the apron are shown in Figure 3.3.8.3. There was considerable settlement on the eastern side of aircraft stand #1, around the center line of aircraft stand #2, and the middle of aircraft stand #3.

The cracks in the apron were around 3mm at their widest, but no faulting was found at any of the cracks. Moreover, no faulting was found at the joints between the concrete slabs. These cracks were concentrated around the areas of localized settlement. So rather than having been caused by seismic motion, it was thought that these cracks had occurred as a result of considerable localized settlement of the slabs due to liquefaction of the ground.

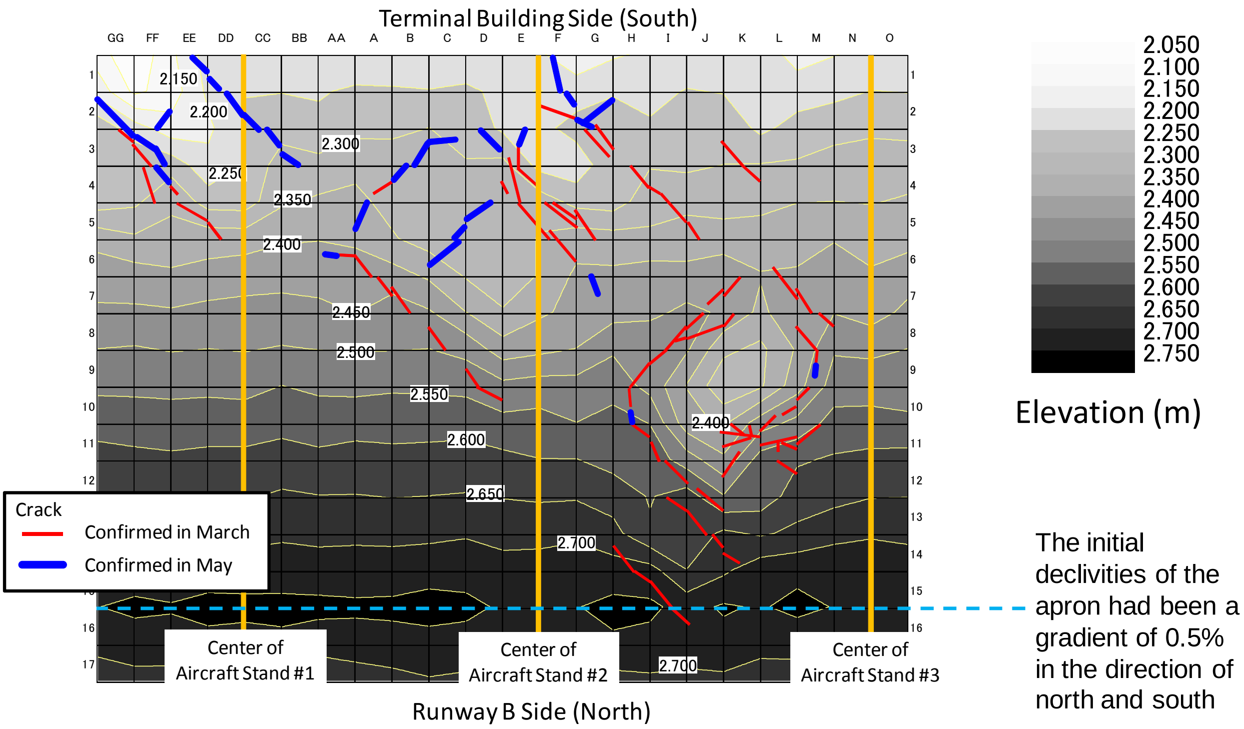

Figure 3.3.8.3 Apron Cracks and Height (squares represent a single slab of concrete (7.5m×7.5m))

(5) Repair Work

Table 3.3.8.1 provides a chronological summary of the repair work carried out at the airport from the immediate aftermath of the earthquake. Repair work was carried out over the following three stages, with a view to reopening the airport at the beginning of April.

・Stage 1

Rubble clearance and other work was carried out, with the goal of opening 600m of the eastern side of Runway B and part of the apron for helicopters transporting emergency supplies and conducting search and rescue operations. Usage of these areas commenced on March 15, four days after the earthquake occurred.

・Stage 2

Rubble clearance and other work was carried out, with the goal of opening 1,500m of the eastern side of Runway B for aircraft transporting emergency supplies. Usage of these areas commenced on March 16, five days after the earthquake occurred. Rubble clearance and other work continued thereafter and usage of 3,000m of Runway B commenced on March 29, 18 days after the earthquake occurred.

・Stage 3

With the goal of reopening the airport for civil aviation, areas that needed to be repaired before reopening were considered with reference to the results of the aforementioned survey and falling weight deflectometer (FWD) tests. As a result, it was decided that the parts of the apron with localized settlement would remain closed for the time being; the cracks on the runway and taxiway were repaired using sealing materials and the sections of pavement on the parallel taxiway that had suffered localized settlement were replaced. Following this, a limited number of domestic flights began operating on April 13, 33 days after the earthquake occurred.

After reopening of the airport, repair work at aircraft stand #3 was carried out in order to meet the deadline for the start date of international flights, which were due to commence on July 25.

First, the concrete slabs were cut into cube-shaped chunks on the apron and lowered artificially in order to fill the void underneath the slabs. Next, an asphalt mixture was paved over them. Usage of these areas commenced on July 25.

Subsequently, soil stabilization and concrete pavement replacement work was carried out in regard to the parts of the apron that had suffered settlement, and full-scale repair work was completed by the end of FY2011.

Table 3.3.8.1 Overview of Repair Work

Date	Number of Days Since the Earthquake	Situation/Response
March 11	0	14:46 Earthquake occurs 14:47 Sendai Airport Office commences urgent inspection 14:49 Tsunami warning issued (6 m in height) 15:14 Tsunami warning updated (at least 10m in height) 15:59 Tsunami reaches Sendai Airport
March 13	2	07:30 Alert downgraded from tsunami warning to tsunami advisory 17:58 Tsunami advisory lifted Checks of damage status commence
March 14	3	Work to remove soil, sand, and rubble commences
March 15	4	Interim use of Runway B (600m on the eastern side) commences (restricted to helicopters for search and rescue operations)
March 16	5	Interim use of Runway B (1,500m on the eastern side) commences (restricted to aircraft transporting emergency supplies)
March 20	10	Drainage work by the River Bureau commences (some had already commenced on March 13)
March 29	18	Interim use of Runway B (3,000m) commences (restricted to aircraft transporting emergency supplies)
April 13	33	Sendai Airport reopens Limited domestic flights begin operating
July 25	136	Regular domestic flights begin operating Limited international flights begin operating
September 25	198	Regular International flights begin operating

Acknowledgments

In writing this report, we received various data from the Civil Aviation Bureau, the Sendai Airport Office, the Tohoku Regional Development Bureau and the Sendai Port and Airport Technology Survey Office at the Ministry of Land, Infrastructure, Transport and Tourism. We would like to express our profound gratitude to all concerned.

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2) Tsubokawa, Y., Mizukami, J., Hata, I., Maekawa, R.: *Report on Damages of Pavement at Sendai Airport due to 2011 Tohoku Region Pacific Coast Earthquake*, Technical Note of National Institute for Land and Infrastructure Management, No.680, 2012.

3.3.9 Building

3.3.9.1 Damages Survey, Field Support

The National Institute for Land and Infrastructure Management (NILIM) in conjunction with the Building Research Institute (BRI) was preparing to respond to calls for help in regions damaged by the earthquake this time. It started its activities with the preliminary investigation of the sites in order to plan countermeasures against future earthquakes or flooding from Tsunami on the basis of the current status of damage mainly to buildings and the "NILIM and BRI Joint Council to Study an Action Plan for Mitigation of Building Damage from Earthquakes" shall be held on March 12 (Saturday) from 9 a.m.

A team of 49 persons from NILIM and 91 persons from BRI was dispatched 43 times in all to the damaged areas in Aomori, Iwate, Miyagi, Yamagata, Fukushima, Ibaraki, Tochigi, Chiba, Tokyo and Kanagawa prefectures over a period of about 10 months by January 27, 2012, to survey the damage from the earthquake, tsunami and fire, mainly to buildings, in response (about 2 weeks after the earthquake) to the appeal of the Housing Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. The execution status of the damage survey is shown in Table 3.3.9.1.

Table 3.3.9.1 Status of Damage Survey

	Period	Place	Number of persons dispatched		Details	Requested by
			NILM	BRI		
1	2011 March 12	Ibaraki	1	1	Investigation of damage to the Ibaraki Airport terminal building from caving of the ceiling.	Housing Bureau
2	March 14	Ibaraki	-	1	Investigation of the danger of prefectural houses (wooden houses) collapsing from liquefaction	Kanto Regional Bureau
3	March 14 - 16	Iwate Miyagi	1	3	Investigation of damage to wooden buildings from earthquake vibration	Housing Bureau
4	March 14 - 15	Fukushima	2	2	Investigation of damage to RC building s from earthquake vibration	Housing Bureau
5	March 15	Ibaraki	1	2	Investigation of damage to general buildings from earthquake vibration	Housing Bureau
6	March 16	Ibaraki	1	3	Investigation of damage to general buildings from earthquake vibration	Housing Bureau
7	March 23	Ibaraki	1	2	Investigation of damage to wooden buildings from earthquake vibration	Housing Bureau
8	March 24-26	Miyagi Fukushima	2	3	Investigation of damage to RC buildings from earthquake vibration	Housing Bureau
9	March 24 -25	Fukushima Tochigi	1	1	Investigation of damage to wooden buildings from earthquake vibration	Housing Bureau
10	March 24	Ibaraki Chiba	1	2	Investigation of damage to building foundation from earthquake vibration	Housing Bureau
11	March 25	Ibaraki	-	4	Investigation of damage to wooden buildings from earthquake vibration	Housing Bureau
12	March 30 -31	Ibaraki	1	1	Investigation of damage to steel buildings from earthquake vibration	
13	March 30 -31	Ibaraki	-	3	Investigation of damage to steel buildings from earthquake vibration	
14	March 30 -April 2	Iwate Miyagi	2	3	Investigation of damage to general buildings from tsunami	
15	March 31	Chiba	1	1	Investigation of damage to general housing from liquefaction	Kanto Regional Office
16	March 31 -April 3	Miyagi Iwate	1	-	Investigation of sites by the Ministry of Land, Infrastructure, Transport and Tourism for understanding the status of devastation and urgent restoration	
17	April 6 -9	Iwate Miyagi	1	4	Investigation of damage to general buildings from tsunami. Jointly conducted with the Port and Airport Research Institute.	
18	April 6 -9	Miyagi	3	3	Investigation of damage to wooden buildings from tsunami	
19	April 8 -10	Miyagi	-	1	Investigation of damage to buildings from fire induced by earthquakes. Jointly conducted with the Tokyo University of Science.	
20	April 11-12	Ibaraki	1	2	Investigation of damage to steel buildings from ground shaking	
21	April 12	Ibaraki	-	2	Investigation of damage to steel buildings from ground shaking	
22	April 15-16	Miyagi Fukushima	2	1	Investigation of damage to building land from ground shaking	
23	April 20-22	Miyagi Iwate	3	-	Investigation of damage to buildings from fire caused by earthquakes	
24	April 21-22	Miyagi Fukushima	3	2	Investigation of damage to buildings conducted by the C Building construction standard committee of NILIM	
25	April 21	Ibaraki	1	4	Investigation of damage to wooden buildings from ground shaking	
26	April 24-26	Miyagi	-	2	Investigation of damage to buildings from fire caused by earthquakes	
27	April 26 -28	Aomori	2	-	Investigation of damage to buildings from fire caused by earthquakes	
28	April 27 -29	Miyagi Tochigi	1	4	Investigation of damage to wooden buildings from ground shaking	
29	May 11 -14	Fukushima Ibaraki Tochigi	1	4	Investigation of damage to RC buildings from ground shaking	

30	May 24 -27	Iwate Miyagi	1	6	Investigation of damage to wooden buildings from tsunami	
31	June 1 -2	Miyagi Yamagata	2	3	Investigation of damage to steel buildings from ground shaking	
32	June 27 -30	Miyagi	-	2	Investigation of damage to general buildings from tsunami. Joint investigation with ASCE.	
33	June 30 -July 2	Iwate	1	1	Investigation of damage to general buildings from tsunami. Joint investigation with ASCE.	
34	June 30	Ibaraki	-	2	Investigation of damage to steel buildings from ground shaking	
35	July 1	Ibaraki	1	2	Investigation of damage to steel buildings from ground shaking	
36	July 4	Tokyo	2	1	Investigation of damage to steel buildings from ground shaking	
37	July 6	Ibaraki	1	2	Investigation of damage to steel buildings from ground shaking	
38	July 8	Miyagi	2	1	Investigation of damage to steel buildings from ground shaking	
39	Aug 29 -30	Miyagi	1	-	Investigation of damage to fire-proof buildings from ground shaking. Jointly conducted with the maintenance department of NILIM.	
40	Aug 31 -Sep 1	Miyagi	1	2	Investigation of damage to general buildings from ground shaking. Jointly investigated with the American research team (members of UJNR) .	
41	Sep 22 -24	Miyagi	1	2	Investigation of damage to wooden buildings (public housing) from tsunami	
42	Oct 13-16	Miyagi	1	5	Investigation of damage to wooden buildings from tsunami	
43	Nov 30	Kanagawa	2	1	Investigation of damage to steel buildings from ground shaking	

Considering the status of damage seen, there was a need to review the technical standards applicable to safety measures. The "Building Structure Standards Committee" was therefore set up in April, which surveyed the sites to draft the technical standards for building construction with the help of experts. The committee studied the status of earthquake damage perceived in the initial stage and set up the tasks related to damage caused by tsunami, liquefaction, ceiling collapse, or falling escalators and the like in the course of the project of updating the standards for collection and organization of the technical knowhow required to draft and revise the technical standards of the nation, and carried out survey research with external help.

3.3.9.2 Damage to buildings from earthquakes

The committee first analyzed the records of observation of effects on buildings and ground for example from ground shakings in the course of the investigation of damage to buildings from earthquakes. It also conducted a detailed analysis of ground liquefaction and non-structural elements in addition to different type of structures of reinforced concrete buildings, steel buildings, wooden buildings and earthquake-proof buildings based on field investigation of damage and its result. The summary is given below.

(1) Ground shaking and response analysis

The following characteristics were confirmed on analysis of the observation records.

Several long-period and high level strong motion seismograms caused by the destructive process in the epicentral area of the main quake were extensively observed. Large-amplitude records on the numerous large scale tremors which took place in succession were collected. The displacement response spectrum on ground shakings recorded mainly at the devastated areas was about as large as the earthquakes which occurred in the past. The long-period ground motion component of 4 seconds or more was not particularly large in the devastated areas and areas around Tokyo. Rather the long-period component was predominant in several regions far-flung from the earthquake center such as Saitama or Osaka, as shown in figure 3.3.9.1. Particularly in the skyscrapers in the bay area of Osaka, continuous response of max approximately 130 cm amplitude was recorded on the top floor (52nd floor) for more than 10 minutes.

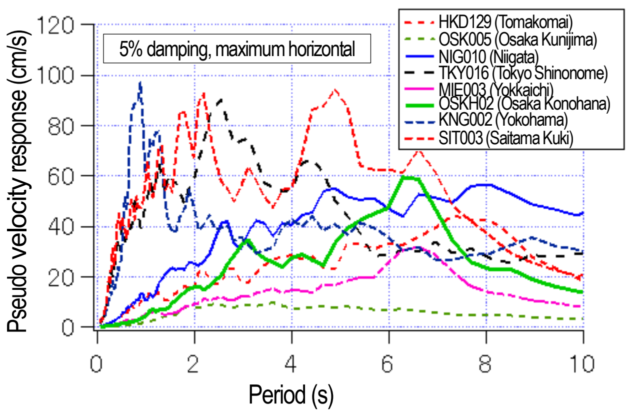
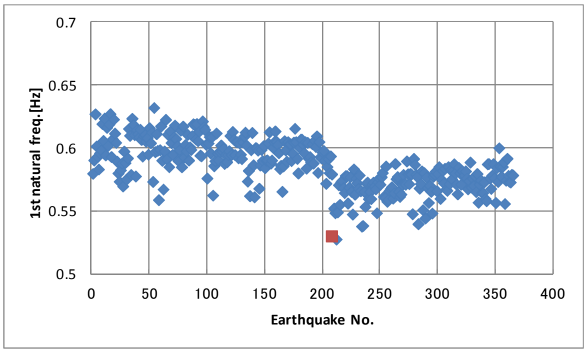


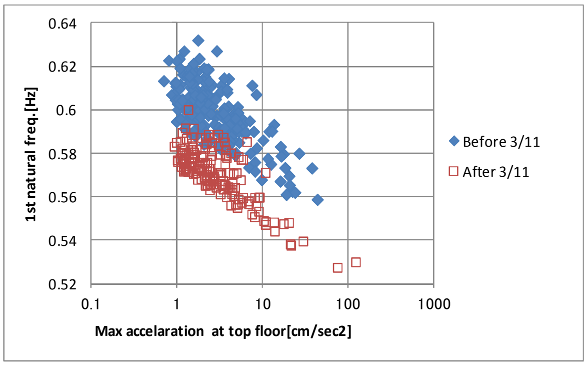
Figure 3.3.9.1 Pseudo velocity response spectrum of observations recorded in areas other than the affected areas (K-Net and KiK-net[3.3.10-1])

Strong motion accelerations were collected from the damaged (including wrecked) structures. The system verification method performed by using observed records confirmed variations in the 1st natural frequency before or after the main quake as shown in figure 3.3.9.2. Seismometers were additionally installed in buildings and surrounding ground after the main quake to confirm the behavior of each building using aftershocks. The relative displacement at expansion joints was calculated with the help of these observation records to evaluate the natural frequency or damping of buildings and study the input loss.

Further, when the input earthquake motion on these buildings (gyms) at the time of the main quake was estimated from the aftershock observation result to investigate the damage from ceiling collapse, it showed that there is a response acceleration of around 2G or greater on roof surfaces which serve as the bases for suspending the ceiling, this may be substantial enough to make them rock violently.



(a) 1st natural frequency (■ is the main quake)



(b) Relation between response acceleration and 1st natural frequency

Figure 3.3.9.2 Result of analysis of observation records on steel buildings before and after the main quake (21-story building in Tokyo)

Additionally, the results of the questionnaire survey conducted on people using skyscrapers whose strong motion observations were recorded to see how they would behave at the time of an earthquake and the effects of damage, evacuation and proactive measures were organized.

(2) Reinforced concrete (RC structures) buildings

The damage patterns on RC building structures was classified and compared to the damage patterns induced by the 1995 Kobe Earthquake. As shown in Table 3.3.9.2, the similar damage patterns were reported between Kobe Earthquake and this earthquake to the element level, while the damage patterns of the total frame decreases. . In fact, severe damage on the total frame was not observed in buildings designed according to the current building code enforced in 1981. From the viewpoint of the technical standards, it indicates that major part of the typical damage patterns of the building observed in previous earthquake was prevented by revision of the technical standards so far.

Table 3.3.9.2 Comparison of damage patterns of RC buildings between in 1995 (Kobe Earthquake) and 2011 (Great East Japan Earthquake)

	Damage observed from the 1995 Kobe Earthquake[3.3.10-2), 3.3.10-3)]	Existence of damage	
		1995	2011
Damage at member level	1) Shear failure of column	○	○
	2) Compression failure at the concrete end section on column	◎	◎
	3) Bending failure at the column top or bottom (including damage by tensile or compression axial force)	◎	◎
	4) Axial failure on the longitudinal reinforcing bar joint on columns	◎	–
	5) Damage on anchorage of the 90° hook hoops	○	○
	6) Bond failure on columns or beams	○	○
	7) Shear failure of beams (including beams with penetrating holes)	◎	○
	8) Shear failure of structural walls (including beams with openings)	◎	◎
	9) Bending failure of structural walls	◎	◎
	10) Shear failure of beam-column joint	◎	△
	11) Rupture of reinforcing bar on the gas pressure welded point	○	–
	12) Damage to non-structural walls in apartment buildings	◎	◎

Note: If any relevant damage is observed, [○] is entered in the “Damage existence” column, and if no damage is observed, [-] is entered. If the damage level was slight, △ is entered. If damage is observed among buildings designed according to the current building code, ◎ is entered.

A detailed survey and post-earthquake damage observation was carried out on damaged 11 RC buildings designed by the old building code before 1981. 4 buildings were categorized as severe damage, 4 as moderate damage, and 3 as minor damages. Some buildings show severe damage like shear failure in short columns (Photo 3.3.9.2) or shear failure in load bearing walls. Although the damage to structural elements was comparatively minor, the damage of non-structural wall such as shear failure in partition walls (Photo 3.3.9.2), the damage of non-structural elements like inner/exterior cladding, and the danger of falling object accompanied by above nonstructural elements damages made it difficult to use continuously. This proved that it necessary not only to ensure the safety of the structure by retrofitting, but also to reduce the damage of non-structural elements for sustainable use of the existing buildings after the earthquake

Photo 3.3.9.1 Shear failure of short column

Photo 3.3.9.2 Shear failure of non-structural wall

The analysis results confirmed that if structural slits were made in the spandrel or hanging walls of buildings which suffered major damage from shear failure in short columns, the building could achieves the ductile behavior in a range of the response of the story drift with an equivalent single-degree-of-freedom system. It indicates if the seismic retrofitting including improvement of the entire building strength is difficult in terms of the time, budget and life cycle cost, the damage can be temporarily mitigated by making the structural slit preceding to the strengthening when the adequate strength and ductility of the bare frame can be confirmed.

On the other hand, with regard to damaged large eccentric buildings, building models with additional load carrying capacity in order to improve torsional behavior was created and earthquake response analysis was carried out. The result showed that there was almost no improvement in its torsional behavior from original model. It is generally recommended to try improving eccentricity, rather than to increase the lateral load carrying capacity of buildings for large eccentric buildings.

(3) Steel buildings

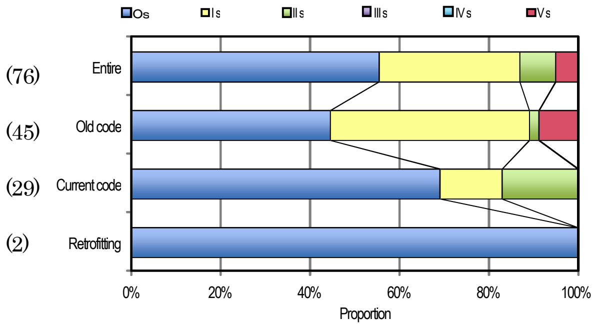
Detailed analyses of damage to steel buildings have been conducted on school gymnasiums similar to factories or warehouses on the basis of the results of the field surveys in the devastated areas. Structure types of school gymnasiums designed in accordance with the old and current building codes were compared and studied in addition to retrofitted school gymnasiums. The result is given below.

The damage to the structures of school gymnasiums designed by the old building codes (55 gymnasiums) was classified into 6 types. In these types, (1) Buckling or fracture of bracing elements and fracture of joints and (2) Buckling of diagonal elements of lattice columns, were classified as major damage, which were seen in 4 school gymnasiums (less than 10% damage rate). This damage rate was smaller than that of the gymnasiums built by the old building codes damaged in the Mid Niigata Prefecture Earthquake in 2004 targeted in a similar survey[5)-7)] (about 30% damage rate). Comparatively, unlike the gymnasiums built by the current building codes, the braces or columns of these gymnasiums designed by the old codes did not have sufficient structural strength, and they did not have joints of load-carrying capacity, which were considered to be the main reasons of damage. In this survey of retrofitted gymnasiums reinforced with braces, almost no damage was observed. Thus we can say that damage to buildings can be mitigated by proper retrofitting.

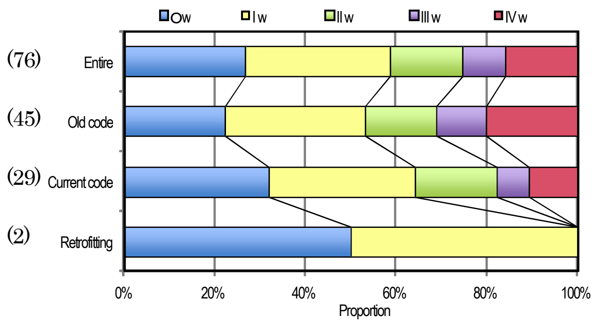
On the other hand, damage types (1) and (2) mentioned above were not seen in gymnasiums built by the current building codes (29 gymnasiums). They suffered damage of other types, namely (3) Abrasion or cracks in concrete at the joints (bearing support parts) of RC columns and Steel roof frames, (4) Deflection of roof horizontal braces, (5) Cracks in column base concrete, and (6) Others (overturning of floor struts, etc.. However, the damage level of these types was determined [4)] as minor in almost all cases, except for 1 gymnasium which suffered moderate damage. Unlike the damage rate of gymnasiums designed by the old building codes, the damage level of buildings designed by the current building codes was determined as minor in most cases, and there was no major damage. Further it was seen that among the damage types described earlier, the rate of type (3) Damage at the joints (bearing support parts) as shown in Photo 3.3.9.3 was comparatively high. The types of damage and their countermeasures are described in "Design Recommendations for Composite Constructions"[8)] of the Architectural Institute of Japan for example. Also, the methods of designing RC columns, gable walls and Steel roof joints used in seismic diagnosis and seismic reinforcement include those such as first finding out the seismic intensity acting on the roof surface from the horizontal load-carrying capacity of the top story, and then calculating the roof shear force depending on the roof area ratio, or if an abbreviated calculation method is desired, calculating the required strength by multiplying the weight that should be transferred from the roof surface by $0.55 \times Ai \times Fes$.[10)] Suitable design methods like these can reduce the damage to these parts from earthquakes.

Photo 3.3.9.3 Example of damage at RC column and Steel roof joints (bearing support parts)

Besides, damage of non-structural elements of gymnasiums such as ceiling and lighting fall, exterior wall collapse, interior wall collapse, and window glass breakage was observed. Damage of extensively fallen ceilings was observed in 4 gymnasiums. Damage of ceiling break or fall was observed in relatively large numbers in the gymnasiums designed by the current building codes. There was not much difference in the tendency of ceiling damage in the gymnasiums designed by the old and current building codes. The ratio of the gymnasiums with IIw or greater in the damage level classification of non-structural elements was relatively higher in the current building codes than in the old ones.



(a) Damage level classification of structural frames



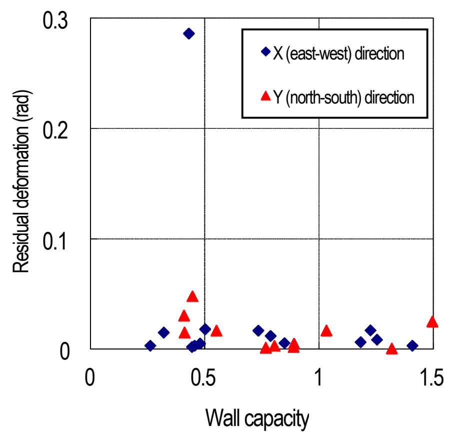
(b) Damage level classifications of non-structural elements

Figure 3.3.9.3 Damage level classification (numbers in ( ) on the far left indicate the number of gymnasiums

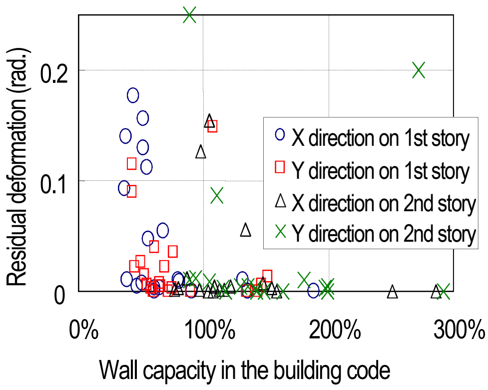
(4) Wooden Buildings

Several cases of damage to wooden buildings due to ground ground motion were confirmed at Osaki city in Miyagi prefecture, Sukagawa city in Fukushima prefecture, Nasu town in Tochigi prefecture, Hitachiota and Naka city in Ibaraki prefecture. In Kurihara city in Miyagi prefecture where the seismic intensity was 7, the damage to wooden buildings was not severe, unlike the past records of earthquakes of the same seismic intensity. Damage due to ground deformities other than the structural members was large in housing areas in cities like Sendai in Miyagi prefecture and Yaita in Tochigi prefecture, and as a result the number of damaged buildings was also greater. Further, damage of roof was greater in Fukushima and Ibaraki, than in Miyagi prefecture where the number of the past earthquakes damage is larger. Other than that, ground motion is likely to be greater in housing areas developed by filling swamps or rice paddy fields, even if there is no ground deformity as seen near Kurihara and Osaki cities in Miyagi prefecture, Nasu town in Tochigi prefecture and Hitachiota city, Naka city, Joso city and Ryugasaki city in Ibaraki prefecture.

As part of the detailed survey of damage to wooden buildings, structural specifications, layout of structural elements was studied along with the damage status of several buildings in areas where the damage was comparatively greater. The relation between the wall capacity (ratio of shear walls in the investigated buildings to required shear walls by building code) and residual deformation was also studied. As residual deformations of investigated buildings were not large in wooden buildings as shown in Figure 3.3.9.4 (a) ,there was no definite trend between wall capacity and residual deformation. The result of the study on the relationship between the rate of eccentricity and residual deformation was also the same. From the result of a similar study[11)] conducted after the Mid Niigata Prefecture Earthquake of 2004 shown in Figure 3.3.9.4 (b), we can see that the tendency of residual deformation is smaller when the wall capacity is greater. This is because of several factors such as the different characteristics of ground motion related to damage to wooden buildings and the difference in seismic intensity. However the result cannot be affirmed, as few buildings were surveyed this time.



(a) 2011 Great East Japan Earthquake (First floor only)



(b) Mid Niigata Prefecture Earthquake of 2004 (seismic intensity 7)[11)]

Figure 3.3.9.4 Relationship between wall capacity and residual deformation

In addition, the areas recorded strong ground motion where the amount of damage to wooden buildings was larger [1),12)] (Respective NS and EW element of JMA Furukawa-Mikkamachi, K-NET Furukawa, K-NET Ishinomaki and K-NET Saitama) were used to calculate the earthquake response, with the wall capacity of each story as the parameter of structural models of 2 story wooden houses.

The result showed that the response by the input of JMA Furukawa-Mikkamachi and K-NET Furukawa increased in case that the wall capacity was less than 1.0, and the maximum deformation angle did not exceed 1/10rad, even when the wall capacity was about 0.6. A comparison of this result to the damage condition of wooden buildings observed in the detailed survey shows that the damage condition of Ishinomaki city in Miyagi prefecture and Naka and Hitachiota cities in Ibaraki prefecture matches the analysis result to a great extent, but the damage condition in Furukawa city in Miyagi prefecture was smaller than the analysis result.

(5)Seismically Isolated buildings

A field survey was conducted on 16 seismically isolated (hereinafter to as SI) buildings in Miyagi and 1 in Yamagata Prefecture (offices, medical institutes, etc.). There was little damage to building frames in every building, and even during severe earthquakes with intensity exceeding 6 minus, the seismic isolation appeared to have performed well. Because the expansion joints and covers did not follow the movement of isolation layers, some of them were damaged (Photo 3.3.9.4). These damages were considered as damage due to lack of estimation in the design.

Scratch boards were installed to measure displacement of the isolation layer during earthquakes. It was confirmed that there was a displacement of about 20 cm in most of the 8 SI buildings surveyed, and the largest displacement was about 40cm.

Among the seismic isolation devices (hereinafter to as SI devices), lead dampers, cracks (Photo 3.3.9.5) appeared on their surfaces, and some of dampers actually had to be replaced. As for steel dampers, their surface coating peeled off, and in some cases residual deformation was observed on the steel part. These deformities did appear in the series of earthquakes which occurred during main shock on March 11 and its aftershocks. In addition, rust and other such defects also appeared on the surface of junctions and other parts in some of the SI devices.

In some of the buildings affected by the tsunami, the isolation layer was submerged in the water. This does not mean that the performance of the SI devices does not be kept. In this case, to check the performance of SI devices, it is necessary to conduct of proper maintenance for assessing the durability of the SI devices and its joints. A similar survey, which was conducted on the SI buildings in Kanto region, showed the same results, though the response and damage level was less.

Field surveys were carried out on 10 SI single family houses in Miyagi. The intensity of ground shaking measured around these SI houses was between 5.5 (6 minus) to 6.2 (6 plus). There are no structural damages of these houses, showing that the isolation layer had performed well.

Photo 3.3.9.4 Cover broken by contact etc.

Photo 3.3.9.5 Cracks in lead damper

However, the outer structural parts where the seismic isolation layer did not respond well got damaged, as seen in the blocks in the outer foundation flanks around the buildings from the tsunami or ground shaking, and damage on the floors around the gateways. The displacement records of the scratch boards around 5 buildings were confirmed, and the direction of displacement was found in the south-east direction in most cases, and the maximum displacement was about 10 cm to 35 cm.

The seismic behavior of SI buildings can be understood from seismic observation records and from the result of scratch boards. Among the observed accelerations below isolation layer, the largest one was observed in a building of Fukushima Prefecture[14)] followed by Miyagi and Ibaraki prefectures, and lower in Tokyo and Kanagawa prefectures. As shown in Figure 3.3.9.5, as the maximum acceleration becomes larger in lower part of the isolation layer, the maximum accelerations at upper part of isolation layer tend to be less. The displacement locus of the isolation layer calculated by using the acceleration records was nearly circular in Miyagi, whereas the shape was particularly large in the east-western direction in Fukushima. The largest displacement from the origin of the isolation layer was 24.5 cm in buildings of Fukushima. A good correlation was observed between maximum displacement of the isolation layer and seismic index of JMA at nearest earthquake observation records, as shown in figure 3.3.9.6. The results of scratch boards were very useful to confirm the response of the isolation layers, and to compare the displacement locus to the analysis result.

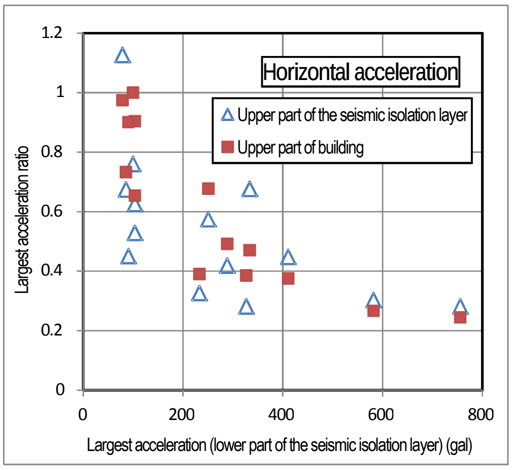
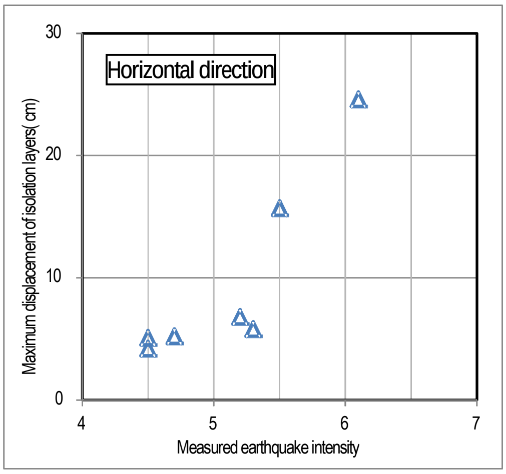
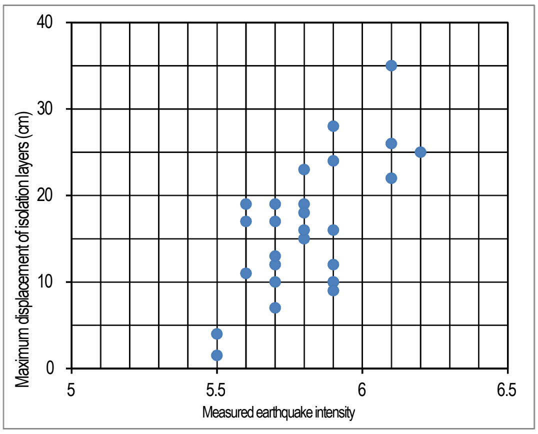


Figure 3.3.9.5 Largest acceleration at the upper part of isolation layer and the top of the building vs. the lower part of isolation layer



(a) SI buildings



(b) SI houses

Figure 3.3.9.6 Relation between measured earthquake intensity of earthquake motion, and maximum displacement at isolation layer

A questionnaire survey was conducted on residents and users of both SI and non-SI buildings regarding safety and habitability. The effect of seismic isolation in reducing the shake was apparent which helped in alleviating the fear and discomfort of the residents and users. And to the question on difficulty in performance, few people replied that "I cannot move." A comparison of the status of furniture and other movables showed that the damage in the rooms was minimal from falling of cupboards, rolling of furniture etc in SI houses and in medical facilities etc., it was confirmed that there was no damage in the rooms and work resumed as usual immediately after the earthquake, because of the private generators and emergency feed water lines installed for emergency use for lifelines.

(6) Liquefaction

One-dimensional effective stress analyses were performed for the vertical array recordings of strong ground motions[15)-17)] at Chiba port and Yumenoshima sites, to estimate the number of equivalent cyclic shear for liquefaction, N_{eq}, in the Tokyo bay area. The correction factor to determine soil liquefaction resistance with seismic magnitude employed in the Recommendations for Design of Building Foundations (Architectural Institute of Japan)[18)] could be verified from the relationship between the estimated N_{eq} values and earthquake magnitude.

It was revealed that the duration of strong ground motions in Tokyo bay area during the 2011 earthquake is much longer than those at the liquefied zones during the past earthquakes in Japan. Also was suggested that the amplitude and predominant period of acceleration time history change drastically due to soil liquefaction in the area. As shown in Table 3.3.9.3, the N_{eq} values estimated at Chiba port and Yumenoshima sites for the 2011 earthquake were about 20 to 60, which are about two times larger than those for the 1987 earthquake. For the both earthquakes, there were no liquefaction remarks on ground surface at the sites because the equivalent shear stress ratios might be lower than the soil liquefaction resistance.

The N_{eq} values estimated in Kobe port island during the 1995 earthquake could be, however, about 5-10[19)], which might be about 1/4-1/6 times smaller than those in Tokyo bay area during the 2011 earthquake.

Based on the estimated results and discussions on their relationships with earthquake magnitude, it is concluded that the N_{eq} values could roughly be predicted for a huge earthquake with magnitude $M > 8$ by extrapolation of the existing M-N_{eq} relations for the past earthquakes with magnitude $M < 8$, those were empirically proposed in the previous studies[19)-21)].

Table 3.3.9.3 Number of equivalent cyclic shear and shear stress ratio for soil liquefaction during earthquakes

Earthquake	Site	Number of equivalent cyclic shear	Shear stress ratio
2011 Great East Japan Earthquake (M_W=9.0)	Chiba Port	20-50	0.12-0.18
	Yumenoshima	30-60	0.10-0.15
1987 Chiba Toho-oki Earthquake (M_j=6.7)	Yumenoshima	10-30	0.05-0.08
1995 Kobe Earthquake (M_w=6.9)	Kobe Port Island	5-10	0.3-0.5

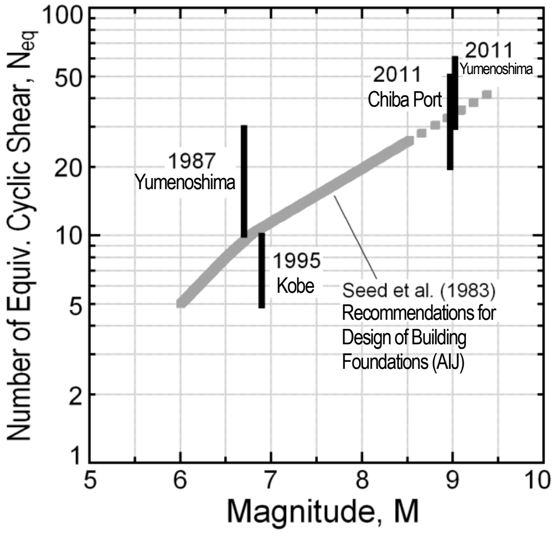


Figure 3.3.9.7 Relationship between earthquake magnitude and number of equivalent cyclic shear for soil liquefaction

(7) Nonstructural components

More damage was observed to the nonstructural components with the older construction method. Also, the damage type of breaking and falling was observed to the nonstructural components installed in higher places. As for ceilings, the damage tended to be greater with more severe structural damage, for example damage to the horizontal braces on the roof or to the roof joints (supports) (Photos 3.3.9.6 and 3.3.9.7).

As for window glass at the gymnasiums, the damage was greater at the building designed with the old quake-resistance standards than at those by the new standards.

Photo 3.3.9.6 Collapse of furring ceiling

Photo 3.3.9.7 Collapse of integrated ceiling

3.3.9.3 Damage to buildings by tsunami

(1) Background of field investigation and study

The NILIM and the BRI jointly created a tsunami damage survey team consisting of 27 members, for autonomous investigation of sites mainly to understand the actual status of damage by Tsunami to grasp the whole damage of the Great Earthquake and also to gather information on the structural, locational, functional and other such requirements of tsunami evacuation buildings during restoration. The First Tsunami Damage Survey Study Meeting was held on March 17, 2011 and the field survey team was first on March 30, 2011, about three weeks after the outbreak of tsunami, and the NILIM and BRI conducted three such field surveys in all.

After that, “40. Study towards Preparing the Construction Standards for Tsunami-hazard Areas” was conducted during the construction standards preparation promotion project of the Ministry of Land, Infrastructure, Transport and Tourism in 2011 and the “Basic Study of Structural and Evacuation Safety of Tsunami Evacuation Buildings” was conducted in the course of basic research by the BRI in 2011. The construction standards preparation promotion project of 2011 was a joint research project of the BRI and researchers from the Institute of Industrial Science, the University of Tokyo and they submitted two interim reports to the Ministry of Land, Infrastructure, Transport and Tourism in July and October 2011 respectively. These interim reports included the assessment of tsunami load and tsunami evacuation building design requirements based on the damage investigation results.

The Ministry of Land, Infrastructure, Transport and Tourism established additional findings on the design method of construction for safety in the event of a tsunami on November 17, 2011 and Notification No. 1318 of the Ministry of Land, Infrastructure, Transport and Tourism (the construction method for safety from the estimated tsunami force while settings the estimated tsunami inundation area defined on December 27, 2011) which is a structural safety standard for tsunami evacuation buildings based on the interim reports.

On the other hand, the NILIM and BRI jointly conducted field surveys starting May 2012 also, to grasp the whole damage to buildings by the tsunami. In particular, to understand the status of damage to wooden buildings, the NILIM and BRI investigated the sites in Miyagi and Iwate in May, September and October 2012, and discussed a calculation method on the tsunami resistance performance of wooden houses.

(2) Case studies on damage to reinforced concrete (RC) buildings

The variant patterns of damage which occurred in RC buildings due to tsunami in the Great East Japan Earthquake are also noteworthy. However, most of the RC buildings survived the Tsunami, and the survival rate was estimated to be higher in the comparatively newer buildings. No serious damages or cracks in the framework of these buildings were observed, and even the non-structural walls did not suffer any major damage except the window glasses and doors.

1) Case of Tsunami Evacuation Building A

Building A, a 4-story RC structure located in Minamisanriku in Miyagi prefecture is a public apartment complex built in 2006. The outside stairs could be used to escape to the roof, and it was designated as a tsunami evacuation building (see Photo 3.3.9.8).

Although the flood water reached about 1m above the roof level, excluding the damage to non-structural elements, there was no structural damage to the building framework by ground shaking, and it stood ground even after the tsunami. The flood water from the tsunami reached 15.4m above ground level at the building site, and several buildings in the surrounding area were either destroyed or washed out. The ratio of the lateral load carrying capacity of the first story of Building A against the horizontal tsunami load caused by hydrostatic pressure was 1.70. The building base shear far exceeded the tsunami load acting on it, thereby the building could survive after the tsunami.

Photo 3.3.9.8 Tsunami Evacuation Building A

2) Case of Building B

Building B is a 2-storied RC structure that is 10.5 m wide, 4.5m long and 6.1m high (see Photo 3.3.9.9). It is a wall frame structure with 1×2 span, and is located in Onagawa Town in Miyagi. The building pile was pulled out and overturned by the force of the tsunami.

The rate of the moment of resistance (including the buoyancy acting on the building and the pile pulling-out resistance) of the building against the overturning moment caused by hydrostatic pressure was about 79%, and the analysis result matched the actual damage result of the overturned building.

Photo 3.3.9.9 Building B

3) Case of Building C

Building C has 3 and 2-story RC structures located in Onagawa in Miyagi and built in 1993 (called C-1 and C-2 buildings respectively as shown in Photo 3.3.9.10). C-1 building was higher than the tsunami height, and kept evacuees away from tsunami as a shelter. C-2 on the other hand could not save evacuees because of tsunami waves higher than the building. The ratio of the lateral load carrying capacity of the 1st story against horizontal tsunami load caused by hydrostatic pressure in Building C-1 was 1.12, and proved by the fact that it could survived after the tsunami. On the contrary, the ratio of C-2 was 0.79 and the building base shear was less than the tsunami load. Despite that it survived against tsunami in actually.

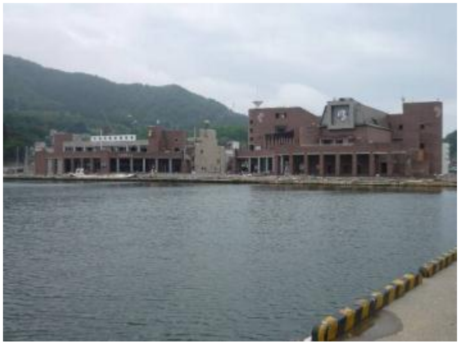


Photo 3.3.9.10 Building C

4) Case of Building D

Building D is a 3-story RC structure located in Sendai city in Miyagi. The tsunami load acting on it caused out-of-plane deformations in the outer wall, and attached columns and beams of the building (see Photo 3.3.9.11).The section of the outer wall which got destroyed is well hole from the first floor to the top floor with 4 spans in the longitudinal direction.

Not the whole structure but the outer walls of this section were destroyed in this building, so that the collapsing mechanism strength due to the tsunami load will change according to the estimated folding line on the wall panel. In this study, the induced tsunami load was evaluated with a hinge mechanism model by assuming folding lines on wall surface based on the measurement result of the wall deformation. The damage investigation confirmed traces of water (5.0m) inside the buildings and as a result, the tsunami load acting on this wall was calculated presuming that the hydrostatic pressure behind the walls also exerted force in addition to the wave force in front of the wall. The work exerted by the external force of the tsunami was 98% of the work generated by the internal force of the building in hinge mechanism. Thus the estimated external force of the tsunami matched the actual extent of damage.

Photo 3.3.9.11 Building D

5) Case of Building E

Building E, a 2-storied wall frame type precast RC structure built in 1970 (consisting of ribbed medium sized concrete panels) is a public housing complex (see photo 3.3.9.12). The inundation depth in front of the neighboring 3-story RC apartment complex was 7.5m. No significant structural damage was apparent in the building although it suffered damage to the gable walls on the 2nd floor because of the colliding floating materials and also tilted from scouring of the surrounding soil.

Although the lateral load carrying capacity of the building was 37% of the tsunami wave load acting on the building that was caused by the hydrostatic pressure, the analysis result did not match the actual damage status of the surviving building. This may have happened because the sea water entered through the several openings inside the building which must have helped in reducing the wave pressure acting on it.

Photo 3.3.9.12 Building E

(3) Study of damage to steel buildings

Many skeletons of steel buildings remained most likely due to the reduction of the tsunami wave pressure caused by the early breakaway of the external walls. Meanwhile, a fair number of buildings were found to have collapsed, have overturned, have been displaced, or have been washed away. These were presumed to have been subjected to high wave pressure before the external walls were washed away.

Inundation depth η' corresponding to a hydrostatic load equal to the horizontal load at the time of collapsing of a building was taken as the "inundation depth equivalent to the building strength", and the maximum inundation depth η_m measured in the field investigation was taken as the "measured maximum inundation depth". η'/η_m was defined as the water depth coefficient 'a' and the correlation between the damage to each of the surveyed buildings and the water depth coefficient was studied.

The strength of a building was calculated by conducting a simple plastic analysis that was based on the assumption of the collapse mechanism. Depending on whether external walls assumed to be washed away or not, 2 types of opening ratios were set at 0.3 and 0.8. (In other words, the load reduction ratio α for buildings without openings was 0.2 and 0.7).

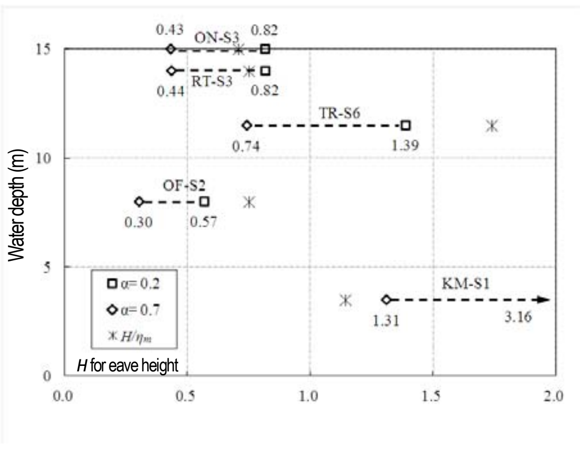


Figure 3.3.9.8 Water depth coefficient *α* estimated from the strength of the steel skeletons that survived

Figure 3.3.9.8 shows the investigation results of the steel skeletons of 5 buildings. In the case of Onagawa City (ON-S3) and Rikuzentakata City (RT-S3), where the measured maximum water depth η_m was 14 - 15 m, the range of the water depth coefficient *α* shown by a dotted line was below 1. In the case of Taro in Miyako City (TR-S6), where η_m was 11.5 m, the range of *α* was nearly 1. On the other hand, in the case of Kamaishi City (KM-S1), where η_m was value of 3.5 m, the range of *α* was far beyond 1. In the case of Ofunato City (OF-S2), where the steel skeleton survived despite a low value for '*α*', it was believed that due to other buildings that survived on the periphery or in the direction of the sea, the load exerted by the tsunami was comparatively lower in this case. From the aforementioned results, it is inferred that in regions where η exceeded 10 m, since the water had gushed into the surroundings of the building before the maximum water depth was reached or the tsunami waves surged in from all directions, the situation of the hydrostatic load equivalent to the measured maximum inundation depth acting from one side did not arise.

(4) Study of damage to wooden buildings

In the areas where the maximum water depth was about less than 1-story window height (about 1.5m - 2m), almost all wooden structures remained intact. Although many wooden construction buildings were washed away, in the areas where the maximum water depth was 1-storey height (3m - 4m), a few cases of buildings remaining intact were also confirmed. When the maximum water depth exceeded the 1-story height (more than 4m), almost all wooden buildings including 1-story and 2-story wooden buildings were washed away.

The lateral shear capacity and tsunami load was calculated for a wooden public housing building for which detailed survey was done and the values were compared to the actual damage to verify the adequacy of the calculation formula. The wooden houses used for the study was the city-provided housing (Suzaki Housing) of Higashi Matsushima (See photo 3.3.9.13)

Figure 3.3.9.9 shows the results calculated for an areas where the water depth coefficient *a* = 1.0, 1.5, 2.0. The tsunami wave load was integrated with the direction of the height of the building and the window openings were not considered. Although the water depth by the damage survey results was about 4.5m. Although the calculated results shows that the tsunami wave load exceed the lateral shear capacity when a = 1.0 and water depth is about 4.5m, about half the number of houses escaped complete wash-out. It was also believed that the RC structure in the direction of the incidence of the tsunami also had an influence.

Photo 3.3.9.13 Intact wooden public housing

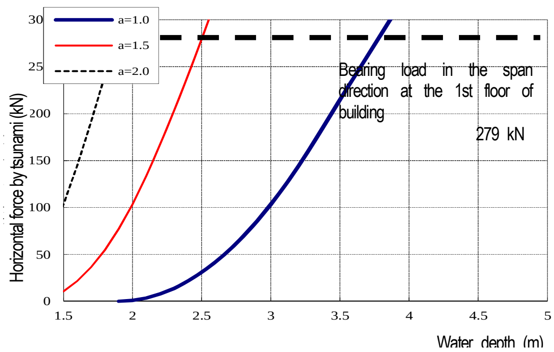


Figure 3.3.9.9 Relationship between lateral shear capacity and tsunami wave load

(5) Study of the structural design method of tsunami evacuation buildings

"The basic concept of structural requirements" is given at the end of the document (2) of the "Guidelines for Tsunami Evacuation Buildings" [22] (referred to as 'the guidelines' hereinafter in this section) given by the Cabinet Office in 2005, based on the results of an independent study conducted by the Building Center of Japan in 2004. It contains information that is helpful in verifying that the structure does not collapse, overturn or slide against the tsunami load on the building. Moreover, it is necessary to verify that the pressure resistant material used for the pressure surface (surface of the building that would be subjected to direct pressure from the tsunami wave) would not be destroyed by the wave pressure and would not lose its vertical bearing capacity or resistance capacity to horizontal force. Even in this study, the aforementioned concept is being followed without any changes as a policy for the structural design method of tsunami evacuation buildings, and the 3 items shown in Table-3.3.9.4 are verified in the tsunami evacuation building design. Moreover, the material used for pressure surface is classified into the conventional pressure resistant material (material designed to resist direct tsunami wave pressure) and pressure non-resistant material (material which is allowed to be destroyed by the impact of direct tsunami wave pressure) and it is verified that the pressure resistant material is not affected by the tsunami wave pressure. Figure 3.3.9.10 shows the design flow in the form of a pattern diagram. The structural design of tsunami evacuation buildings is carried out by the following flow.

Table 3.3.9.4 Structural design method of tsunami evacuation buildings

1) Tsunami load lower than the horizontal strength of each story of the building
2) Overturning moment lower than the resistance moment considering buoyancy
3) Tsunami load lower than the basic frictional force or horizontal strength of pile
※ Advisable to separately consider resistance to horizontal motion
※ Pressure resistant material used in pressure surfaces should remain under tsunami pressure

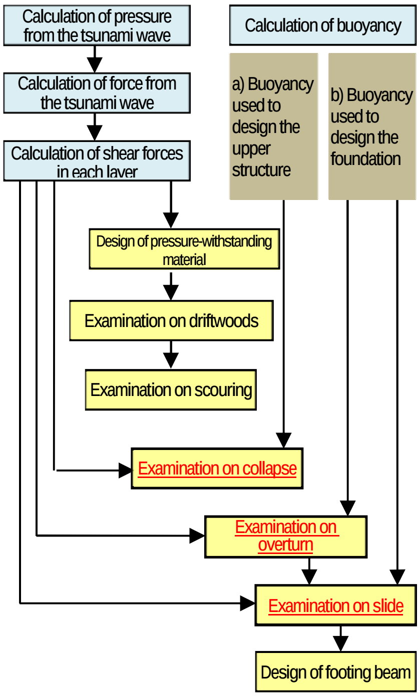


Figure 3.3.9.10 Structural design flow of Tsunami evacuation buildings

In the guidelines, it has been given that the water depth coefficient *a* should be taken as 3 and the tsunami wave pressure should be created by applying hydrostatic pressure, three-times the water depth in the design, on one side. This was a proposal given by Asakura et al. in relation to the tsunami pressure acting on the building in the form of tidal wave run-up on land after overflowing the upright seawall, and it was based on the results of mock tests conducted by varying the location of the structure, the slope gradient of the water way, wave characteristics such as cycle, or wave-height, the fact that the wave-pressure distribution was triangular distribution, and its height was almost 3 times the water depth. In other words, the influence of underlying flow velocity has been included in the formula for calculating tsunami wave pressure generated by hydrostatic pressure.

In this study, based on the results of the field investigation, the "3" in the wave pressure calculation method in the "guidelines" was believed to be variable depending on the momentum of the tsunami (Froude number), and this "3" was kept as "*a* (water depth coefficient)", and *'a'* was verified based on the damage facts. In this verification, the strength was estimated depending on the type of damage to the structure (relatively simple constructions and buildings), and the water depth coefficient equivalent to the strength of the structure while presuming hydrostatic pressure distribution was reverse calculated using the measured water depth at the site. Furthermore, as a result of hearings conducted with experts on tsunami engineering, the concept that the wave pressure of the tsunami in the Great East Japan Earthquake is not necessarily the imagined maximum and it is not appropriate to amend the maximum value of wave pressure only based on the damage was introduced. The conventionally believed equation of "hydrostatic pressure = 3 times the designed water depth" was taken as the case of maximum wave pressure acting on the structure and the scenarios where the water depth coefficient *a* could be reduced were investigated. The water depth coefficients obtained as a result of this are given in table-3.3.9.5 and the details of the studies related to water depth coefficients are given in 1) and 2) below.

Table 3.3.9.5 Setting water depth coefficient *a*

	There is a shielding object		No shielding object
Distance from coast or river, etc.	500m or further	Less than 500m	Does not depend on distance
Setting of water depth coefficient *a*	**1.5**	**2**	**3**

1) Study Item 1 (Influence of shelter/cover)

A case where masking was used to reduce the wave pressure of the tsunami from the incident directions was taken up whereby the water depth coefficient *a* would be reduced. In the study, in addition to other buildings around the building, a seawall at the entrance to the bay or a seawall or breakwater of sufficient height (estimated to be at least more than ½ the height of the tsunami wave) considering the height of the tsunami wave were considered as shelters/covers expected to reduce the wave pressure. As a result of the study, when the water depth coefficient *a* in case of masking expected to reduce the wave pressure of the tsunami was compared to the case where masking was not used, it was understood that masking reduced the pressure by 1/1.5. Thus, it was possible to bring the water depth coefficient *a* to

3/1.5 i.e. “2” when the masking is expected to reduce the tsunami wave pressure.

2) Study Item 2 (Impact of distance from the coast or river)

A case related to the distance from the coast or river was taken up where the water depth coefficient *α* could be reduced. From the study it was derived that the momentum of the tsunami (Froude number) reduces according to the distance from the coast or river, and in case where the distance from the coast or river is more than 500m, it was possible to show that *α* = about 1.0. Furthermore, taking into consideration that this study was confined to the data obtained from the field investigations, that strength calculation was an abbreviated calculation, that there was variation in the measured water depth and the water depth based on the tsunami simulation, a maximum margin of 1.5 times was allowed in the results of the field investigation. Hence, the water depth coefficient *α* when masking was used and the distance was more than 500m away from the coast or river was taken as about 1.5. Furthermore, it is necessary to ascertain that there are no elements that may increase the flow velocity due to factors like a downslope or building layout that can concentrate the flow while paying attention to the topography of the region surrounding the building.

3.3.9.4 Damage to buildings from fire

(1) Fire investigation summary

The Great East Japan Earthquake followed by tsunami caused numerous fire outbreaks mainly in the prefectures on the Pacific Ocean, between Aomori and Chiba prefectures, and in the Tokyo Metropolitan area, Saitama and Kanagawa prefectures. A summary of the result of investigation of the fires is given below. (For details, refer to National Institute for Land and Infrastructure Management, Technical Note No. 674).

The fire outbreak caused by the Great East Japan Earthquake was characteristic of; widespread fire outbreak at numerous locations, large-scale fire spread in tsunami-flooded areas, and large-scale fire outbreaks at petroleum complexes.

The areas most affected by the fire include the regions damaged due to tsunami flooding, Tokyo metropolitan surroundings, urban areas of Chiba and Yokohama city. Besides, these were the areas that were hit by earthquakes measuring upper-5 on the Japanese scale.

Considering the number of fires (a percentage of fire outbreaks) per municipality per 10,000 households, greater the earthquake intensity higher is the percentage of fire outbreaks. A significant difference is seen in the percentage of fire outbreak between intensity of over lower-6 and less than upper-5. Thus, it shows the same tendency as the Mid Niigata prefecture earthquake of 2004. However, if we calculate the fire outbreak rate by classifying it into tsunami specific and non-specific fire outbreaks, the rate of municipalities suffering no damage from tsunami flooding (approximately 1.0 per 10,000 households) was about 1/4th of that of the Mid Niigata prefecture earthquake (approximately 0.25 per 10,000 households in the regions where earthquake intensity is greater than upper-6) whereas the fire outbreak rate of municipalities that suffered tsunami flooding was extremely high at 8.14 per 10,000 households.

Interviews with residents living in the vicinity and Fire Fighting head office were conducted to obtain information related to individual fire cases.

Incidents of fire outside the tsunami-flooded areas mainly occurred immediately after the earthquake, and kept occurring until April 15, mostly during the hours from 6pm to midnight. The factors leading to fire outbreaks immediately after the earthquake are; fire equipment and ceiling gadgets such as electric stove and waste oil stove in use, electrical substation equipment and electrical wiring related devices.
In many cases, fire broke out in residential buildings, but due to effective firefighting operations, only 1 residence was burned in about 70% of the fires.

Among the all tsunami-flooded areas, the total fire spread area went up to 72 ha, and there were a total of 7 territories, namely, Miyako City (Taroariya district), Yamada Town (heart of the city), Otsuchi Town (central part), Kesennuma City (Shishiori district) and (Southwest coast), Ishinomaki City (Kadowaki district) , and Natori City (Yuriage district), in which the area burnt down by fire spread reached up 3.3 ha (10,000 tsubo) or 3.3 ha (33,000 square meters). Even in the Great Hanshin-Awaji earthquake of 1995, the total fire spread area was about 63 ha, and similar to this time, 7 territories had more than 3.3 ha area burnt down by fire. Besides, it has been confirmed that there are many regions that still have several nearby but discontinuous traces of fire. Out of 29 confirmed tsunami fire cases, almost 21 cases are related to vehicle fires caused by natural fire outbreak due to insulation failure of electric components subsequent to the tsunami flooding. In the territories that suffered massive fire, it was the collapsed houses and vehicles swept away by tsunami waves that spread the fire.

3.3.9.5 Response based on Building Damage

(1) Particulars of response based on building damage

NILIM and BRI jointly started investigating damage to buildings from the next day when the earthquake occured.

Later the data of damage investigation results from both NILIM and BRI were published on their websites as Technical Note of NILIM and BRI Research Paper.

As a summary of last report published in March 2012, following challenges need to be addressed.

① Measures against tsunami

② Measures to prevent damages of non-structural elements like ceilings

③ Measures against long-period earthquake motions

④ Measures against liquefaction damages

NILIM established the Building Structure Standards Committee (Chairman:Tetsuo Kubo, an honorary professor of Tokyo University) in April 2011 to study the proposed technical standards in the structure field. The committee initiated the study of measures in building architecture against damages caused by the Great East Japan Earthquake and conducted field investigations on April 21 and 22, 2011 (see photo 3.3.9.15)

The committee discussed the measures as follows.

Round 1 (June 18, 2011)

- Damage survey for buildings
- Measures against Tsunami
- Measures to prevent damages of non-structural elements like ceilings
- Measures against long-period earthquake motions

Round 2 (August 18, 2011)

- Measures against Tsunami
- Measures to prevent damages of non-structural elements like ceilings

Round 3 (October 13, 2011)

- Measures against Tsunami
- Measures against long-period earthquake motions

Round 4 (July 9, 2012)

- Situation of response to the Great East Japan Earthquake
- The draft of technical standards concerning measures to prevent the fall of ceilings
- The draft of technical standards concerning measures to prevent the fall of escalators
- Measures against long-period earthquake motions

Round 5 (October 22, 2012)

- Measures for ensuring safety of buildings against damages caused by the Great East Japan Earthquake
- The draft of technical standards concerning measures to prevent the fall of ceilings
- The draft of technical standards concerning measures to prevent the fall of escalators

Based on these discussions, the guidelines concerning structural requirements for tsunami-evacuation buildings were revised (as Notified by a Director General, Housing Bureau on November 17, 2011) and were incorporated in publication of technical standards for specific evacuation facilities based on the Act concerning the Development of Tsunami-resistant Communities (Notification no. 1318 published by Ministry of Land Infrastructure and Transport on December 27, 2011). Public comments was also invited from July 31, 2012 on the draft of technical standards concerning measures to prevent the fall of ceilings and escalators.

Further, due to the long-period earthquake motions, significant shakes were recorded on a skyscraper located about 700km away from the origin of earthquake. Based on this data, the committee established "Working Group for investigation of measures against long-period earthquake motions" and continues to investigate the same.

Photo 3.3.9.14 Buildings damaged by tsunami

(2) Survey details of analysis of buildings damaged by tsunami and technical standards

1) Damage analysis and creation of guidelines on constructional requirements for the tsunami-evacuation buildings

Tsunami-damaged buildings were seen in a wide area in coastal regions. The NILIM and BRI investigated the damage to buildings at the field survey, and based on the results of the investigations the technical standards for construction design methods for the tsunami-evacuation buildings was reviewed. This section reports on the technical standards.

In the Great East Japan Earthquake, many buildings were destructed and damaged owing to Tsunami, which highlighted the importance of ensuring structural safety of tsunami-evacuation buildings used as temporary shelters to cope with tsunami. As a result, Housing Bureau, the Ministry of Land, Infrastructure, Transport and Tourism and the NILIM immediately conducted studies related to design methods for structural safety of buildings to cope with tsunamis. Particularly in FY 2011, under the Building Standards Maintenance Promotion Program (subsidized project of Housing Bureau, Ministry of Land, Infrastructure, Transport and Tourism) investigation research agenda was set as “40. Investigation on maintenance of construction standards in Tsunami hazard area”, and the public offering of operating bodies started from April, 2011. Thus, the Institute of Industrial Science, University of Tokyo (Prof. Yoshiaki Nakano) selected as the operating body started the investigative research in partnership with “Earthquake Resistance Renovation Support Centre (Japan Building Disaster Prevention Association) and the Building Research Institute.

Photo 3.3.9.15 Field Survey by Building Construction Standards Association (Onagawa Town)

During their investigation research, the Institute of Industrial Science, University of Tokyo and the Building Research Institute presented the first interim report on July 7, 2011 and the 2nd interim report on Oct 10, 2011. Based on these accomplishments, the NILIM created a draft of technical standards and prepared a design model for tsunami-evacuation buildings after discussions with Building Construction Standards Association in the Ministry of Land, Infrastructure, Transport and Tourism.

In the course of this investigation, unlike analysis of damage by ground shaking, it was necessary to assume the external force generated by tsunamis on each of the damaged buildings, however in the field survey, the information required for assuming the appropriate external force was not sufficient and the NILIM also conducted the investigations with the cooperation of the River Department and Building Department.

Herewith, the existing guidelines (“guidelines on tsunami evacuation buildings” (by the Cabinet Office in 2005), hereinafter referred as “the Cabinet Office Guidelines”) were referred for setting the tsunami loads in structural design methods, and considering the site situations, etc., the hydrostatic pressure which was set to 3 times the inundation depth was relaxed down to hydrostatic pressure of 2 or 1.5 times of the inundation depth. Also, overturning caused by buoyancy was investigated and designs were clarified to protect against scouring, collision of debris, etc.

As for the technical standards, the Director-General, Housing Bureau of the Ministry of Land, Infrastructure, Transport and Tourism provided additional findings on design methods for structural safety of buildings to cope with tsunamis (Notification No. 2570.3 dated November 17, 2011)”, to all the prefectural governors in the form of “tentative guidelines concerning structural requirements such as tsunami-evacuation buildings (hereinafter referred as “guidelines”) based on buildings damaged by tsunami subsequent to the Great East Japan Earthquake.”

2) Tsunami Disaster Prevention Area Construction Act

For reconstruction of areas extensively damaged by the tsunami, and for prevention and reduction of tsunami damage in the future, it is necessary to promote tsunami disaster prevention area construction with the help of “multiple defenses” inclusive of hard and soft policies and measures. Therefore, the “Act related to tsunami disaster prevention area construction” (Act No. 123, 2011, hereinafter “Tsunami Disaster Prevention Area Construction Act” was announced as framework through Diet deliberations in December 2011.

The specified evacuation establishments pointed in the Tsunami Disaster Prevention Area Construction Act are equivalent to the aforementioned tsunami-evacuation buildings, and must meet the following criteria.

① Conform with the technical standards created by the Ministry of Land, Infrastructure, Transport and Tourism as structures safe against tsunami

② Having safe rooftops or other places that are higher than the design water depth to be used for evacuation, and safe stairways or routes to reach to such places

③ Conform to given standards for management of buildings, that is, opening the stairways or routes to public at tsunami disaster, and etc.

Based on the contents of the aforementioned guidelines, the technical standards mentioned in point ① are being standardized as the Notification “the construction method for safety from the estimated tsunami force while settings the estimated tsunami inundation area defined on December 27, 2011 (Notification no. 1318 by Ministry of Land, Infrastructure, Transport and Tourism, 2011, hereinafter referred as “technical standards notification” based on Article 31 of the Ordinance for Enforcement of the said Act, and the act related to tsunami disaster prevention area construction.

(3) Overview of technical standards related to tsunami-evacuation buildings, etc.

1) Points on technical standards related to structural design methods

The points sorted on the aforementioned guidelines and technical standards notification (hereinafter referred as “guidelines”) are shown below (For overview, see Fig. 3.3.9.11).

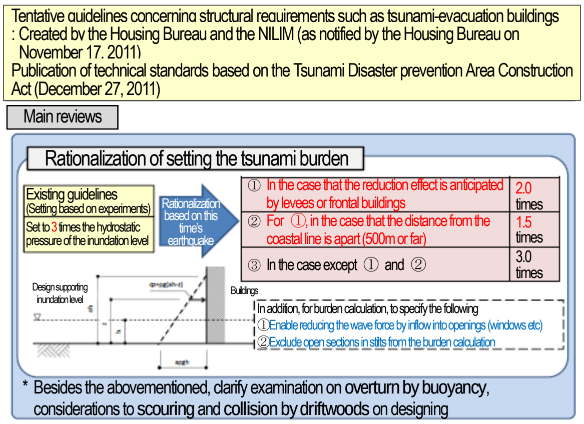
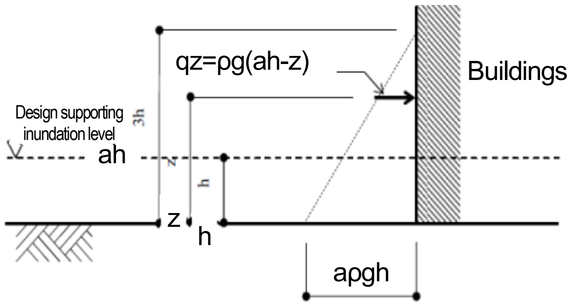


Figure 3.3.9.11 Overview of technical standards related to structural requirements for tsunami-evacuation buildings

(a) Calculation formula of Tsunami wave load

① Tsunami wave pressure calculation formula

The Cabinet Office Guidelines provided the formula for calculating the tsunami wave pressure as hydrostatic pressure equivalent to 3 times of inundation depth for design, however, the calculation formula in the guideline was revised on the basis of the results of collaborative research by Institute of Industrial Science, University of Tokyo and the Building Research Institute.



The tsunami wave pressure in tsunami run-up direction was calculated for structural design using the following formula

qz =ρg(ah－z) ・・・ (i)

Here,

qz: Tsunami wave pressure in tsunami run-up direction for structural design (kN/m2)

ρ: density of water (t/m^3)

g : gravity acceleration (m/s^2)

h : Inundation depth for design (m)

z : Height of said part from ground level (0≦z≦ah) (m)

a : Coefficient of depth of water. Set to 3. However, when it corresponds to the requirements mentioned in the following table, it can be considered as the numerical values given in column “value of a” respectively. (Note: this coefficient does not represent the degree of rise in water level due to tsunami afflux in front of buildings, etc.)

	Requirements	Value of a
(1)	When establishment or other buildings are covering the tsunami evacuation buildings in tsunami coming direction (only the case when efficient mitigation of water flow can be anticipated)	2
(2)	In case of (1), when tsunami evacuation building is located 500m away from the coast or rivers	1.5

Figure 3.3.9.12 Tsunami wave pressure calculation formula

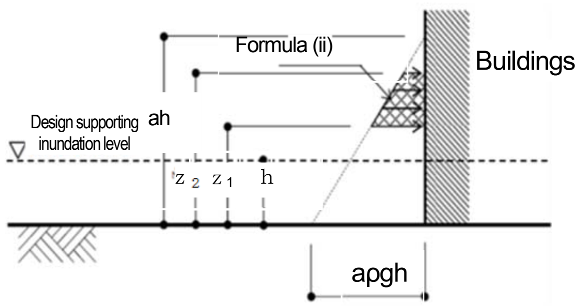
Therefore, a hydrostatic pressure equivalent to 3 times of inundation depth for the design was standardized and it was decided to decrease the scaling factor (defined as water depth coefficient a derived from formula (i)) when it is estimated that the force of tsunami can be reduced (Fig-3.3.9.12).

Specifically, when there is a obstacle such as establishments or other buildings in tsunami invasion direction from tsunami evacuation buildings in which the reduction effect can be anticipated, the water depth coefficient can be decreased from 3.0 to 2.0. Whereas, when the tsunami evacuation buildings are located 500 m away from the coast or river in the tsunami invasion direction, it can be decreased from 2.0 to 1.5.

② Tsunami wave force calculation formula

The tsunami wave pressure of ① represents the tsunami wave force per unit area, so the tsunami wave force can be calculated by integrating the tsunami wave pressure with wave loading area.

Formula (ii) is used for calculating tsunami wave force when the minimum height of wave loading area is z1, and maximum height is z2 (Fig-3.3.9.13). Further it is assumed that the width of wave loading area in building was different from the height and it was decided to integrate it with width B of wave loading area.



Tsunami wave force in tsunami run-up direction for structural design is calculated using the following formula, assuming that the tsunami wave pressure is generated at the same time.

$$Qz=\rho g\int_{z_1}^{z_2}(ah-z)\,B\,dz \quad \cdot\cdot\cdot \quad \text{(ii)}$$

Here,

Qz : Tsunami wave force in tsunami run-up direction for structural design (kN)

B : Width of wave loading area in said part (m)

z_1 : Minimum height of wave loading area ($0\leqq z_1\leqq z_2$) (m)

z_2 : Maximum height of wave loading area ($z_1\leqq z_2\leqq ah$) (m)

Figure 3.3.9.13 Tsunami wave force calculation formula

The width B of wave loading area does not always constant from the base to the top, and therefore, integration is done by using the each width of wave loading area at the each height.

(b) Reduction due to openings

In the guidelines, after obtaining the damage investigation results for reduction efficiency of tsunami wave force by openings, it was decided to specify the reason of excluding tsunami wave force in openings from the calculation as a general rule of the tsunami wave force prior to exclusion not being below 70%. In the calculation of tsunami wave load for structural design of the building, the “openings” mentioned here are in the wave loading area and are assumed to be non-pressure resistant components that can be confirmed destruction.

As for the method of wave force mitigation, 2 methods have been shown; ① calculation method in which sum total of width of opening is excluded from the width of wave loading area, and ② calculation method in which the wave load discount in proportion to a reduction factor derived from a ratio of residual wave loading area excluding opening area to the total wave loading area.

In ①, calculation is done by excluding the sum total of opening width from the tsunami wave loading area in each story. When the wave force integrated by excluding the opening width is smaller than 70% of the wave force on the tsunami wave loading area, excluding opening width reduce according to a coefficient in which the total wave force has been adjusted to reach 70% of the wave force on the tsunami wave loading area.

In ②, wave force is equal to (reduction rate) = 1 - (total of opening area / tsunami wave loading area), and the above reduction rate must not be smaller than 0.7.

The lower limit of aforementioned reduction rate is set to 0.7 since the reduction efficiency of wave force decreases if there are any inner walls, etc.

As for handling of open sections such as piloti, it was decided to clarify the exclusion of the tsunami wave pressure on open sections as well as the openings in the guidelines. As for the open sections, unlike the openings, a lower limit of reduction rate was not established.

(d) Horizontal load direction

Particularly, the geography around estuaries and harbors is complex and since it is difficult to assume the tsunami invasion direction, it was provided in the guidelines to assume that tsunami is going to generate from all the horizontal load directions. As a general rule, in this case a equivalent wave pressure was assumed in tsunami run-up direction (X-direction) and orthogonal direction (Y-direction). Moreover, for the back wash also it is appropriate to estimate the same wave pressure.

However, the tsunami run-up direction can be specified with plain geography and proper application of numerical simulation results exceptionally, but a careful examination will be required in those cases since the tsunami invasion direction may change depending on the analysis assumption of numerical simulation, positioning of surrounding structures, etc.

(e) Calculation of buoyancy

Some buildings were found to have overturned due to the tsunami in Great East Japan Earthquake. In such buildings, the piles did not have sufficient resistance to bear the overturning moment by tsunami including buoyant force.

Based on the field survey results, it assumes that buoyant force may generate corresponding to the cubic volume under the inundation depth at the maximum, while on the other hand, many cases were observed wherein there was reduction by water inflow from the openings.

Based on such results, since water inflow inside the buildings cannot always be anticipated when the tsunami water level is rising at a great speed, the guideline was sorted considering the buoyancy proportionate to the inundated building cubic volume (including volume of internal spaces), and it was decided that the volume rate can be deducted from buoyancy only in cases when the volume of water flowing into the buildings (inundation volume) can be calculated. In such cases, it is necessary to consider buoyancy of volume rate of the skeletons itself.

(f) Special investigations and studies

In order to provide future support for development of research and study, regulations on “depth water coefficient according to appropriate numerical values for calculations based on special research or studies" have been incorporated in the guideline.

At the present, it is assumed that value of a decrease according to the Froude number Fr (Fr = u/$\sqrt{g\eta}$, here u: flow velocity, g: gravity acceleration, η: inundation depth. Higher the Froude number, stronger the flow force) shown in report[24), 25)] of aforementioned buildings code revision promotion project.

(g) Design flow of the buildings

The guideline shall confirm the strength of buildings against the tsunami load. Specifically, the following items were validated.

① There is no destruction of pressure-resistant components due to tsunami wave pressure
② The horizontal load bearing strength exceeds the tsunami wave force in each direction and each floor
③ Considering the buoyancy and self-weight, the building does not get overturned or slide due to the tsunami load
④ It should be designed to consider soil erosion and impact load by debris (Fig-3.3.9.14).

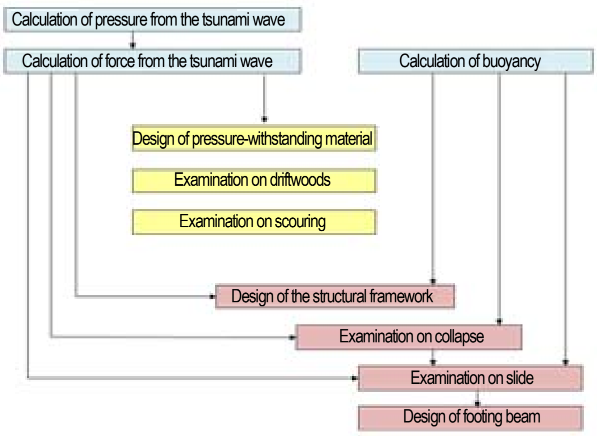


Figure 3.3.9.14 Design flow (overview)

(h) Other design-related considerations

Guideline recommended pile foundations, or spread foundations which have provision to protect the incline of the building considering corrosion. Further, for preventing damage due to debris impact, it was ascertained that the major element consisted frame structure does not damaged or the destruction in a part of columns or load bearing walls do not cause collapsing of the whole building by debris impact.

2) Technical manual and design examples

The aforementioned technical standards notification was announced and enforced on December 27, 2011, but for providing technical support to the structural designers, the National Institute for Land and Infrastructure Management undertook the work of creating technical manual and design examples including above contents and guideline. The creating manual and examples has been totally supported by Building Research Institute.

Moreover, it created the design examples with the cooperation of the Urban Renaissance Agency, Japan Structural Consultants Association.

The design examples were based on the existing reinforced concrete residential complexes with the purpose of providing an actual calculation process, and cases having the following different inundation depths were created; ①design example assuming inundation depth of 10m and water depth coefficient a = 2.0 , ②design examples assuming inundation depth of 15m and water depth coefficient a = 2.0

The important notice in detail design clarified through the creation of design examples were incorporated in the technical manuals. Those contents are also compiled as a National Institute for Land and Infrastructure Management Report (no.673) [4)], and lectures has been carried out for the managers of local government based on lecture notes with additional design examples under Ministry of Land, Infrastructure, Transport and Tourism subsidized projects.

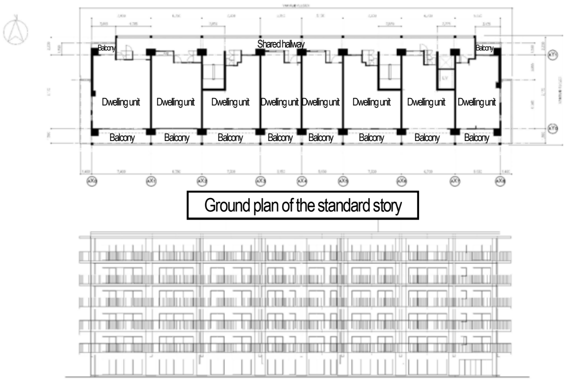
3) Overview of design example

This section provides an overview of the design examples.

(a) Reinforced concrete construction of 6 storied residential complex

This building was designed to carry tsunami wave load in case of 10m inundation depth with the water depth coefficient a being 2.The original design was an 8 storied residential complex but was revised to 6 stories (Fig-3.3.9.15).

The desired load carrying capacity was confirmed by increasing the thickness of load bearing walls ([ex: 1 story] 230 mm in original design -> 350 mm for evacuation building), increasing the piles (18 piles in original design -> 20 piles for evacuation building), and changing the pile diameter (1300φ in original design -> 1900φ for evacuation building).



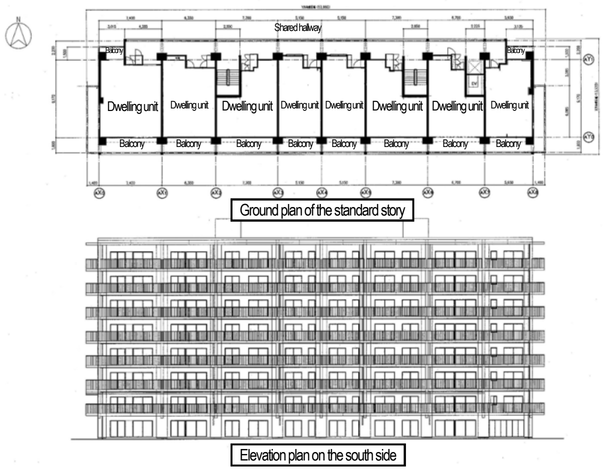
Usage Number of stories	Housing complex 6 stores above ground, 1 rooftop structure
Building height	18.07m
Standard floor height	2.85m
Structure type	Longitudinal direction bare frame structure Transverse direction wall frame structure
Foundation type	Piled foundation (concrete composite steel pile cast in place)

Figure 3.3.9.15 Design example (1) overview

(b) Reinforced concrete construction of 8-storied residential complex

This building was designed to carry tsunami wave load in case of 15m inundation depth with the water depth coefficient a being 2. The original design is same as the one mentioned in (1) (Fig. 3.3.9.16).

The required load carrying capacity was confirmed by further increasing the thickness of load bearing walls (Ex: 1 story) maximum 500mm), increasing the piles (18 piles in original design -> 34 piles for evacuation building), and changing the pile diameter (1300φ in original design -> 2000φ for evacuation building).



Usage, Number of stories	Housing complex 8 stores above ground, 1 rooftop structure
Building height	23.77m
Standard floor height	2.85m
Structure type	Longitudinal direction bare frame structure Transverse direction wall frame structure
Foundation type	Piled foundation (concrete composite steel pile cast in place)

Figure 3.3.9.16 Design example (2) overview

(4) Backing up measures related to support for damage to buildings by ground shaking

1) Response to ceiling collapse damage

The Great East Japan Earthquake caused much ceiling damage in many buildings over a wide area. The survey by the building standards development promotion project showed that more than 2000 buildings suffered ceiling damage.

Conventionally, the Order for Enforcement of Building standards Law has stipulated that the ceiling should not fall by ground shaking. No specific engineering standards have been defined and the countermeasures have been given in the technical advice.

After the disaster, a survey item 41 "a research study for the promotion of the seismic standards on nonstructural components with regard to the Great East Japan Earthquake" was announced as a part of the building standards promotion project. The Building Performance Standardization Association took the survey item and formed a committee to examine the damage and work on the seismic design of suspended ceiling chaired by Isao Sakamoto, a Professor emeritus at the University of Tokyo.

Based on this result, the ceiling seismic design STG made a standard draft, which was established under the technical standards draft TG of the NILIM building structural standard committee.

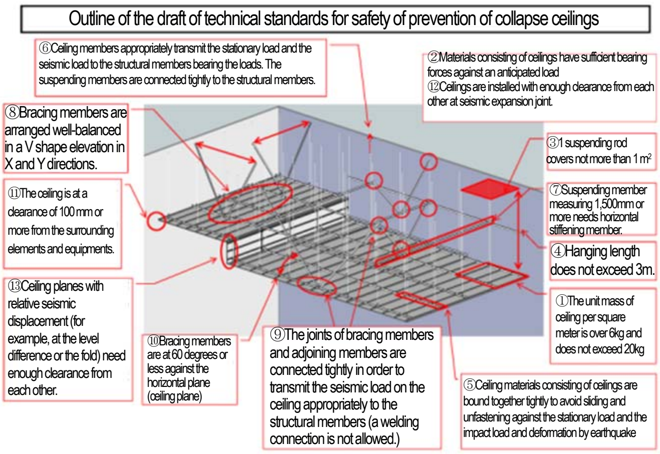


Figure 3.3.9.17 Summary of the "specification route" for prevention of ceiling collapse

The draft had three routes applicable to the ceilings suspended at 6m or above and covering more than 200m^2. The routes were "specification route", "calculation route" and "special verification route."

The specification route had criteria according to the unit mass of the ceiling such as a tight connection between each ceiling member to avoid any damage or fall during an earthquake, a well-balanced layout of sufficient bracing members to diminish harmful resonance, a sufficient clearance between the ceiling and the surrounding members and a sufficient clearance at the level difference and others to avoid the collision. The route also allowed fail-safe measures like extending the net beneath the ceiling or hooking the ceiling members with wires.

The calculation route had criteria for verification: ① no damage with a load three times of the dead load, ② no damage to the members and the joints with the inertial force calculated by the spectral method, the simple spectral method or the seismic coefficient method considering the acceleration on the ceiling surface, ③ no collision to the surrounding walls and others with a clearance more than the calculated horizontal displacement.

The special verification route was also made to enable individual verification.

A public comment for the draft was conducted by the housing bureau of MLIT and the NILIM between July 31, 2012 and September 15, 2012 after some modifications reflecting the comments by the NILIM building structural standard committee.

2) Measure to prevent the fall of escalators

By the Great East Japan Earthquake, it was confirmed that 4 escalators fell in commercial facilities, although no one was fortunately hurt.

With regards to the installation of escalators, the Building Standards Law has not any specific regulations for the structural framework. The industrial guideline (which is not compulsory legislation) requires that the bearing width should be more than 1/100×height of an escalator+20mm.

Based on the current damage, in order to promote the arrangement of the data required for damage analysis and technical requirements, the research subject [45. Review for the earthquake safety measures with respect to lift and escalator] has been set up under the Building Standards Maintenance Promotion Program. In the Building Performance Standardization Association which was elected by the general invitation, the committee of experts was set up and the technical survey concerning the damage analysis and measures to prevent the fall of escalators was promoted.

Based on this result, the draft of technical standards to prevent the fall of escalators were made by the Housing Bureau and NILIM through the deliberations on the Building Structure Standards Committee. The draft requires that the bearing width should be more than 1/40×height of a escalator+20mm and so on. Public comments was invited on the draft between July 31 and September 15, 2012, And the technical standards based on these results are scheduled to be arranged.

3) Measures for Exterior material collapse damage

With regards to the damage caused to the exterior material in the Great East Japan Earthquake, falling of ALC panels of large commercial buildings, exterior wall tiles, mortar etc was reported but fortunately there was no human fatality involved. However, although there was no report of any major damage to the main structure, there were many damages such as lifting or peeling of the outer walls which were finished with tiles or mortar.

With regards to the finished materials including exterior materials, the construction method was specified in Article 39 of the Building Standard Law Enforcement Order and Notification No. 109 of the Ministry of Construction of 1971, however, technical standards including the standard for method of mounting are not yet developed.

Based on the recent situation of damage, the upgrading of the law or technology and standards related to the earthquake-proof safety in order to target the insufficient the exterior materials like tile/mortar etc., ① establishment of the technology and standards for the spalling prevention considering the earthquake-proof safety of the external materials, ② aiming at the establishment of the method to evaluate the soundness of the external materials post the earthquake, is planned to be carried out from 2012 for the period of 3 years [Research on methods and criteria for evaluation of the seismic safety exterior material] by NILIM.

Also, prior to this, in 2011, as for the public facilities, by implementing the earthquake damage investigation of the external materials caused by the Great East Japan Earthquake the manufacturing and construction method, a number of case studies were collected on the relationship between damage such as peeling and lifting etc. Moreover, with regards to the tile walls using organic adhesives which is increasingly applied in the recent years, by collecting data from the survey of industry associations, wide range of the earthquake damage data related to the exterior materials was summarized.

4) Future investigation topics

With respect to long-period earthquake ground motion, the NILIM Building Structural Standard Committee set up the long-period earthquake ground motion review WG. Taking into account the status of the examination conducted by the Central Disaster Management Council and the Headquarters for Earthquake Research Promotion, the study has been continued. Tentative measures of long-period earthquake ground motion were announced in December 2010 prior to the Great East Japan Earthquake. Public comments were collected and the study shall continue based on the comments received. Regarding the countermeasures for liquefaction, simple diagnostic method for detached houses etc, will be continued to be investigated in the building standards development promotion project.

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3.3.10 Housing

This section gives an overview of human damage and housing related damage caused by this earthquake, which will become the assumption for efforts to be taken in the residential sector, and it also explains the role played by the National Institute for Land and Infrastructure Management (NILIM) in the efforts for emergency response and recovery in the residential sector. Furthermore, the contents of this section are based on the data and conditions etc. at the time of writing this document (October 2012). One must keep in mind that these can change over time.

(1) Overview of the damage to residential property and the response afterwards

1) Overview of damage

Extensive areas of land were damaged in the Great East Japan Earthquake due to the main shock on March 11, 2011, the tsunami disaster, and the aftershocks that were centered near the Pacific coast of the Tohoku and Kanto regions. According to reports published by the National Police Agency (October 31, 2012), areas reported to have been affected with

Table 3.3.10.1 Human damage and housing damage in the Great East Japan Earthquake, and housing conditions thereafter

■ The Great East Japan Earthquake Situations of human damage, damage to housing and subsequent residency

	Human damage (person)		Number of refugees (person)		Damage to housing (house)		
	Dead	Missing	Temporary housing, public housing	Total	Complete collapse, etc.	Half collapse	Total
Iwate Prefecture	4,671	1,195	41,303	41,969	19,214	5,037	24,251
Miyagi Prefecture	9,529	1,359	113,759	114,787	85,450	151,736	237,186
Fukushima Prefecture	1,606	211	99,229	99,229	21,094	71,954	93,048
Subtotal in three prefectures	15,806	2,765	254,291	255,985	125,758	228,727	354,485
Other prefectures	66	4	56,094	70,888	4,121	37,504	41,625
Total	15,872	2,769	310,385	326,873	129,879	266,231	396,110
Note	National Police Agency on October 31, 2012	Same as on the left	Reconstruction Agency on October 4, 2012	Same as on the left	National Police Agency on October 31, 2012 (including washed away and complete or partial loss by fire)	National Police Agency on October 31, 2012	National Police Agency on October 31, 2012

	Temporary housing, etc. (house)						(Application of own house)
	Construction	Housing rental	Existent public housing, etc	UR	National public officers' housing, etc.	Total	Emergency repair
Iwate Prefecture	13,984	3,355	167	0	15	17,521	2,767
Miyagi Prefecture	22,095	25,005	1,055	48	134	48,337	67,548
Fukushima Prefecture	16,775	21,967	424	0	82	39,248	27,970
Subtotal in three prefectures	52,854	50,327	1,646	48	231	105,106	98,285
Other prefectures	315	12,245	7,249	921	1,283	22,013	2,358
Total	53,169	62,572	8,895	969	1,514	127,119	100,643
Note	Housing Bureau of MLIT on October 1, 2012 (Number of houses completed)	Reconstruction Agency on October 22, 2012 (Number of houses occupied)	Housing Bureau of MLIT on September 24, 2012 (Number of houses occupied)	Same as on the left	Ministry of Finance on October 28, 2012 (Number of houses occupied)		Ministry of Health, Labour and Welfare on October 2, 2012 (Number of applicants)

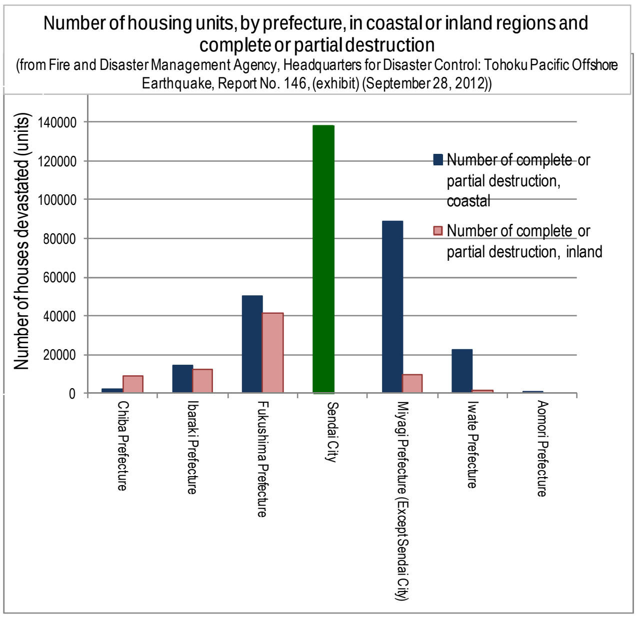
	Permanent housing				Note
	Required number of housing (plan)	Public housing (plan)	Same as on the left, results (construction started)	Disaster recovery housing loans	
Iwate Prefecture	17,600 ~18,600	5,600	223	542	
Miyagi Prefecture	72,000	15,000	396	4,390	
Fukushima Prefecture	Unfixed	Unfixed	230	1,354	
Subtotal in three prefectures	89,600 ~90,600 plus Fukushima's share	20,600 plus Fukushima's share	849	6,286	
Other prefectures			94	793	
Total			943	7,079	
Note	By October 2012 (Round figures, including rebuilding on its own in private sector, public housing, etc.)	Information grasped by the Housing Bureau by October 2012	Housing Bureau of MLIT on October 31, 2012 (Construction to start)	Japan Housing Finance Agency (Tohoku) on September 30, 2012 (application for use)	

human damage and damage to housing etc. extend over 21 prefectures from Hokkaido down to Kochi in the west. The death toll in 12 prefectures totaled to more than 15,000, the missing count more than 2700 people, and more than 99% of these figures pertained to the three prefectures of Iwate, Miyagi and Fukushima (hereinafter "3 Disaster-stricken Prefectures").

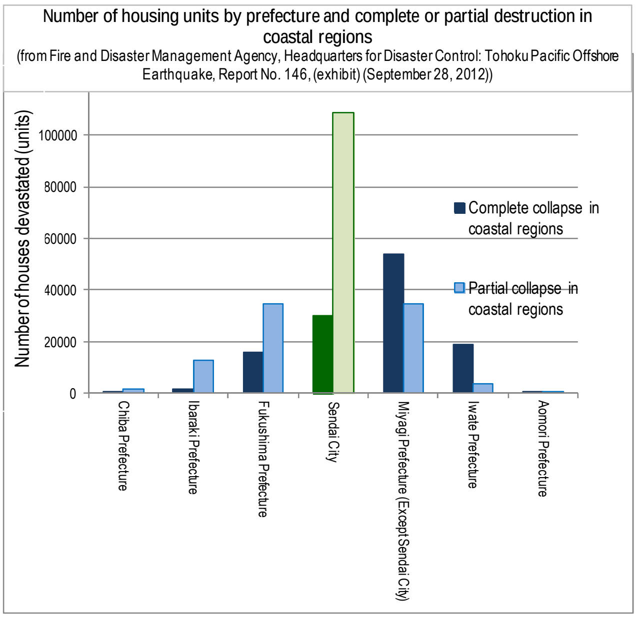
Furthermore, 130,000 housing units were completely destroyed (of which 126,000 were from the 3 Disaster-stricken Prefectures), the total number of totally and half collapsed housing units was 396,000 (354,000 from the 3 Disaster-stricken Prefectures), and the number of evacuees was 327,000 (these data were from National Police Agency data (housing damage in terms of number of housing units) and Reconstruction Agency data. Table 3.3.10.1 upper section)

Figure 3.3.10.1 is a summary of housing damage in the six prefectures bordering the Pacific Ocean from Tohoku to Eastern Kanto, totaled for coastal regions (towns and villages bordering the Pacific Ocean), inland regions (regions other than those mentioned above), and prefectures (Number of buildings are totaled based on data of the Fire and Disaster Management Agency. Sendai City spreads across a wide region including inland urban areas, so separate totals were prepared for Sendai City, and it was not included in the totals for other regions of Miyagi prefecture.). The impact of the tsunami caused extensive damage in the 3 Disaster-stricken Prefectures, and among these the cases of total collapse (including washed away) seen in Iwate and Miyagi prefectures was relatively greater. There was large number of damaged residences in metropolitan Sendai, and although there was much damage in the coastal regions of Fukushima Prefecture and further south, the damage in the inland regions was also comparable in magnitude.

Figure 3.3.10.2 compares these damages with the Great Hanshin-Awaji Earthquake. Looking at human damage, the Great East Japan Earthquake saw a higher death toll compared to the number of injured people, due to the impact of the tsunami. As far as the damage to housing was concerned, one can see that the two earthquake disasters had almost equivalent quantitative damage in terms of number of housing units damaged (we could not obtain the total number housing units damaged by the Great Hanshin-Awaji Earthquake, so the comparison was effected by substituting the number of housing units with the number of households).

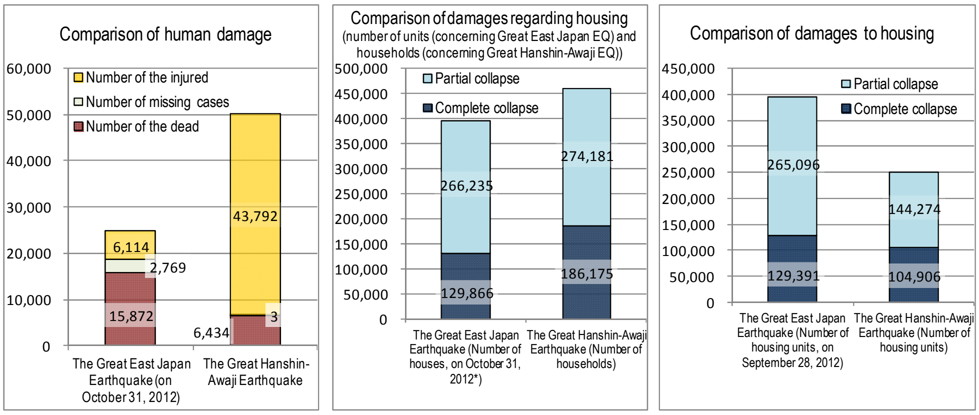


(1) By prefecture-wise, by region (coast/inland)



(2) By prefecture in coastal regions

Figure 3.3.10.1 Number of housing units, by complete or partial destruction



(1) Human Damage (2) Housing damage (No. of housing units/households) (3) Housing damage (No. of buildings)

Figure 3.3.10.2 Comparison between Great East Japan Earthquake and Great Hanshin-Awaji Earthquake

On the other hand, in addition to the aforementioned fact that the damage caused by this earthquake was widespread, depending on the city, town and village, several percent of their population died, and central management functions of the local government was greatly damaged (13 cities/towns with a death toll of more than 500, of which 4 cities/towns with a death toll of more than 1000. 6 cities/towns having a death toll that amounted to more than 3% of their population, of which 3 cities/towns having this amounting to more than 5% of their population, all data totaled from data published by the Fire and Disaster Management Agency).

2) Emergency measures for housing

In response to such damage, 127,000 housing units (105,000 housing units in the 3 Disaster-stricken Prefectures) were prepared and secured by means of emergency housing (emergency temporary housing, etc.), new construction ("temporary construction"), private housing rental ("temporary rental") and the use of existing public housing or housing for government workers. 310,000 (254,000 from the 3 Disaster-stricken Prefectures) of the evacuees are residing in this temporary housing, etc. (Source: Reconstruction Agency data).

This time, "temporary rental" (and units treated as temporary construction) was widely used among temporary housing, and although it gradually declined after the peak period (April-May 2012), at present about half of the total number, i.e. about 63,000 units (50,000 units in the 3 Disaster-stricken Prefectures), and more than half in the two prefectures of Miyagi and Fukushima are rented. This sort of housing was provided on a large scale outside the 3 Disaster-stricken Prefectures (12,000 units "temporary rental," 7,000 units "public housing"), which is assumed to have received evacuees moving out of the disaster prefectures ("temporary construction" outside the 3 Disaster-stricken Prefectures: 315 housing units). Furthermore, another characteristic of this time's response was that as far as "temporary construction" was concerned, various provisions other than conventional pre-fabricated standardized housing, such as provision by "house makers," wooden construction by local housing builders, etc. were promoted (Table 3.3.10.1, middle section).

Also, the "emergency repairs" system was widely used for households whose homes suffered damage to an extent similar to half collapse, and did not occupy emergency housing; the total number of applicants was 100,000 (98,000 in the 3 Disaster-stricken Prefectures) (the ratio of "emergency housings + emergency repairs" to "cases of complete/partial destruction" was 57.5%).

3) Initiatives to secure permanent housing

From now on, the securing of permanent housing (self-rebuilding, post-disaster public housing, etc.) must proceed in an appropriate manner. The required number of housing units including privately owned/rented housing and public housing is 72,000 in

Miyagi Prefecture (according to the "Prefectural Housing Reconstruction Plan"), and is 17,600 – 18,600 in Iwate Prefecture (according to the "Basic Policy of the Prefectural Housing Reconstruction Plan," etc.).

As far as post-disaster public housing is concerned, the planned number of housing units for Iwate and Miyagi prefectures is a total 20,600 housing units, whereas no specific number has been given for Fukushima Prefecture. The total number of housing units for which construction work has already commenced is 943, of which 849 are in the 3 Disaster-stricken Prefectures (as of the end of October 2012) (Table 3.3.10.1, lower section).

The present state of self-rebuilding is such that in Miyagi prefecture, the number of privately-owned houses for which construction work has commenced is somewhat greater than that before the earthquake disaster (before the earthquake disaster it was 400 – 500 housing units/month, and the pace has gone up to 700-800 housing units/month since the second half of 2011); however in other prefectures the increasing trend is not so clear (Figure 3.3.10.4 (made at the Tohoku branch of the Japan Housing Finance Agency, from data published by the Ministry of Land, Infrastructure, Transport and Tourism)). There are a cumulative 7,079 cases of "use of disaster recovery housing loans" from the Japan Housing Finance Agency by the end of September (6,286 in the 3 Disaster-stricken Prefectures).

The flow chart of the aforementioned sections 2) – 3) is shown in Figure 3.3.10.3, and the status of the efforts (quantitative) taken for damages and emergency measures is shown in Table 3.3.10.1.

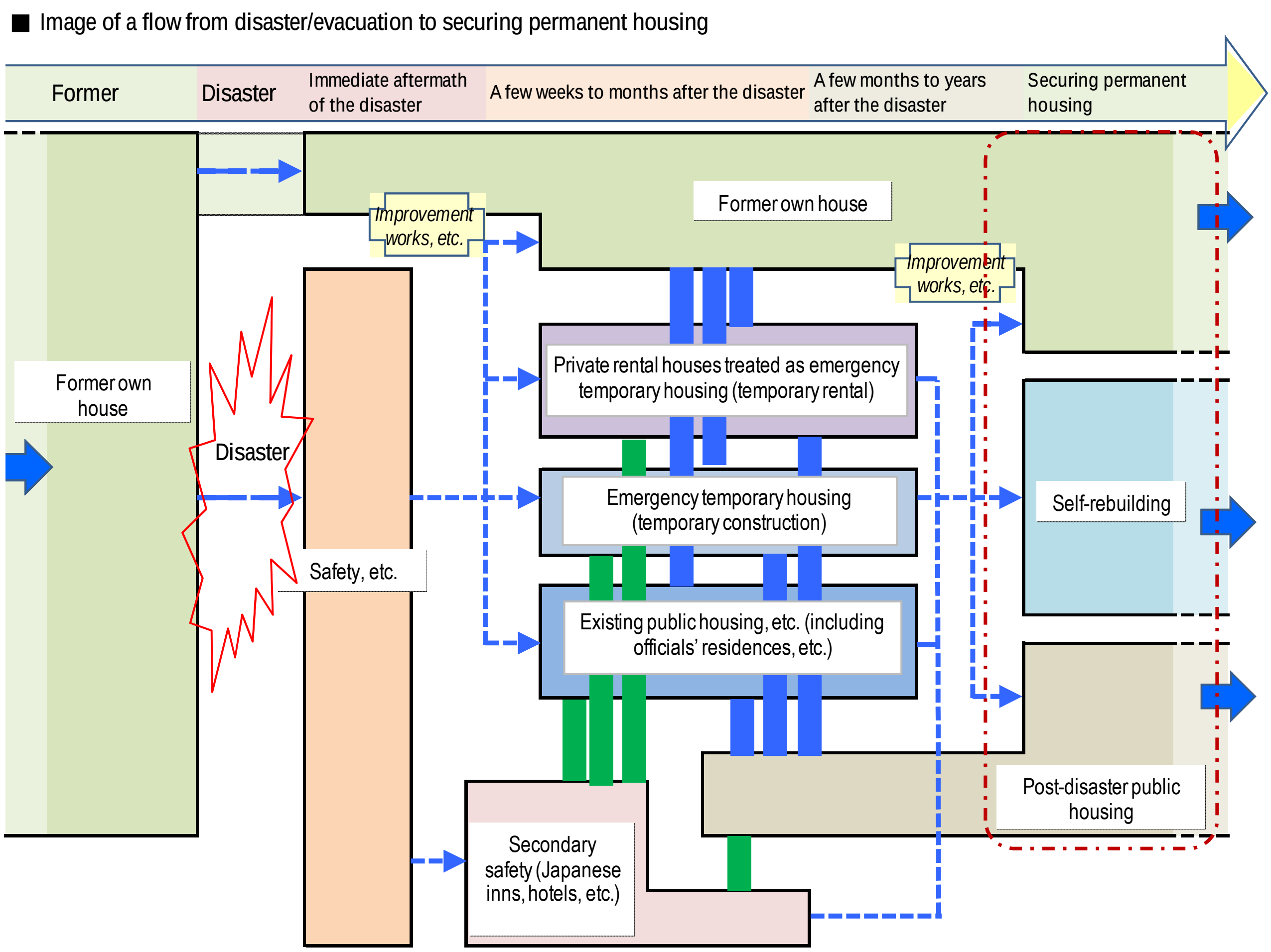


Figure 3.3.10.3 Flow from disaster/evacuation to securing permanent housing (image)

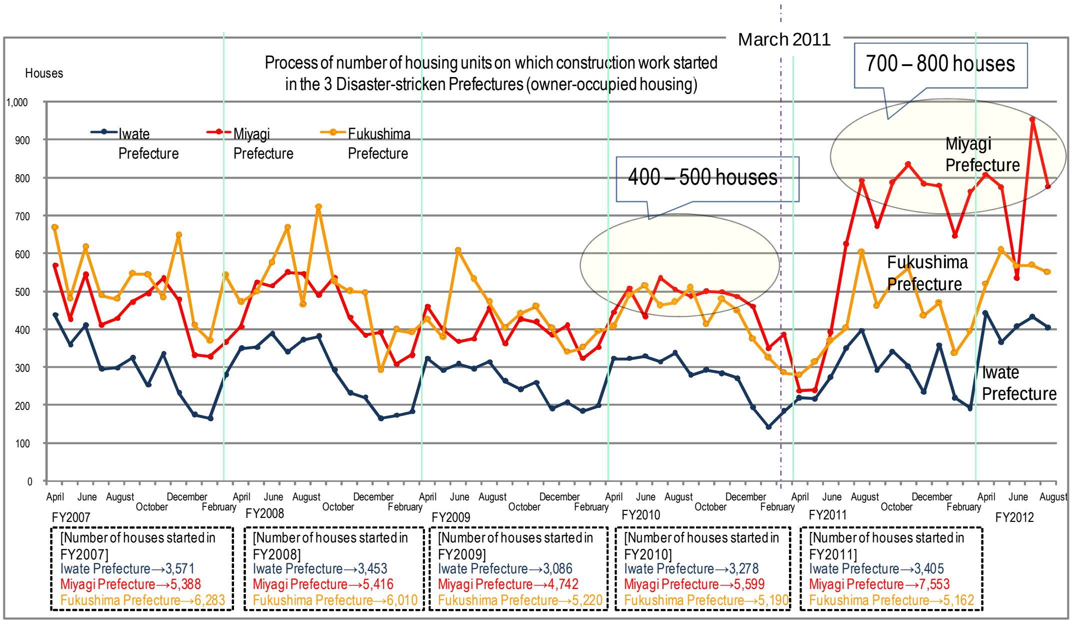


Figure 3.3.10.4 Number of housing units on which construction work started in the 3 Disaster-stricken Prefectures (privately-owned)

(2) Survey and technical support by NILIM

The actual condition survey and technical support related to main bodies (local public bodies and/or related agencies including private) of the efforts in the aforementioned process (Figure-3.3.10.3) are central to the efforts of NILIM in the residential sector. The outlines of each stage are as follows.

1) The survey of emergency housing and efforts of housing builders etc. after the disaster

An actual condition survey on the efforts of local housing builders and distributors of building materials (lumbers, timbers etc.) to secure housing (rebuilding/repairs of housing, etc.) on site was carried out mainly in tsunami-devastated areas since May after the disaster (still continuing now).

The following dotted line box is from results of the interview survey (survey period: June, September and November 2011, Survey target: 15 small housing builders etc. in Iwate and Miyagi prefectures) conducted by NILIM, to show the general trend related to recovery and reconstruction activity being carried out since immediately after the earthquake disaster by such companies.

Moreover, a survey about temporary housing matters was carried out as part of the above project. And in June 2011, following a request by MLIT, NILIM dispatched personnel to carry out guidance and coordination for smooth provision of emergency temporary housing in the 3 Disaster-stricken Prefectures. NILIM also participated in and cooperated with the session for study/preparation of the “Emergency Temporary Housing Construction Manual (Interim Report)” (May 2012) organized by MLIT, which was done in coordination with the Regional Development Bureau of MLIT, the local governments, and associations of related industry, based on the series of experiences surrounding the planning and construction of emergency temporary housing.

There was huge damage by the earthquake and tsunami disaster in the devastated areas including 3 Disaster-stricken Prefectures; there was a power failure immediately after the disaster, gas and water supply halted, and telephone services also temporarily failed. Furthermore, construction material workshops located in the coastal regions were damaged by the tsunami, resulting in shortages of some materials and equipment (plywood, heat insulating materials, roofing tile material, etc.). In such a situation, local housing builders revived construction activity, moving towards recovery and reconstruction in the region.

While the restoration of lifelines had still not progressed in a large part of the disaster areas, immediately after the main shock, local housing builders, conducted temporary inspections of buildings and housing their companies had built, and carried out emergency repairs as required and started their activities. Full-fledged restoration activities began after telephone lines were restored, but even after that, movement and activities were restricted due to gasoline shortages and shortages of heat insulating material etc. due to the earthquake disaster. Activities by local housing builders began at levels that were manageable by themselves, and it transitioned over time to becoming full-fledged maintenance and repair work with the disappearance of shortages of gasoline and materials.

Relatively large scale repair work by local housing builders began one month after the occurrence of the earthquake disaster, about mid-April when the method for the distribution of the donation money to each prefecture was decided on. Looking at the example of Miyako City in Iwate prefecture, subsidies for house remodeling that were being implemented before the earthquake disaster were put to use, and moves were also seen to allocate these to expenses for maintenance and repair work. Recently, some movement is being seen in residential reconstruction (reconstruction/ new construction), but the local housing builders mainly continue to receive a considerable number of orders pertaining to maintenance and repair work even now.

2) Support to the efforts for "Regional Recovery Housing"

"Regional Recovery Housing" is an initiative on part of local housing builders and suppliers. It is estimated that the housing demand arising in the disaster areas hereafter would far exceed the housing demand volume in the pre-disaster period (normal times), and it is necessary to effectively utilize the material and production capacity of local housing builders while also promoting, as required, the use of the capacity and cooperation of housing builders and suppliers from outside the region.

NILIM, along with the Building Research Institute, provided support in technical aspects, and participated in the studying processes of the "Regional Recovery Housing Coordination Committee," which was the promoting parent organization, and taking over from this the "Regional Recovery Housing Promotion Committee" of each prefecture.

The aforementioned "Coordination Committee" started in September 2011 with the cooperation of related public and private bodies in the 3 Disaster-stricken Prefectures. It prepared the "Design and Building System Guidelines" in December 2011. Various model design samples, including examples of the utilization of post-disaster public housing, the scheme for method of construction/design that takes the topography and costs reduction into consideration, were being posted for each region, wherein "Regional Recovery Housing" was defined as "housing units that fit into the concept comprising 6 items (long-term use, environment-responsive, low-cost, etc.), built on the basis of the design plan for conventional wooden housing units and the building system for ensuring smooth supply which can handle a demand far exceeding that during normal times." Furthermore, proposals that take into consideration the utilization of "Disaster Recovery Housing Loans" (mentioned earlier) of the Japan Housing Finance Agency or the "Regional Housing Branding Project" of MLIT (aid for long-term good housing by producers' groups practicing the regional housing production system) have also been put forth. The Coordination Committee was reorganized in February 2012, and a "Regional Recovery Housing Promotion Committee" was established in each of the 3 Disaster-stricken Prefectures; and their promotion was promoted with the recruitment/ registration of housing production groups (consisting of the architect offices, housing builder offices, material distributors for materials like lumber, etc.) that provide housing in accordance with the "guidelines" (the number of registered groups in May 2012 was Iwate 136, Miyagi 76, Fukushima 90) (see Figures 3.3.10.5 to 6).

Hereafter, along with making use of the various support measures being adopted, it is desirable to conduct PR in such a way that the advantages and merits of “Regional Recovery Housing” are easy for the disaster victims to understand, and to reinforce a practical coordination system for each of the production groups that would respond to the increasing demand.

Moreover, although not explained in detail here, in addition to “Regional Recovery Housing” initiatives, a variety of initiatives are being promoted related to home-providing by housing builders/ suppliers (building contractors, material distributors for materials like lumber, etc.) in the region; some of these initiatives started earlier, and some took root after the earthquake disaster. Hereafter, it is expected that we focus on such activities in response to the housing demand that is getting more and more acute day-by-day and town/city rehabilitation.

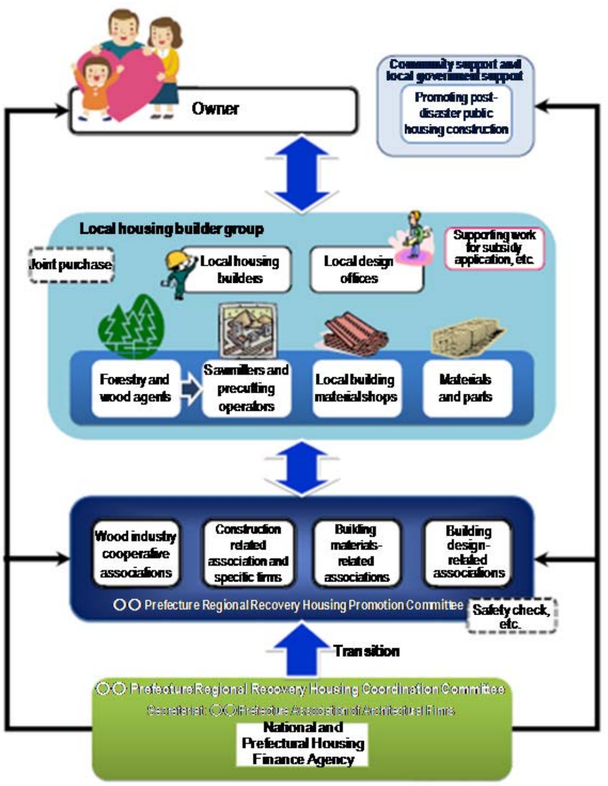


Figure 3.3.10.5 Production/Promotion System for Regional Recovery Housing

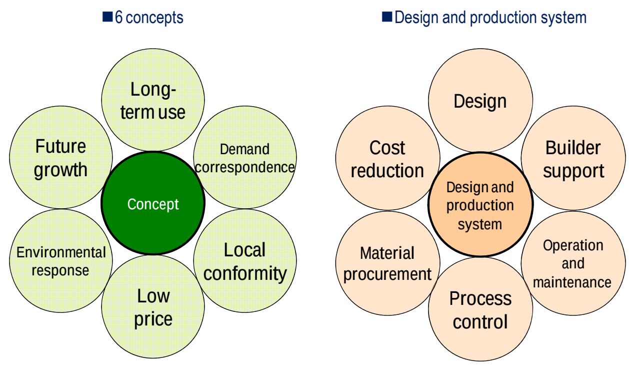


Figure 3.3.10.6 Regional Recovery Housing “6 Concepts” and “Planning and Production System”

3) Support for development of post-disaster public housing

Post-disaster public housing is another important aspect for the securing of permanent housing; a supply that responds to the various demands of the region to ensure residential stability for victims is needed. In a general disaster, the local public body provides post-disaster public housing (**) to a victim who has lost his home in the disaster and has income at or below the standard (*); however, in the case of the recent earthquake disaster, under the Great East Japan Earthquake Recovery Special District Act, special measures are established related to the requirements for occupying housing units, such as abolishing the income prerequisite during a certain period (maximum 10 years) after the occurrence of the disaster.

(*) Depends on the regulations of the local public body.

(**) As methods of provision, there are “construction,” “purchase” and “rent”).

Furthermore, in an effort to promote quick and efficient provisions by the local public body of the disaster-struck region, MLIT (Housing Bureau) conducted a “Study on Methods of Planning and Providing Post-disaster Public Housing” (FY2011 third supplementary budget). The objective of this study is to conduct, in the form of a study under the direct control of the ministry, a study of the basic plan for housing developments, the master provision plan usually carried out by the local public body for those cities, towns and villages in regions which request this and which are covered by the Act on Special Financial

Support to Deal with the Designated Disaster of Extreme Severity, and to extensively provide its results to local public bodies of disaster regions. NILIM accepted a request by the ministry, carried out technical support for the coordination of results based on exchange of opinions and coordination of the study, and put forth a practically feasible proposal with high effectiveness along with BRI, cooperating with many other bodies concerned in addition to towns and cities, the 3 Disaster-stricken Prefectures, and related organizations (UR, other ministries and agencies, local agencies, etc.) (Figure 3.3.10.7).

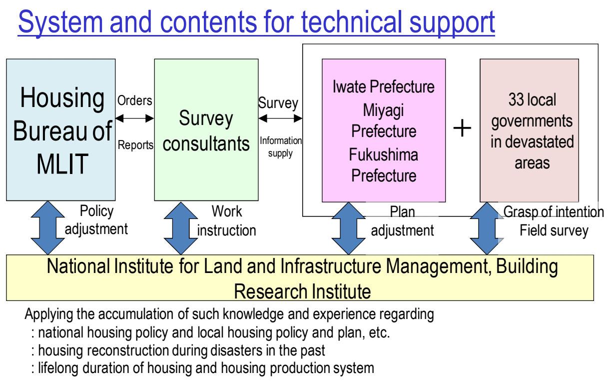


Figure 3.3.10.7 Study framework and role of NILIM in "Study on Techniques of Planning and Providing Post-disaster Public Housing"

The survey consists of a region-wise study and a theme-wise study; the former was conducted in 33 cities/towns/villages (Iwate 9, Miyagi 16, Fukushima 8). It offers proposals for the various types of housing units and housing estates adopting various types of construction such as low-rise wooden structure, medium and high-rise RC, and for introducing various functions for residences of elderly people, in a format to respond to each of the region's situations and policy, taking into consideration the safety for tsunamis, topographical characteristics of the region etc. Moreover, measures for widespread promotion were proposed and implemented depending on the present situation of each region, as a model study about landscape formation for post-disaster public housing, and preparation/distribution of system/ technical reference materials regarding post-disaster public housing for cities/towns/villages that have little project implementation experience.

The study on the basic plan for housing developments etc. for cities/towns/villages which made a new request was conducted also in FY2012, and NILIM participated in the study as it did in FY2011.

Furthermore, in theme-wise studies by the Housing Bureau, studies on the subjects of community/elderly population, disaster prevention and crisis management, etc. were conducted, and their results were used in the planning studies in each region (see Fig. 3.3.10.8).

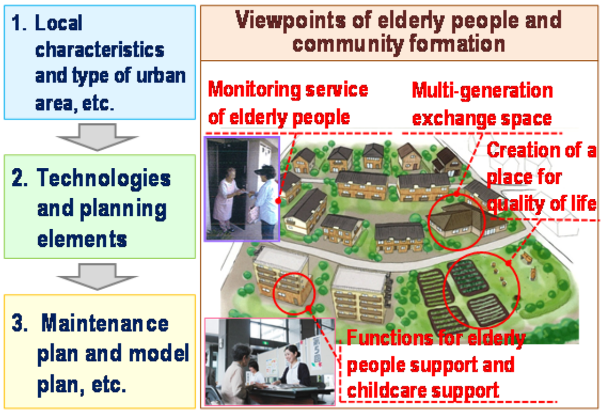


Figure 3.3.10.8 "Study on Methods of Planning and Providing Post-disaster Public Housing" study examples from the point of view of elderly people/community formation

(3) Conclusion

The aforementioned description gave an overview of human damage and the damage to housing caused by this earthquake and tsunami disaster, which becomes the basic postulate of the efforts to be taken in the residential sector, and it also explained the role of NILIM in the efforts for emergency response and recovery in the residential sector.

The important points to be noted about the issues and initiatives in the housing sector in the disaster areas are now changing over to appropriate securing of permanent housing (self-rebuilding, post-disaster public housing, etc.), but it is necessary to push forward with residential development, while working to maintain consistency with urban development and regional development based on a long term and broad perspective. Many issues remain, such as obtaining land, production and supply systems, providing various information to victims, adequate support by the public side, etc. We continue to pray for the fastest possible recovery of the disaster areas.

Acknowledgements

We wish to express our deepest gratitude towards the “Regional Recovery Housing Promotion Group,” the Tohoku Branch of the Japan Housing Finance Agency, and all other related people who provided us with the data used in this document.

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6) Fire and Disaster Management Agency, Headquarters for Disaster Control: 2011 Tohoku Pacific Offshore Earthquake, Report No. 146, Exhibit (September 28, 2012), 2012
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8) Ministry of Land, Infrastructure, Transport and Tourism (Housing Bureau): Status of the numbers of units of Publicly-Operated Housing, UR rental housing, etc. possible to be contributed to the victims, and which are already occupied, 2012
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10) Ministry of Finance: Actual results in provision of national property in the Great East Japan Earthquake, 1. National Public Officers’ Housing (as of September 28), 2012
11) Reconstruction Agency: Number of occupied housing units of emergency temporary housing by renting private rental housing (October 22, 2012), 2012
12) Reconstruction Agency: Number of evacuees etc. nationwide (October 10, 2012), 2012
13) Reconstruction Agency: Status and initiatives of reconstruction (October 16, 2012), 2012
14) Regional Recovery Housing Coordination Committee in the 3 Disaster-stricken Prefectures (Iwate, Miyagi, Fukushima): Regional Recovery Housing Design and Building System Guidelines, 2011

Useful reference websites

1) Regional Recovery Housing Promotion Group
Iwate Prefecture: www.hukkoujuutaku.sakura.ne.jp
Miyagi Prefecture: www.hukkoujutaku.com
Fukushima Prefecture: fukushima-hukkoujuutaku.org
2) Japan Housing Finance Agency, special web page on Great East Japan Earthquake: http://www.jhf.go.jp/shinsai/index.html
3) Building Research Institute, Special page on Tohoku Pacific Offshore Earthquake: www.kenken.go.jp/japanese/contents/topics/20110311/index.html

3.3.11 Cities and Towns

3.3.11.1 Damage situation of built up areas

(1) Findings such as damage situations in the built up areas suffering from the tsunami based on the examination and investigation study on the revival techniques [1)] (by City Bureau, MLIT)

The City Bureau carried out the examination and investigation of revival techniques for built up areas suffering from the tsunami using the first revised budget in 2011, and performed a study of the damage situations that was necessary to support the local governments for revival, where their power was cut for the restoration measures.

The findings were announced (as quick reports) sequentially after August 2011, and their main contents were as follows.

① "Findings of the present damage situations by the Great East Japan Earthquake" (the First report) (August 4, 2011, publication)

・The inundation area is about 535km^2, in which more than 40% has an inundation height above 2m, and the number of the suffering buildings is approximately 220,000, of which approximately 120,000 buildings are completely destroyed which includes being washed away.

・There is a large difference in the relation between the inundation heights and building suffering situations at around 2m of the former, namely; the percentage of completely destroyed buildings were predominant in areas where inundation heights exceeded 2m.

② The second report (October 4, 2011 publication)

・According to the number of building floors based on the study of the relation between the inundation height and the building suffering situations, in the case of a three-story building or higher, such as reinforced concrete constructions, the ratio of destruction danger is low when persons are above the inundated floor and the inundation height is considerably lower than the building height.

・Concerning the relation between the inundation height caused by the tsunami and the human damage, the ratio of dead persons of 65 years or older exceeds that of the whole suffering communities, and it accounts for the majority of the dead. In addition, the death rate rises with the inundation height.

③ The third report "The fact-finding results of the refuge from tsunami" (quick report) (December 26, 2011, publication)

・The persons who started the refuge action before the tsunami came after the earthquake was generated are approximately 63% of the whole.

・Whereas the actions for the preparation for refuge from the tsunami or for the refuge itself were frequent immediately after the earthquake occurrence, there were also many actions for the search of their family members, relatives and acquaintances as well as for the checking of the damage situations.

・The refugees by foot and those by car were almost half-and-half, but for younger generations, the ratio of car evacuation was higher.

These results of this investigation on the tsunami damage situations were provided to local governments, and the main aggregate data were shown on the homepage of Ministry of Land, Infrastructure, Transport and Tourism.

(2) Analysis about the suffering situations of the built up area

The NILIM in cooperation with the Building Research Institute (Incorporated Administrative Agency, Japan) summarized the results of the survey and study on the damage to buildings and so on as the "Report on Field Survey and Subsequent Investigations of Building Damage Following the 2011 off the Pacific coast of Tohoku Earthquake 2)" in March 2012.

The summaries of the report on the analysis on the damage situations of the built up areas that NILIM was in charge of were as follows.

1) Comparison of the damage of the built up areas with those the past great earthquakes and other disasters

Concerning the scale of the built up areas that received tsunami inundation by the Great East Japan Earthquake disaster and that of the reconstruction projects estimated in the future, we performed the comparison with the main disasters in the urban area of our country after the 20th century.

Table 3.3.11.1 Scales of the damages of main urban disasters and post-disaster reconstruction projects

Disaster name	Main disaster types	Devastated city		Areas burned out and inundated	Post-disaster reconstruction project area
The Great Kanto Earthquake	Fire in an urban area	One metropolitan prefecture and 6 prefectures	Tokyo City	About 3,470ha	About 3,600ha
			Yokohama City	About 924ha	About 358ha
Damages by the Pacific War	Fire by air raids	215 cities		About 64,500ha	102 cities About 28,200ha
Isewan Typhoon	High tide (inundation)	21 prefectures and 570 local governments		About 18,540ha	— (focusing on temporary housing and infrastructure restoration)
The Great Hanshin-Awaji Earthquake	Fire in an urban area	2 prefectures and 25 cities and towns		About 63ha	20 districts About 265ha
The Great East Japan Earthquake	Inundation damage by a tsunami	7 prefectures and 190 local governments (including the tsunami devastation of 6 prefectures and 62 local governments)		About 53,500ha	Unfixed
	Inundation damage area (partial collapse or more)			About 15,700ha	
	Fire by tsunami			About 65ha	

2) The building damages caused by the tsunami

We created an original database by building unit on the basis of the surveys of "Building damage situation" and "Height of the inundation by the tsunami" in the abovementioned "Survey of the damage situation by Tsunami" by the City Bureau of MLIT, and we summed this up by prefecture's boundary and by a 500m mesh unit and then analyzed it. (Based on the survey data at the end of November 2011)

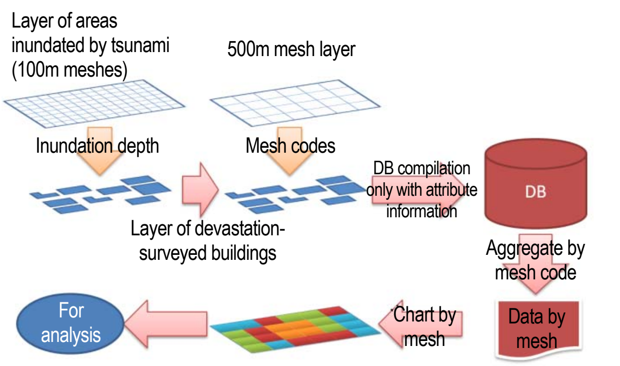


Figure 3.3.11.1 Analysis image of building damages caused by the tsunami

The summaries of the analysis are as follows.

① The maximum damage levels in the meshes

When we add up the values in the meshes of damage levels that take the maximum, the total of the top three prefectures occupies about half of the complete destruction by three divisions. The ratio of the meshes that take the maximum of damage divisions more than that of partial destruction differs depending on prefectures.

Table 3.3.11.2 Damage divisions that take the maximum value in each mesh

	3 Prefectures		Iwate Prefecture		Miyagi Prefecture		Fukushima Prefecture	
	Number of meshes	Proportion	Number of meshes	Proportion	Number of meshes	Proportion	Number of meshes	Proportion
Complete destruction (washed away)	1,532	39.7%	500	13.0%	789	20.5%	243	6.3%
Complete destruction	282	7.3%	37	1.0%	218	5.7%	27	0.7%
Complete destruction (Inundation on 1st floor's ceiling or more)	112	2.9%	45	1.2%	41	1.1%	26	0.7%
Large-scale partial destruction	301	7.8%	53	1.4%	221	5.7%	27	0.7%
Partial destruction (inundation above floor level)	363	9.4%	56	1.5%	215	5.6%	92	2.4%
Partial loss (inundation below floor level)	304	7.9%	27	0.7%	208	5.4%	69	1.8%
No damage	927	24.0%	0	0.0%	89	2.3%	838	21.7%
Unknown or not surveyed	35	0.9%	9	0.2%	0	0.0%	26	0.7%
Total	3,856	100.0%	727	18.9%	1,781	46.2%	1,348	35.0%

② The complete destruction rate in mesh

In three prefectures, mesh completely destroyed rate over 80% exceeds 40% of the total. Though the meshes with a high rate of complete destruction were mostly near shorelines, and the influence of the tsunami run-up river was also observed.

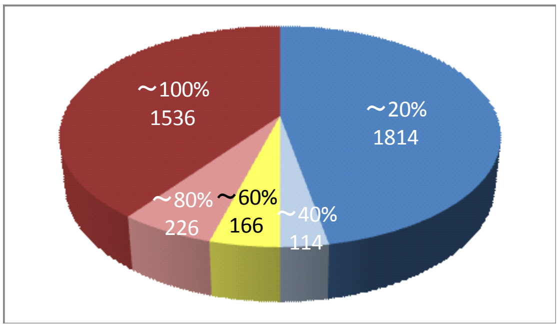


Figure 3.3.11.2 Complete destruction rate in each mesh

③ Relations between the tsunami inundation height and the damage

In the relations between the inundation height and the complete destruction rate, a great difference is observed at inundation heights of 3m or less and more than 3m. More detailed analysis is required concerning influences such as the topography.

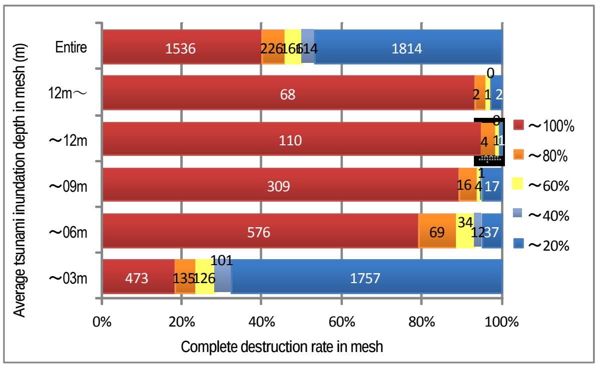


Figure 3.3.11.3 Relations of the tsunami inundation height and complete destruction rate

3) The number of refugees and the restoration situation of the lifelines

As a whole, the tendency of a decrease in the number of the refugees with the restoration of the lifeline was seen in case of the Mid Niigata prefecture Earthquake in 2004.

However, for the present earthquake, we cannot read clear relations between the lifeline restoration and the decrease of refugees in Iwate and Fukushima prefectures. In Miyagi prefecture, the number of refuge households was decreased with the restoration of electric power until the end of March, however the number of refuge households hardly decreased after late March, even though the waterworks and city gas were restored.

As for this factor, it is thought that a large number of houses were damaged by this earthquake and it was impossible to come back to the homes in such situation even if the lifeline was restored.

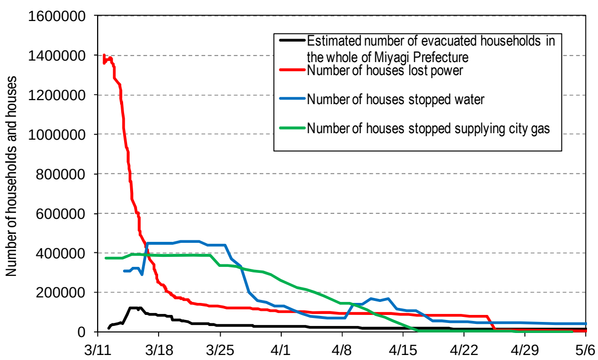


Figure 3.3.11.4 Relations of the estimated number of the refuge households and the lifeline restoration situation (Miyagi prefecture)

3.3.11.2 Restoration and the revival of suffering community areas

(1) Investigation and surveys on the revival techniques for the community areas suffering from the tsunami. (City Bureau)[1]

The City Bureau performed the examination of the types of community area revival patterns in order to contribute to the realization of recovery policy in the built up areas of local government such as ① the investigation and classification of the types of the reconstruction projects according to the damage situations and the community characteristics, and ② the study of revival methods appropriate for the patterns of reconstruction of the built up areas.

The report of the investigation was performed as follows.

1) Examination and investigation of the built up area revival patterns

Based on findings such as the tsunami suffering situations, the City Bureau examined the built up area revival patterns depending on the damage situations, and the community characteristics and the local intentions, made basic materials for examination of such matters as the revival technique and supported the decision of revival plans by the suffering local governments.

The investigation summary documents of every city, town and village became accessible on the homepage of the MLIT.

2) Correspondence scheme to the policy problems which are common to the tsunami stricken areas

The following examination and investigation were carried out concerning the policies for the common problems in the stricken areas, and the "Investigation of the tsunami suffering built up area revival techniques (Conclusion)" was published on April 24, 2012. In addition, the individual findings of ① to ⑤ as well as the detailed data of ⑥ were released.

① Studies of the improvement of parks and afforested areas relevant to the recovery from the Great East Japan Earthquake disaster: "The technical guidance about the improvement of parks and afforested area" (March 27, 2012, publication)

② The investigation of the utilization of debris for quick recovery and restoration; "A fundamental concept of the utilization of reproduction materials to residential land development laying, contributing to quick restoration, revival" (March 27, 2012, publication)
③ Investigation and survey of concepts of planning and designing of the urban spaces: "Fundamental concepts of making the landscape and urban spaces for the revival" (April 19, 2012, publication)
④ Investigation for the inheritance of historical and cultural heritages in the revival projects: "Fundamental concepts of urban area recovery by utilizing the historical and cultural heritages" (April 24, 2012, publication)
⑤ Investigation for the maintenance and management of local community in the revival state: "Guidelines for the community policies, the collaboration of measures for health, medical care and welfares as well as the community formation after the Great East Japan Earthquake disaster" (April 24, 2012, publication)
⑥ Affairs concerning the construction of consensus formation support tools in the interactive community recovery process.
⑦ Affairs concerning the location of evacuation routes and refuge facilities as well as refuge guidance.
⑧ Investigation affairs concerning reconstructing local industries and, broad-based production and distribution functions in the stricken areas.

(2) Integral anti soil liquefaction measures for public facilities and residential areas in the damaged areas

Using the 2011 supplementary budget, the City Bureau performed the survey of safer and lower-cost anti soil liquefaction measures for building up the projects to promote and to advance integral anti soil liquefaction measures. The survey was performed in cooperation with the NILIM and its achievements were published as the "Study and survey for the revival of the built up areas suffering from liquefaction by the Great East Japan Earthquake disaster: (Guidance [plan])[3)]" coauthored by the NILIM in April 2012. The first part summarizes the flow of rebuilding of liquefaction-damaged built up areas and the supporting system, and the second part describes the methods for how to grasp the suffering situation and the geological survey.

The survey continued in 2012, and an investigation was carried out, and it was published[4)] coauthored by the NILIM likewise in August, and "effect, influence facility calculation seat" (trial version) for liquefaction of the ground control in an area "of the ground-water level lowering" was utilized for actual examination of the anti soil liquefaction measures in the suffering built up areas.

(3) Residential land anti soil liquefaction measures utilizing the construction technology and research development furtherance system (Minister's secretariat, MLIT)

Utilizing the construction technology research development furtherance system, the minister's secretariat called for proposals for technology and research developments with the problem themes of "The technology and research development on economical and efficient anti soil liquefaction measures in existing public facilities and residential areas" in the 2011 supplementary budget and "The technology and research development for more economical and precise prediction of liquefaction disasters" in the 2012 budget.

As a result, ten problem themes were adopted, respectively, and the furtherance to technology development was being carried out.

NILIM joined in the adoption process.

(4) Arrangement of correspondences such as the risk judgment of damaged residential lands and the construction building restrictions (NILIM)

Concerning the risk judgment of damaged residential lands and the building restrictions, the outlines of the correspondences by MLIT or local governments that the NILIM rearranged in the "Report on Field Survey and Subsequent Investigations of Building Damage Following the 2011 off the Pacific coast of Tohoku Earthquake"[2)] are as follows.

1) Post-earthquake quick inspection of damaged residential lands

According to a publication document by the MLIT dated January 10, 2012, inspection was conducted on the damaged level of residential land in 56 cities, towns and villages in 9 prefectures, and in 6,456 places of investigation points, 1,450 places were judged "unsafe" and 2,142 were "limited entry."

Table 3.3.11.3 Result of post-earthquake quick inspection of the damaged residential lands (by prefecture)

		Danger (red)	Caution (yellow)	Surveyed (green)	Total
by prefecture	Iwate Prefecture	114	103	162	379
	Miyagi Prefecture	886	1,470	1,843	4,199
	Fukushima Prefecture	277	266	494	1,037
	Ibaraki Prefecture	30	64	41	135
	Tochigi Prefecture	94	173	125	392
	Gunma Prefecture	24	9	7	40
	Saitama Prefecture	0	27	104	131
	Chiba Prefecture	10	18	9	37
	Niigata Prefecture	15	12	79	106
Total		1,450	2,142	2,864	6,456

2) The implementation progress of the building and urban planning restrictions (as of the end of January 2012)

① Iwate prefecture

The construction restrictions with compelling force are not enforced, while the self-restraint in the building activity is requested by the local governments in some inundation areas (Miyako-city and Kamaishi-city).

② Miyagi prefecture

- 2 months after the earthquake: 4 cities and 2 towns partially designated asbuilding restricted areas according to Article 84 of the Building Standard Law.
- 6 months after the earthquake: 4 cities and 3 towns were partially designated as building restricted areas by the Special Provisions of the Building Restrictions Law.
- 8 months after the earthquake: 4 cities and 3 towns were partially designated by the law.
- After 8 months or more after the eathquake: 4 cities and 2 towns were partially designated as damaged built up area revival promotion areas, and in 1 city and 1 town, disaster danger district codes were established and areas partially designated.

③ Fukushima prefecture

In Soma-city, Minamisoma-city and Shinchi-machi, disaster danger district codes were established, and areas partially designated.

3.3.11.3 Action of residential land anti soil liquefaction measures in the damaged built up areas

(1) Liquefaction analysis of the suffering blocks by three-dimensional FEM

The NILIM examined the effect of integral anti soil liquefaction measures of public facilities and residential areas based on the combination of plural methods of construction at the liquefaction-stricken areas as a model case of the Great East Japan Earthquake disaster by computer analysis using the 2011 supplementary budget.

The result was used as examination materials about effective methods of construction to control the re-liquefaction in the suffering built up areas performed by MLIT.

The procedures of the examination are as follows.

① Setup and adjustment of the ground model (before the measures)

We built the present ground on a computer and simulated the liquefaction behavior for the seismic wave of the Great East Japan Earthquake disaster.

② Setup of the ground model and earthquake response analysis (after the measures)

We set the state that is expected on the basis of the present ground model and analyzed the effect of the liquefaction restraint against the seismic wave.

③ Presentation of the analysis results

We analyzed the effect of anti soil liquefaction measures according to the intercomparison by the combinations of having anti soil liquefaction measures or not as well as of the countermeasure methods of construction.

For example, concerning countermeasures in adjacent residential areas, we confirmed the applicability of reproducing such transformations of the ground where buildings next to each other are seen to bow as observed in many locations in the liquefaction stricken areas, we quantitatively analyzed the difference of the effects by the independent measures based on the ground water level lowering method and by the combination of basement water level lowering and excess pore water pressure dispersion methods with drain pipes, and calculated in combination the effect of the synergy of the measures of the road part and the residential area part and various measure mechanics.

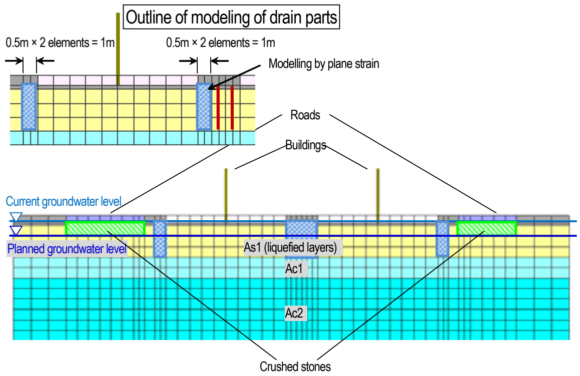


Figure 3.3.11.5 Placements of calculation meshes and measure constructions

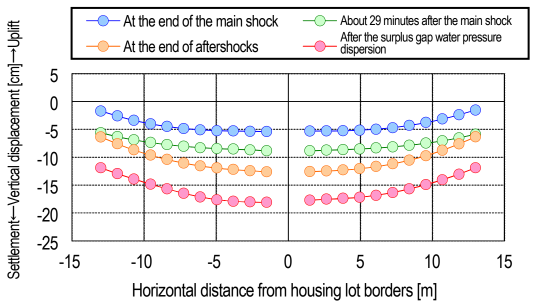


Figure 3.3.11.6 Reappearance of the recent situations

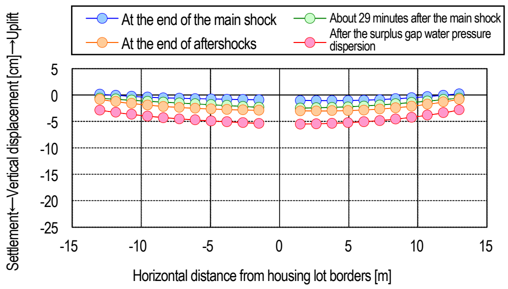


Figure 3.3.11.7 Independent effects of the countermeasure (groundwater level lowering method)

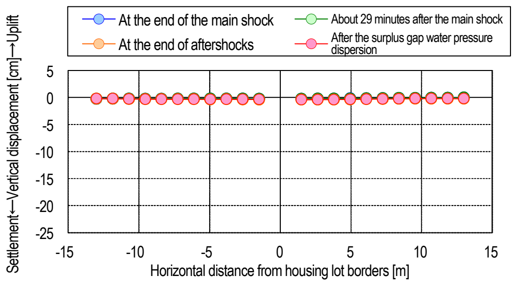


Figure 3.3.11.8 Compound effects of the countermeasure (groundwater level lowering method and drain pipe)

(2) Full-scale vibration experiments for countermeasures against residential land liquefaction (Measurement of the effective range of the drainage off method with a drain pipe)

The NILIM made measurements of the depression effect and the range (namely, the horizontal distance from the diameter center of the drain pipe) with the water pressure dispersion method using drain pipes to determine items such as coefficients to use for computer analysis of the design method of integral anti soil liquefaction measures for public facilities and residential areas using the supplementary budget in 2011.

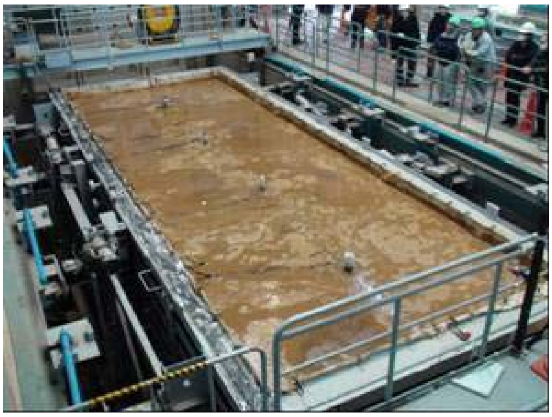


Photo 3.3.11.1 Appearance of the test body ground

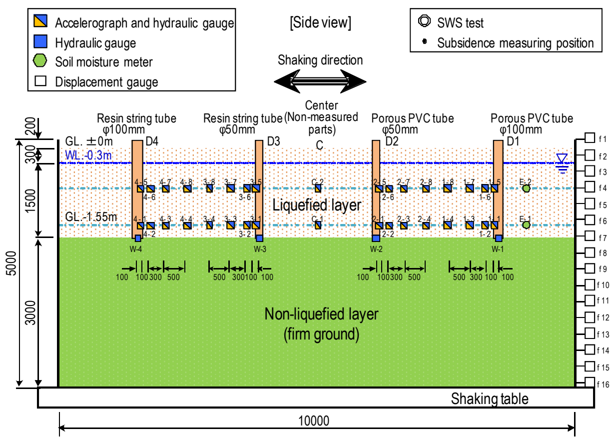


Figure 3.3.11.9 Placements of the drain pipe and sensors in test body ground

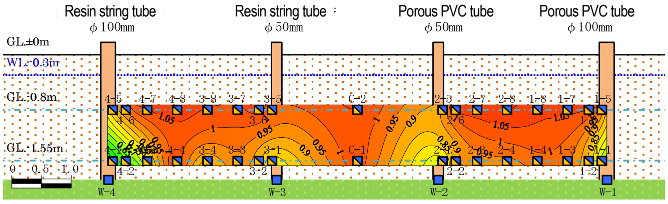


Figure 3.3.11.10 Distribution of the excess pore water pressure ratio

It was confirmed that the liquefaction depression effect of drain pipes had influences on the seismic waves observed at the time of the Tohoku district Pacific offing earthquake around Tokyo Bay area within a range of horizontal distance around 50cm in the drain for an input of almost equivalent repetition shear waves on loose sand deposits, and it did not reach to 1m.

From this fact, it is thought that it is necessary to position the drain pipes at a distance of nearly 1m when we use them as anti soil liquefaction measures.[7)]

(3) Simple calculation sheets for effects and influences by the groundwater level lowering method

The City Bureau and the NILIM published "Simple calculation sheets for effects and influences by the groundwater level lowering method (trial edition)." in August 2012.

As for the anti soil liquefaction measures for public facilities and residential areas as a whole, given the thickness of the layer of the shallow part where groundwater outruns and that liquefaction does not occur, the groundwater level lowering method is one of the strong choices. However, we might invite subsidence as a side effect due to compaction when there is a layer of the viscous soil in the lower part of the ground, and hence it is thought to be an obstacle in the examination by local governments of the damaged areas as we cannot easily evaluate such effect and influence. Therefore, the simple calculation sheets mentioned above were adopted as a technological assistance tool to easily grasp the quantity of the compaction subsidence of the lower clay layer that is the effect of anti soil liquefaction measures corresponding to the present conditions of the groundwater level lowering and the side effect of this measure by inputting the ground survey data of each district and the assumed earthquake scales for the evaluation and publication of them and to allow anyone including the local governments of the stricken area to download and use them.

The public offer of the calculation sheets is described on the homepage of the NILIM as Technology Breaking News No. 2.[4)]

(4) The FEM analysis of the liquefaction depression effect of residential land grounds with the grid-form soil-cement walls

"The grid-form soil cement wall" is regarded as one of the strong choices of the combined public facilities and residential areas anti soil liquefaction measures in the detached-house areas of the regular blocks. The NILIM proposed to obtain the bases using computer analysis of a number of model patterns in order to make check sheets to be used to judge the suitability of this construction method for the individual suffering disaster areas having various site areas and qualities of soil state, in 2012.

(5) The centrifugal loading vibration experiments on the suitability of "the grid-form soil-cement wall" method for anti soil liquefaction measures in the detached-house areas

The NILIM also proposed, in the 2012 budget, to measure phenomena that occur in the ground of a lattice where houses exist with experiments using a centrifugal force loading device in connection with problems in liquefaction control including the effects and influences of the interval distance of a lattice when the "grid-form soil-cement wall" method is applied to anti soil liquefaction measures in the detached-house areas, to acquires necessary data, and to confirm the effects of measures to be taken additionally.

(6) Caluculation of settlement by liquefaction using airborne LiDAR measurements data

The NILIM proceeded with the maintenance of the damage situation data of the liquefaction suffering residential areas that was necessary for the analysis of effects and influences of the anti soil liquefaction measures, and proposed to maintain them in order to acquire data about the change of the heights of the ground and buildings in the residential areas suffering from liquefaction by taking advantage of the recent improvement of measurement precision, and to arrange them by comparison of recent data of airborne LiDAR measurement before the suffering, in 2012.

References

1) MLIT HP: "Report of the examination and investigation on the tsunami stricken built up area revival techniques from the Great East Japan Earthquake," http://www.mlit.go.jp/toshi/toshi-hukkou-arkaibu.html
2) NILIM, Incorporated Administrative Agency Building Res. Inst.: "Research report of Tohoku district Pacific offing earthquake in 2011 (2012)"
3) MLIT HP: Examination and investigation for the revival of the built up areas suffering from liquefaction by the Great East Japan Earthquake disaster," http://www.mlit.go.jp/toshi/city/sigaiti/toshi_urbanmainte_tk_000004.html
4) NILIM HP: "Presentation of 'simple calculation sheets for the effects and influences of the ground water lowering' for anti soil liquefaction measures in areas stricken by the earthquake (Trial version)" http://www.nilim.go.jp/lab/bcg/sokuhou/file/120801.pdf
5) MLIT HP: The decision of the adopted themes of the 2011 supplementary budget for construction technology research development furtherance system "Advertisement for the technology development for earthquake disasters," http://www.mlit.go.jp/report/press/kanbo08_hh_000169.html
6) MLIT HP: The decision of the adopted themes of the 2012 budget for construction technology research development furtherance system, http://www.mlit.go.jp/report/press/kanbo08_hh_000189.html
7) NILIM HP: Measurement of effects of the anti soil liquefaction measures with the columnar drain (Laboratory finding summary) http://www.nilim.go.jp/lab/jbg/takuti/20120509gaiyo.pdf

3.3.12 Parks and Green Spaces

(1) Damage Investigation

The Great Eastern Japan Earthquake brought devastating damages to the parks and green spaces along the coastal areas from the Tohoku to Kanto region due to the tsunami and ground liquefaction.

The National Institute for Land and Infrastructure Management (NILIM) conducted field surveys at the parks and green spaces on the coast of Miyagi and Iwate Prefecture on April 15 to 16, 2011, in collaboration with the Parks, Green Spaces and Landscape Division of the City Bureau in the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in order to grasp the actual damages by the tsunami. Thereafter, a follow-up survey was conducted on June 23 to 24, 2011, for the parks and green spaces in Miyagi Prefecture in order to ascertain growth inhibition of trees by salt.

Regarding the damages by tsunami, we verified inundation damages to the facilities including buildings and playground equipment, pavement and signage in parks and green spaces (See Photo-3.3.12.1).

In addition, while damages of washout by lodging or breakage were observed for trees and tide prevention forests planted inside the parks (See Photo-3.3.12.2), salt damage by seawater, plant death and reduction of tree vitality by oil adhesion were verified in some species among the remaining trees (See Photo-3.3.12.3).

(a) Damage of Facility

(b) Damage of Playground Equipment

Photo 3.3.12.1 Damages of Park Facilities (Iwanuma City)

(a) Individual Tree (Iwanuma City)

(b) Tide Prevention Forest (Higashi-Matsushima City)

Photo 3.3.12.2 Damage and Lodging of Trees

(a) Plant Death by Salt (b) Reduction of Tree Vitality by Oil Adhesion

Photo 3.3.12.3 Growth Inhibition of Trees (Tagajo City)

Also, NILIM made a field survey in Chiba and Ibaraki Prefecture on April 6, 2011, in order to grasp the actual damages by liquefaction in parks and green spaces.

Damages were verified for buried objects like a water tank inside a park rising to the surface by ground liquefaction due to the Earthquake (See Photo-3.3.12.4). We also verified buried structures like public lavatories and benches and the bottoms of trees by sand boiling (See Photo-3.3.12.5), and cracks and unevenness in a square (See Photo-3.3.12.6). The aftermath in tree growth by sand boiling was not verified.

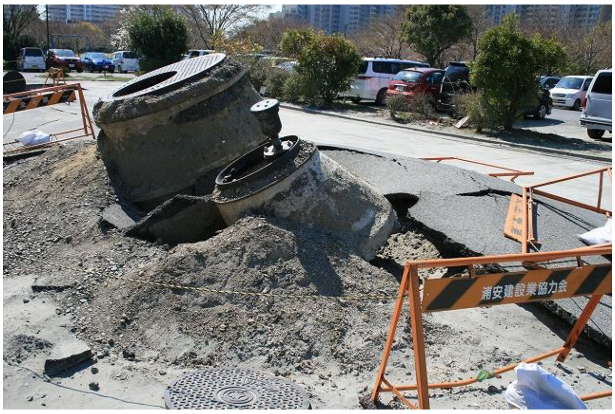


Photo 3.3.12.4 Surfacing of a water tank by ground liquefaction (Urayasu City)

Photo 3.3.12.5 Embedding of a public lavatory by sand boiling (Urayasu City)

(2) Effect of Disaster Mitigation of Parks and Green Spaces Verified by Damage Survey

The following items were verified as the effect of damage mitigation due to the tsunami in parks and green spaces in a damage survey.

1) Trees and Forests

Trees and Forests inhibited a move of castaways due to the tsunami, and then mitigated or protected the secondary damage that occurred due to the move (See Photo-3.3.12.7).

Also, these trees and forests diminished the wave power of the tsunami or surge, lowered the flow velocity and energy, and decreased the destructive force. Photo-3.3.12.8 indicates the damage situations in a place without a coastal forest and a place with one (broad or narrow forest width). The picture clearly shows the worst damage without a coastal forest, followed by with a narrow forest and with a broad forest.

(a) Crack generated on the ground of a square (b) Ground unevenness on the park road

Photo 3.3.12.6 Ground Unevenness (Urayasu City)

Photo 3.3.12.7 Inhibition of a Castaway by Trees (Tagajo City)

Photo 3.3.12.9 Protective Effect on Fire Spread by Forest (Ishinomaki City)

Photo 3.3.12.8 Damping Effect on Wave Power by Tide Prevention Forest (Ishinomaki City)

Also, the preventive effect on fire spread was verified in fires that occurred due to the Earthquake as the stoppage of spreading fire was determined at a forest (See Photo-3.3.12.9).

2) High Embankment

The effect of high embankment (observation deck) in the park was verified as a tentative evacuation area from the tsunami. At Minami-Gamo coast park in Sendai City, five people including staff and visitors and two pets who got left behind inside the park during the tsunami attack evacuated to the observation deck on the top of a high embankment (15.89 meter elevation), and then they were rescued by a helicopter within the day (See Photo-3.3.12.10).

Photo 3.3.12.10 Evacuation Site on High Embankment (Sendai City)

(3) Survey on Damage Factors of Coastal Forest

Regarding the forest area (coastal forest) with disaster mitigation effect against tsunamis, the target for tree growth on recovery was organized after making clear the damage factors by investigating tree configurations and the planting base in the damaged area.

The coastal trees in "Hamabe No Mori (beach area) of Sendai Natural Recreation Forest" in the Ido area, Wakabayashi Ward, Sendai City, Miyagi Prefecture were selected for the survey area because the site was a forest area with remaining trees even with damages by the tsunami and had a mixture of survived and lodged pine trees after the tsunami attack (See Figure-3.3.12.1).

The survey was conducted after the area was divided into three levels of Block A to C by the damage scale of the tsunami. This site is the coastal forest where the tsunami damage at 17 to 19 meters was reported[1)] and there was no difference of tsunami height in the survey area. The survey areas and the number of trees that were not washed out by the tsunami in each block are shown in Table-3.3.12.1.

Table 3.3.12.1 Area and Number of Trees Surveyed

	Area	Number of Trees	Damage
A	64.2m x 58.3m (3,743m^2)	129 (113)	Small
B	66.3m x 52.4m (3,474m^2)	112 (106)	Medium
C	60.0m x 60.0m (3,600m^2)	59 (38)	Large

Note: Figures in parentheses in Number of Trees show only pines.

1) Content of Survey

The trees were classified as "Remaining Type" where a tree was standing or leaning, "Breakage Type" where the root system of a tree was intact but the trunk was broken, and "Lodging Type" where a

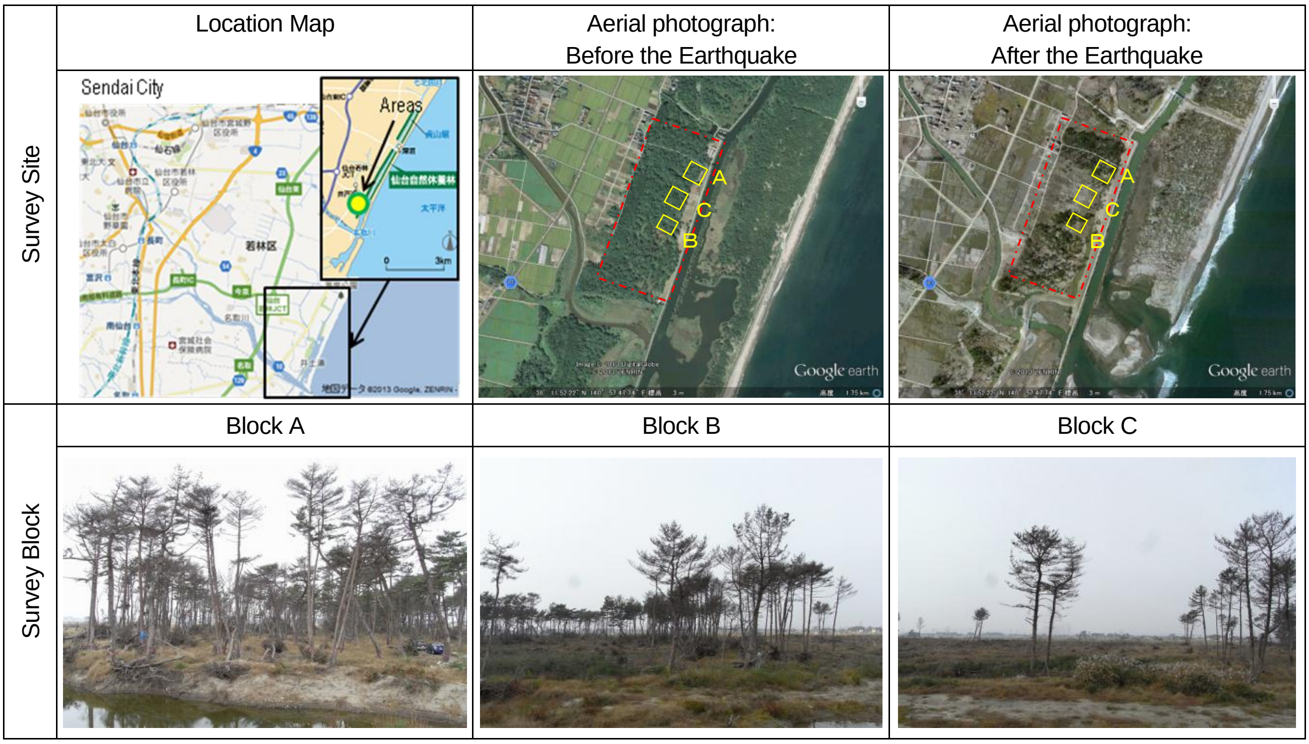


Figure 3.3.12.1 Survey Areas (Source Map: Google Map, Aerial photograph: Google Earth)

tree was lodged with the root system raised or with the root system scoured and fallen out.

・Tree configuration (tree height, trunk girth at chest height, crown height)

・Root system (longitudinal width, vertical depth)

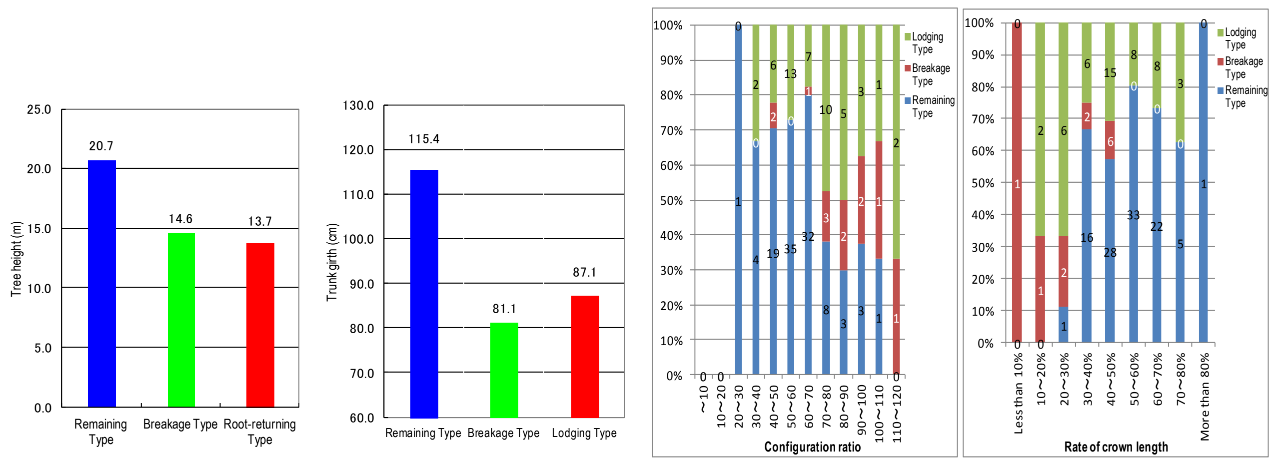
・Ground level and groundwater level

2) Damage Factors and Growing Target

a) Tree Configuration

The result suggested easiness of breakage and lodging in a small pine with low tree height or long-shaped trunk, and with a small portion of canopy consisting of live branches and leaves (See Figure-3.3.12.2).

Then, as for the target for tree growth with a configuration which will tolerate a tsunami like this time, it was considered preferable to have 20m in tree height, 120cm in trunk girth at chest height, 70 or less in the configuration ratio (tree height/trunk diameter at chest height), and 30% or more in the rate of crown length (length of crown with branches and leaves/tree height x 100).



(a) Tree Height (b) Trunk Girth at Chest Height (c) Configuration Ratio (d) Rate of Crown Length

Figure 3.3.12.2 Tree Configuration by Damage Type

b) Root System

The configuration of lodged extension of the root system was classified in four types shown in Figure-3.3.12.3. "Multi-exserted Hanging Root & Two-stage Horizontal Root Type" had the greatest root amounts and the weighted center of the root system in a lower position, and had the greatest resistance against lodging. The ordinal configuration of the pine "Hanging Root & Horizontal Root Type" had the second greatest resistance and both the "Horizontal Root Type" and "Multi-exserted Hanging Root Type" with less developed hanging or horizontal roots showed a tendency to be easily lodged compared to the former types of root system.

In order to grasp the relationship between the dimensions of the root system and the surface part supported by the root system, we estimated the ratio of dimensions of the root system to trunk girth at chest height (calculated as the root clump volume due to a morphologic difference of root systems) by damaged configuration. The results revealed an occurrence of lodging when the figure deriving from the trunk girth at chest height (m) multiplied by 10, which is defined as the threshold of root clump volume (m^3) for lodging to occur, was more than the values calculated by damaged configuration (See Figure-3.3.12.4).

Then, for the growth target of the root system, when assuming a pine tree with 120cm of trunk girth at chest height indicated in section (a), it was considered desirable to promote the extension of the root system to secure about 12 m^3 of root clump volume. It is essential to put the weighted centre of the tree form in a position as low as possible in order to increase the resistance to lodging. And for that reason, deeper extension of hanging roots is required.

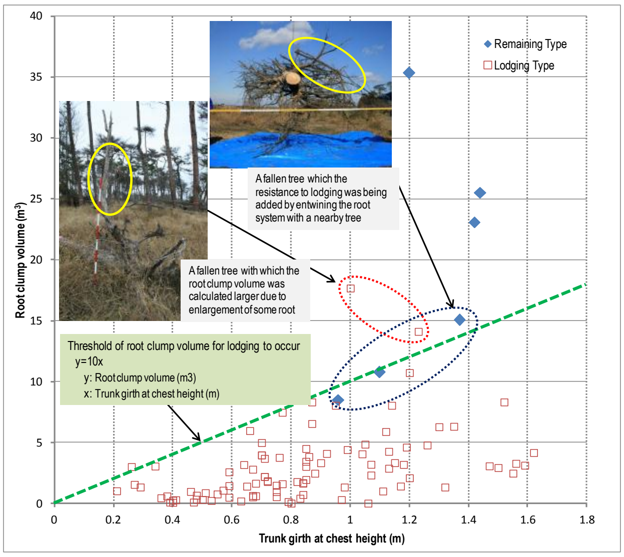


Figure 3.3.12.4 Relationship between Root Clump Volume and Trunk Girth at Chest Height by Damaged Configuration

c) Ground Level and Groundwater Level

In the relationship between damage configuration and elevation, the Remaining Type increased as the elevation was gradually raised until 1.6m of elevation and there was no difference between the Lodging and Remaining Types over 1.6m though the Lodging and Breakage Types were major and the Remaining Type minor at 0.4m of elevation.

Root System Type	Multiple Hanging Root & Two-stage Horizontal Root Type	Hanging Root & Horizontal Root Type	Horizontal Root Type	Multiple Hanging Roots
	Multiple hanging roots and horizontal roots with middle diameter develop, and in addition, the root system horizontally enlarges at the lower part of the hanging root.	One or two thick hanging roots and horizontal roots develop.	There are no hanging roots, but only horizontal roots develop.	Multiple hanging roots with middle diameter develop, but horizontal roots don't develop well.
Lodging Type				
Remaining Type				Nothing

Figure 3.3.12.3 Configuration of Root System Extension

In the relationship between the root system extension and groundwater level, hanging roots extended deeply in accordance with the groundwater level, while vertical roots broadly extended as the groundwater level became shallower.

As a result, we considered that it would be important that 1.5m or more of ground level for the development of the planting basement should be ensured at minimum, and a level as high as 2.0m would be required taking account of the second stage of horizontal roots having developed due to an extension inhibition of vertical roots by the groundwater.

(d) Conclusion

Summarizing this evidence, the target tree configuration was set at 20m or more of tree height, 120cm or more of trunk girth at chest height, 70 or less of the shape ratio and 30% or more of the ratio of crown length for growing the pines to be a robust coastal forest against lodging damages in the case of assuming a tsunami inundation height of about 20m.

In addition, the growth target for root system extension under the ground on the tree configurations was set for the root system extension to be at 12m^3 of the root clump volume (ex. 4m or more of horizontal root, 1.5m or more of vertical root).

In order to ensure the root system extension, it was considered preferable to ensure 2.0m or more of soil layer thickness undisturbed by the groundwater as the planting basement (See Figure-3.3.12.5).

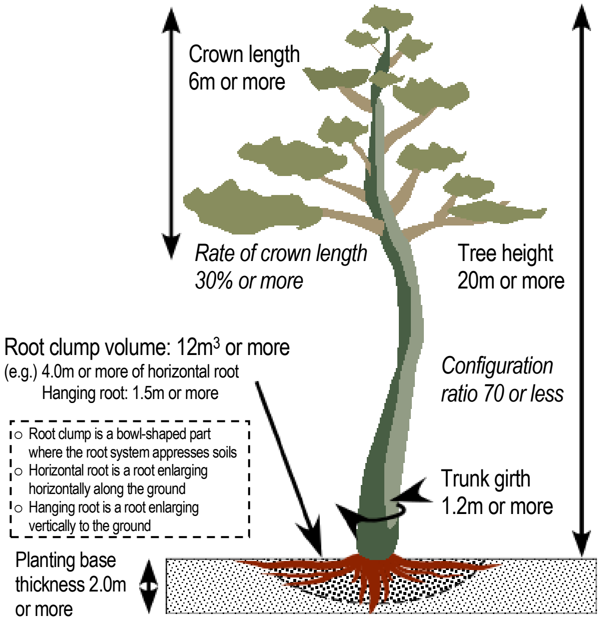


Figure 3.3.12.5 Growth Target for a Robust Pine against Lodging Damages by Tsunami

(4) Measures for Rehabilitation

The MLIT organized "the Research Committee for Improvement of Parks and Green Spaces on the Rehabilitation from the Great Eastern Japan Earthquake", which was composed with the experts on landscape, urban planning, tsunami disaster, civil engineering and environmental geotechnical engineering shown in Table-3.3.12.2, in order to investigate the post-earthquake town reconstruction plan for a devastated town by the local public entity and to summarize technical papers regarding the plans and designs of parks and green spaces in the reconstruction works. The Committee was held four times in August 2011 through February 2012.

The Committee compiled the final report of "the Technical Guideline on Improvement of Parks and Green Spaces Regarding the Rehabilitation from the Great Eastern Japan Earthquake" that would be a reference for the research and realization of the post-earthquake town reconstruction and project plans in devastated towns (See Table-3.3.12.3). As a reference for technical guideline, the Committee also complied the "Technical Papers" and "Related Documents" including the results of field surveys and engineered verifications based on the Guideline, and the "Related Documents" and the "Application Protocol (draft)" for the effective utilization of disaster wastes (See Table-3.3.12.4).

References
1) The Joint Survey Group for the Great Eastern Japan Earthquake and Tsunami (2012) "Information on the Great Eastern Japan Earthquake and Tsunami." http://www.coastal.jp/ttjt

Useful reference websites
1) Press Release of the MLIT "the Technical Guideline on Improvement of Parks and Green Spaces Regarding the Rehabilitation from the Great Eastern Japan Earthquake," released on March 27, 2012. http://www.mlit.go.jp/report/press/toshi10_hh_000097.html

Table 3.3.12.2 Member Composition of the Research Committee for Improvement of Parks and Green Spaces on the Rehabilitation from the Great Eastern Japan Earthquake

Chairman	Hajime KOSHIMIZU	Professor, Department of Agriculture, School of Agriculture, Meiji University
Committee	Mikiko ISHIKAWA	Professor, Department of Urban Engineering, Faculty of Engineering, the University of Tokyo
	Takeshi KATSUMI	Professor, Environmental Infrastructure Engineering Lab., Graduate School of Global Environmental Studies, Kyoto University
	Shunichi KOSHIMURA	Associate Professor, Disaster Control Research Center, Graduate School of Engineering, Tohoku University
	Hidetoshi KOBASHI	Deputy Director, Geology and Geotechnical Engineering Research Group, the Public Works Research Institute (PWRI)
	Tomoki SAKAMOTO	Chief of Laboratory, Meteorological Risk and Buffer Forest Laboratory, Department of Meteorological Environment, the Forestry and Forest Products Research Institute (FFPRI)
	Susumu NAKAMURA	Professor, Department of Civil Engineering, College of Engineering, Nihon University
	Chikayasu HAMANO	Professor, Department of Landscape Architecture Science, Faculty of Regional Environment Science, Tokyo University of Agriculture
	Toyohiko MIYAGI	Professor, Department of Regional Management, Faculty of Liberal Arts, Tohoku Gakuin University
	Makoto YOKOHARI	Professor, Natural Environmental Studies, Graduate School of Frontier Sciences, the University of Tokyo
Observer	Kenji WATANABE	General Manager, City Planning Section, Prefecture's Civil Engineering Division, Iwate Prefecture
	Masayuki SAKURAI	General Manager, City Planning Section, Civil Engineering Division, Miyagi Prefecture
	Eiji HAGA	Director, City Development Promotion Division, Urban Development Office, Public Works Department, Fukushima Prefecture
	Ryo SASAKI	General Manager, Park Section, Hyakunen No Mori Promotion Division, Construction Bureau, Sendai City
Administrative	Toshiaki FUNABIKI	Director of Parks, Green Spaces and Landscape Division, City Bureau, MLIT
Committee	Yoshiaki NAGINO	Director of Green Spaces Environment Office, Parks, Green Spaces and Landscape Division, City Bureau, MLIT
	Keiji NITTA	Director for Parks and Green Project Coordination, Parks, Green Spaces and Landscape Division, City Bureau, MLIT
	Masahiko MATSUE	Head of Landscape and Ecology Division, the National Institute for Land and Infrastructure Management (NILIM), MLIT

Table 3.3.12.3 Composition of Table of Contents for “the Technical Guideline on Improvement of Parks and Green Spaces Regarding the Rehabilitation from the Great Eastern Japan Earthquake”

Chapter 1	Summary of Study
Chapter 2	Outline of the Damages by Tsunami in the Great Eastern Japan Earthquake
Chapter 3	Basic Concepts on Improvement of Parks and Green Spaces
	I. Vision of the Post-earthquake Town Reconstruction
	II. Function of Parks and Green Spaces Based on Lessons from the Great Eastern Japan Earthquake
	III. Basic Concepts of the Parks and Green Space Plan on the Post-earthquake Town Reconstruction
	IV. Vision of the Plan and Design for Parks and Green Spaces
Chapter 4	Basic Concepts on Application of Disaster Wastes in Improvement of Parks and Green Spaces
	I. Actions on Treatment and Utilization of the Disaster Wastes
	II. Outline of Disaster Wastes in the Great Eastern Japan Earthquake
	III. Process Schedule for the Disaster Wastes
	IV. Applications of Disaster Wastes in the Improvement of Parks and Green Spaces
	V. Planting Basement

Table 3.3.12.4 Reference Documents for “the Technical Guideline on Improvement of Parks and Green Spaces Regarding the Rehabilitation from the Great Eastern Japan Earthquake”

Reference 1:	Documents on Improvement of Parks and Green Spaces for Robust Town Development against Tsunami Disasters
Reference 2:	Documents on Applications of Disaster Wastes in Improvement of Parks and Green Spaces
Reference 3:	Application Procedure of Concrete Debris into Embankment in Improvement of Parks and Green Spaces (Draft)
Reference 4:	Application Procedure of the Dump by Tsunami into Embankment in Improvement of Parks and Green Spaces (Draft)
Reference 5:	Improvement Procedure of Planting Basement (Draft)

3.3.13 Disaster Management

(1) Overview

NILIM conducts deliberations concerning measures that should be promoted in order to ensure the optimum division of roles between contractors and outsourcers. Above all, in the event of a disaster, surveys to ascertain the situation and emergency repairs will be carried out under conditions in which the available personnel, organizations, technology, materials, and information are severely limited. Accordingly, the management required differs from that needed under normal circumstances, for example, prioritizing the input of personnel, materials, and equipment, as well as collaboration among administrative bodies, and between government and private sector companies. Furthermore, the recent Great East Japan Earthquake has given rise to serious problems in terms of considering construction management in the event of disaster, such as the fact that it is a disaster that has affected an extensive area and includes tsunami-related damage; the fact that it has occurred amid a situation in which there are various anxieties, such as an ongoing decline in the supply of construction materials due to a sharp drop in the number of public works projects; and the fact that even bigger megaquakes are forecast, such as a Tonankai and Nankai earthquake.

Accordingly, NILIM conducted a survey from the twin perspective of the disaster-afflicted region and the nation as a whole that supports it. NILIM developed questionnaires to consider the reality of the situation and the aforementioned problems in collaboration with bodies including the Tohoku Regional Development Bureau and the Special Committee on the Great East Japan Earthquake of the Japan Society of Civil Engineers to; these were then distributed to construction industry groups (and their member companies) and local construction companies in the latter half of FY2011. Reports on the questionnaire method and some results were reported at an interim briefing session of the Special Committee on December 14, 2011; at a symposium held by the Japan Society of Civil Engineers on March 5, 2012, entitled "One Year after the Quake and Future – Large-Scale Natural Disaster Mitigation, Preparedness, Response and Recovery"; and at a symposium held by the Special Committee on November 6 the same year, entitled "Strengthening Abilities in Disaster Response Management: Learning From the Great East Japan Earthquake". The final results are currently being compiled, so this chapter will provide an outline of the outcomes identified to date.

<Focus on both the group and its member companies>

Japan Federation of Construction Contractors, Tohoku Branch;
Japan Road Contractors Association, Tohoku Branch;
Japan Dredging and Reclamation Engineering Association, Tohoku Branch;
Japan Bridge Association, Tohoku Regional Office;
Japan Prestressed Concrete Contractors Association, Tohoku Branch;
Japan Civil Engineering Consultants Association, Tohoku Branch;
Japan Construction Mechanization Association, Tohoku Branch;
National Construction Machinery and Equipment Leasing Association

<Focus on the group alone>

Tohoku Federation of Construction Industry Associations, Aomori Construction Association, Akita General Construction Association, Iwate General Construction Association, Miyagi General Construction Association, Associated General Contractors of Yamagata, Fukushima General Construction Association, Aomori Survey and Planning Association, Akita Prefectural Land Development Consultants Association, Iwate Survey and Planning Association, Miyagi Survey and Planning Association, Yamagata Survey and Planning Association, Fukushima Survey and Planning Association, Tohoku Geotechnical Consultants Association, Tohoku Federation of Ports and Airports Construction Associations, Aomori Port and Airport Construction Association, Akita Port and Airport Construction Association, Iwate Port and Airport Construction Association, Yamagata Port and Airport Construction Association, Miyagi Port Construction Association, Fukushima Port and Airport Construction Association, Japan Marine Surveys Association, Japan Marine Construction Engineering Association, Niigata Branch of the Japan Association of Construction Divers

(2) Questionnaire Survey for Industry Groups

(i) Questionnaire Method

In January 2012, questionnaire forms were distributed to the 32 construction industry groups (and also to their member companies, in some cases) shown in the box above enclosed in a dotted line (group names are shown as they were at the time the questionnaire was carried out), seeking their responses to questions about their preparations under normal circumstances and how they responded after the earthquake, and asking them to appraise their own performance in these areas. With regard to preparations under normal circumstances, respondents were asked about the conclusion of disaster agreements, the compilation of a BCP or disaster response manual, and the implementation of disaster prevention drills, while in relation to their post-earthquake response, they were asked about responses within the organization, as well as assistance provided to others.

(ii) Overview of Questionnaire Results

90% of the industry groups to which the questionnaire was distributed had established a task force or other system within 14 days of the earthquake (March 11, 2011). Approximately 85% of industry groups (27 groups) had already concluded a total of 93 disaster agreements with administrative bodies prior to the disaster, with support activities being carried out in response to requests based on 58 of those agreements. Only nine industry groups (approximately 30%) had formulated or owned disaster response manuals in addition to such agreements, but 82 of 137 member companies (approximately 60%) had formulated manuals, which covered a comprehensive range of topics, including chains of command when implementing a response and division of roles in relation to disaster response tasks.

As shown in Figure 3.3.13.1, the support mainly involved checks of infrastructure (assistance provided by specialty contractor groups and construction-related industry groups accounted for the majority), with other common forms of support including the provision and transport of construction-related materials and equipment, and the provision of materials, equipment, and construction labor for temporary offices, temporary housing, and evacuation shelters. Moreover, other assistance not stipulated in the agreements includes the supply and transport of emergency supplies unrelated to construction, such as drugs, food, clothing, and fuel. Among member companies, it was ascertained that 65% had concluded agreements directly with administrative bodies or industry groups (a total of 285 agreements), with direct support activities being carried out on the basis of 145 of these agreements.

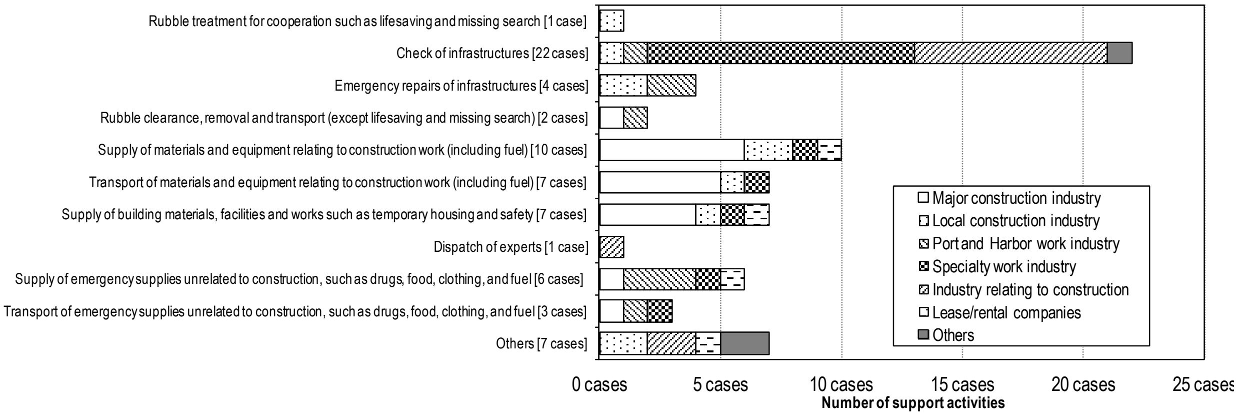
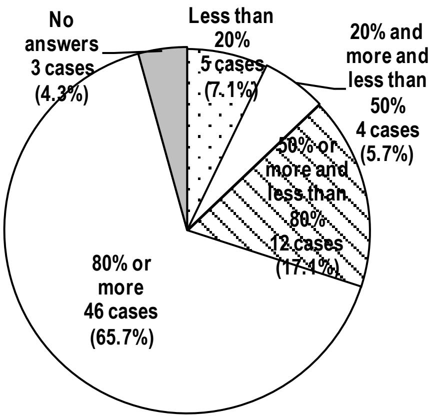
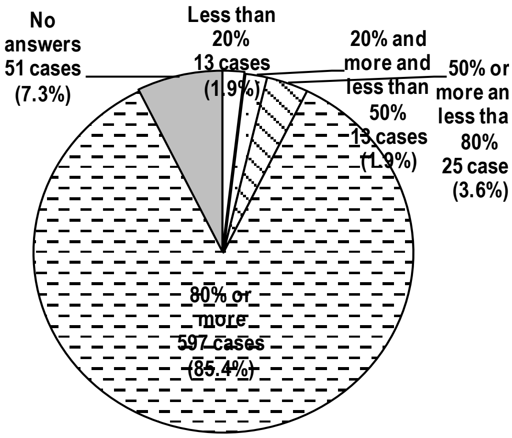


Figure 3.3.13.1 Details of Support Activities by Industry Groups and Member Companies



(a) Appraisal by industry groups



(b) Appraisal by member companies

Figure 3.3.13.2 Appraisal of Support Activity Achievement Level

As shown in Figure 3.3.13.2, when asked to evaluate their own level of achievement in providing support, approximately 65% of industry groups responded "At least 80%", while if those responding "At least 50%" are also included, this figure increases to approximately 80%; there was a good rating overall in the case of member companies as well, with approximately 85% responding "At least 80%". However, more concerning issues were mentioned in the spaces on the questionnaire for free-text responses and in interviews, as described below.

1) In the construction industry, in recent years, contractors have moved away from owning their own construction machinery, switching to the use of rented or leased equipment. However, no prior disaster agreement had been concluded between business groups in the rental/leasing sector and the three disaster-stricken prefectures, so it took some time to establish lines of communication. Moreover, the majority of construction machinery from outside the disaster-afflicted area is leased for a fee, and there was an absolute shortage of construction machinery that could be sent to the disaster-stricken areas. Even if machinery could be procured, cases arose in which requests for support had to be refused because of the straitened circumstances, including being unable to obtain fuel for construction machinery, the trucks and drums required to transport fuel, motors, machinery operators and maintenance personnel, and freight vehicle drivers. Even where business groups in the rental/leasing sector or their member companies had compiled disaster response manuals, only in around half of all cases did those manuals contain details of the status of ownership of construction machinery, materials, and equipment, and methods of

procuring fuel, materials, and equipment when responding to a disaster.

2) The records of disaster-stricken facilities differed from the actual up-to-date status of facilities, so there were cases in which it took about two months to compile the data required for disaster assessments (measurements, drawings and reconstructions, and photographs). Moreover, assessment work has been made more efficient through the use of photographs for desk-based assessments, but there were those who expressed the opinion that the lack of uniformity in terms of the way the photographs are compiled according to the structure concerned increased the burden of work required.

3) Some respondents stated that there was no control over matters that outsourcers should coordinate among themselves and standardize; in particular, some stated that there was confusion in the management of instructions, orders, and coordination in the disaster assessments.

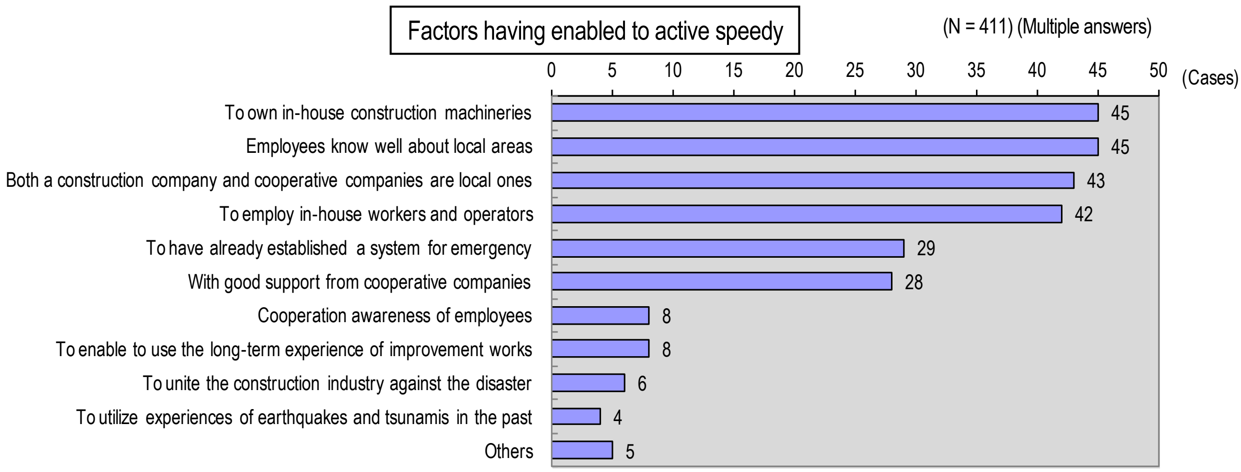


Figure 3.3.13.3 Reasons Why Local Construction Companies Were Able to Carry Out Prompt Disaster Relief Activities

(iii) Tasks for the Future

Based on the survey of industry groups (and their member companies), it is necessary to consider the following matters to prepare for an extensive disaster, such as the Tonankai and Nankai earthquake that is expected to occur in due course.

1) Concluding disaster agreements between administrative bodies and the leasing/rental sector under normal circumstances, concerning the procurement of construction machinery in the event of disaster, and confirming the communication framework to be used in this event. Moreover, concluding disaster response agreements between the construction industry, the lease/rental companies that own construction machinery, and the construction machinery manufacturers that have the technology to provide maintenance support, and giving consideration to implementing management in collaboration with the fuel and freight sectors, even when transporting equipment to the affected area.

2) In terms of infrastructure management under normal circumstances, having outsourcers implement improvements, such as introducing GIS in the maintenance records of each facility and encouraging the development of electronic infrastructure maps, as well as streamlining disaster assessments; in addition, implementing improvements relating to issues in the daily management of infrastructure.

3) Giving consideration to having construction consultants provide support to outsourcers in the management of the disaster assessment process.

(3) Questionnaire Survey for Local Construction Companies

(i) Questionnaire Method

In September 2011, questionnaire forms were distributed to the approximately 1,800 companies that are members of the Tohoku Federation of Construction Industry Associations, which encompasses the six prefectures of the Tohoku region, seeking their responses to questions about the support activities they conducted in the week after the disaster, in partnership with the Tohoku Regional Development Bureau and the Tohoku Federation of Construction Industry Associations, as well as their preparations under normal circumstances and how they responded after the earthquake. During FY2011, the questionnaire forms that had been returned were collated and, as of FY2012, work has started on compiling and sorting the data, with some information having already been released to the press by the Tohoku Regional Development Bureau.

(ii) Overview of Questionnaire Results

Among the local construction companies, a large proportion had been affected by the disaster in Iwate, Miyagi and Fukushima Prefectures (approximately 60% across the three disaster-stricken prefectures); in particular, in Iwate and Miyagi Prefectures, more than 80% of companies located in coastal areas were affected.

In the case of construction companies in Iwate, Miyagi and Fukushima Prefectures, almost 70% of local construction companies had commenced support activities by 16:00, about an hour after the earthquake, despite the fact that they themselves had suffered damage. As shown in Figure 3.3.13.3, the most common factors cited as having contributed to their ability to commence activities so promptly included the fact that they or a company which they cooperated owned construction machinery, the fact that they employed machinery operators in their own company, the fact that they were familiar with the local terrain, and the fact that they had made advance preparations based on past experience of disasters, such as putting in place systems to prepare for emergencies.

In terms of the support provided by local construction companies, the most commonly-cited form of assistance was "emergency repairs", followed by "surveys and checks", and "rubble clearance and transport". In most cases, the emergency repairs and rubble clearance and transport were paid for by the customer, but the proportion of companies conducting surveys and checks free of charge was as high as 40%. As shown in Figure 3.3.13.4, the difficulties faced in conducting support activities included "lack of fuel (diesel, gasoline)", followed by "breakdown of means of communication", and "physical and mental burden on employees", but companies dealt with these issues while continuing to provide support.

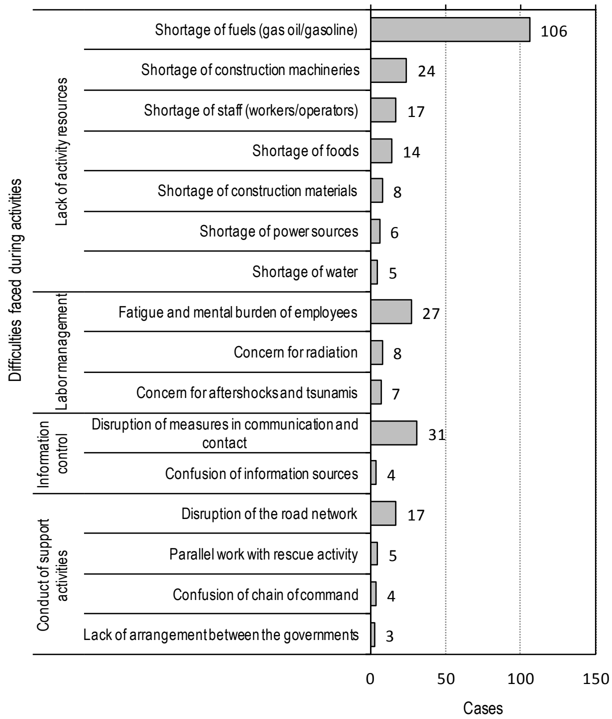


Figure 3.3.13.4 Difficulties faced during support activities

Other problems included the fact that, even when they were able to source construction machinery, they could not work long hours because of the shortage of fuel, and the fact that despite having operators, those operators were unable to reach the sites where they were needed, which was also due to the fuel shortage. Moreover, with means of communication having broken down due to power cuts and problems with telephone lines, it was extremely difficult to coordinate with others, both within and outside the region, and to gather information. Accordingly, many companies sent messengers on foot or made use of the community wireless system to contact people.

(iii) Tasks for the Future

The survey of local construction companies suggests that consideration needs to be given to the following matters, in order to facilitate smooth support activities.

1) The development by outsourcers, local construction companies, and construction industry groups of measures focused on how to maintain construction machinery and operators, and systems for machinery maintenance in a situation in which public works projects are dwindling.
2) The development of regional fuel stockpiles by outsourcers, local construction companies, and construction industry groups, due to the fact that fuel shortages posed a challenge when conducting support activities, and the fact that it was difficult to secure a means of transporting fuel when seeking support from outside the disaster-afflicted region.
3) As mentioned in relation to the survey of construction industry groups, the establishment of a means to enable outsourcers to confirm without delay technical information, such as design documents, due to the fact that the lack of such information was a hindrance when conducting checks and surveys of society capital facilities. Moreover, the construction of a system by outsourcers, local construction companies, and construction industry groups that enables information to be shared regarding fuel, accommodation facilities, and food, in order to facilitate prompt checks and surveys.

4. Future Responses

In order to clarify the roles played by construction industry groups (and their member companies) and local construction companies, as well as the challenges that they faced, we would like to continue our efforts to compile the information gathered and summarize the outcomes in detail in publications such as NILIM technical notes. In compiling this information, we intend to take into consideration results from surveys carried out after past earthquakes, including “the Niigata-ken Chuetsu-oki Earthquake in 2007” and “the Iwate-Miyagi Nairiku Earthquake in 2008”, in the hope that these will also be of assistance in responding to an extensive major disaster such as the Tonankai and Nankai earthquake that is forecast to occur in the near future.

References

1) Tohoku Regional Development Bureau press release: *Local Companies Began Activities Promptly in the Immediate Aftermath of the Disaster*, July 24, 2012
http://www.thr.mlit.go.jp/bumon/kisya/kisyah/images/42180_1.pdf

3.3.14 Information Field

3.3.14.1 Provision of information during Disaster or Recovery

(1) Introduction

With regard to the Great East Japan Earthquake, it was reported that geographical concentration of automobile or traffic jams caused by road cracks, cave-ins, and sputtered rubble as a result of the earthquake prevented victims from smoothly evacuating. For the prevention of the occurrence of such undesirable situations, ITS-based streamlining of road traffic or ITS-based provision of information in disasters has attracted attention as an important measure. In response to this, the NILIM has been promoting researches on provision of information to drivers via ITS Spot, management of heavy vehicles using probe data, and disaster-information gathering using on-board camera. In this section, we introduce our research activities on the above-mentioned themes.

(2) Provision of information to drivers via ITS Spots

1) Nation-wide deployment of ITS Spot

In FY2009, ITS Spot services, as a preceding installation, became available on the Metropolitan Expressways. In FY2010, as the first installation in the nation-wide deployment, ITS Spots were installed nationwide in 1,600 locations on the expressway main roads, and then in FY2011, the services became available nationwide (in the Tohoku district, the start of services was delayed until August due to the occurrence of the Great East Japan Earthquake.)

On the inter-city expressways, ITS Spots were installed at an interval of about 10 to 15 kilometers, and in addition, ITS Spots were installed on the near-side of junctions at about ninety locations. On the city express ways, ITS Spots were installed at an interval of four kilometers. Furthermore, at about fifty service-areas/road stations nationwide including all the service areas on the Tomei Expressway and the Meishin Expressway, ITS Spots were installed.

In 2012, twenty ITS Spots were installed on ordinary roads.

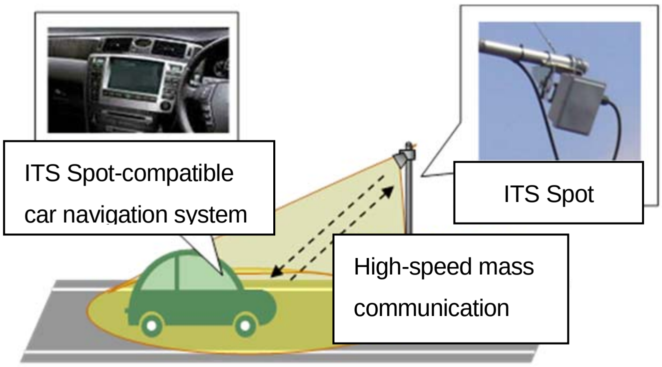


Figure 3.3.14.1 Schematic Diagram of ITS Spot Service

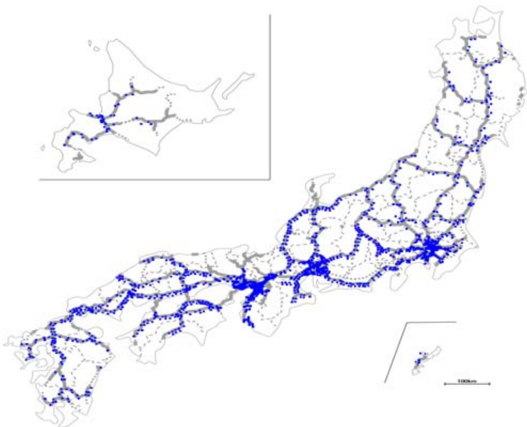


Figure 3.3.14.2 Nation-wide Location of ITS Spots

2) Provision of information at the time of earthquake occurrence,

On the Metropolitan Expressway System, prior to the nationwide deployment, ITS Spot services had been available on the following route; route 3 Shibuya, route 4 Shinjuku, route 5 Ikebukuro, city-loop and others. Those pre-installed ITS Spots, at the time of the earthquake with the maximum seismic intensity of five on March 11 2011, provided earthquake-early-warnings as shown in Figure 3.3.14.3[1).]

Figure 3.3.14.3 Warning to Drivers (actually displayed on the Metropolitan Expressway System)

(3)Heavy-vehicle management using probe data

1) Outline

ITS Spots are radio-wave beacon-equipments installed on road-sides for the purpose of enabling two-way communications to cars equipped with an ITS Spot-compatible on-board unit. An ITS Spot on the road-side receives probe data transmitted from a car. Probe data cannot be used for the identification of a car or person. However, by using additional vehicle-identification information which is added, by making special adjustments to the on-board units, to the original probe data under a contract between MLIT and a transportation-service operator, probe data of specific vehicles can be extracted and used. Such probe data is called specific probe data; its application in finding travelling routes for cargo vehicles in a disaster-situation has been studied with a focus on technical feasibility.

The technology is expected to be effectively used to finding travel routes for heavy vehicles. Below, we will show the outline of the experiments conducted for finding travel-routes of cargo-transportation-service vehicles[2)].

2) Outline of the Experiment

The features of the on-board unit and the outline of the experiment are described as follow;

① Features of GPS-equipped audio type ITS Spot-compatible on-board unit

① -1 Travel-records (time, latitude, longitude) is updated and saved at each 200-meters run or each time of 45 degrees turn. The on-board unit has a saving-capacity of data volume corresponding to Travel-records of about 80 kilometers.

①-2 The on-board unit transmits the saved travel-records and the basic information (manufacturer, model number, and vehicle specific information) to an ITS Spot when passing it, and discards the records after the transmission.

① -3 When the volume of saved travel-records exceeds the storage-capacity, the on-board unit discards the oldest data, in order by age, even if the data is un-transmitted.

①-4 The on-board unit discards and does not transmit to an ITS Spot the data obtained in the range of about one kilometer (exact distance is up to the manufacturer) beyond or before a point where the engine stops or starts.

①-5 The on-board unit informs the driver of the driving safety support information provided by ITS Spots.

①-6 The on-board unit is compatible with the ETC function.

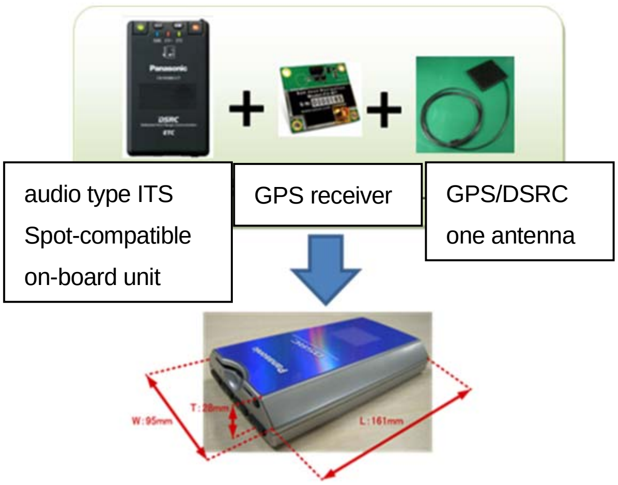


Figure 3.3.14.4 GPS-equipped audio type ITS Spot-compatible on-board unit

② Summary of the experiment configuration

②-1 Period of specific probe data collection: Oct. 1, 2011 to Jan. 31, 2012

② -2 Test vehicles: thirty-six cargo-transportation service vehicles almost regularly using the Metropolitan Expressways.

②-3 On-board unit: GPS-equipped audio type ITS Spot-compatible on-board unit.

② -4 ITS Spots: one hundred seventy-one Spots installed along metropolitan expressways (301.1 kilometers in total)

3) Analysis

Figure 3.3.14.5 shows a travel-records (time, longitude, latitude) included in specific probe data. In spite of losses, as previously described, of the travel-records in about one kilometer beyond and before the engine stop/start points, it was confirmed that the places believed to be the vehicles' destinations and records of a vehicle running on expressways, where a sufficient number of ITS Spots are installed, can be obtained more promptly. However, in the present situation where a sufficient number of ITS Spots have not yet been installed, such real-time capability of obtaining travel-records will be lower when a vehicle travels on ordinary roads for longer hours. Furthermore, data-loss will occur when a vehicle runs in an area where GPS signal-reception is poor such as in a tunnel, or when a vehicle, running along

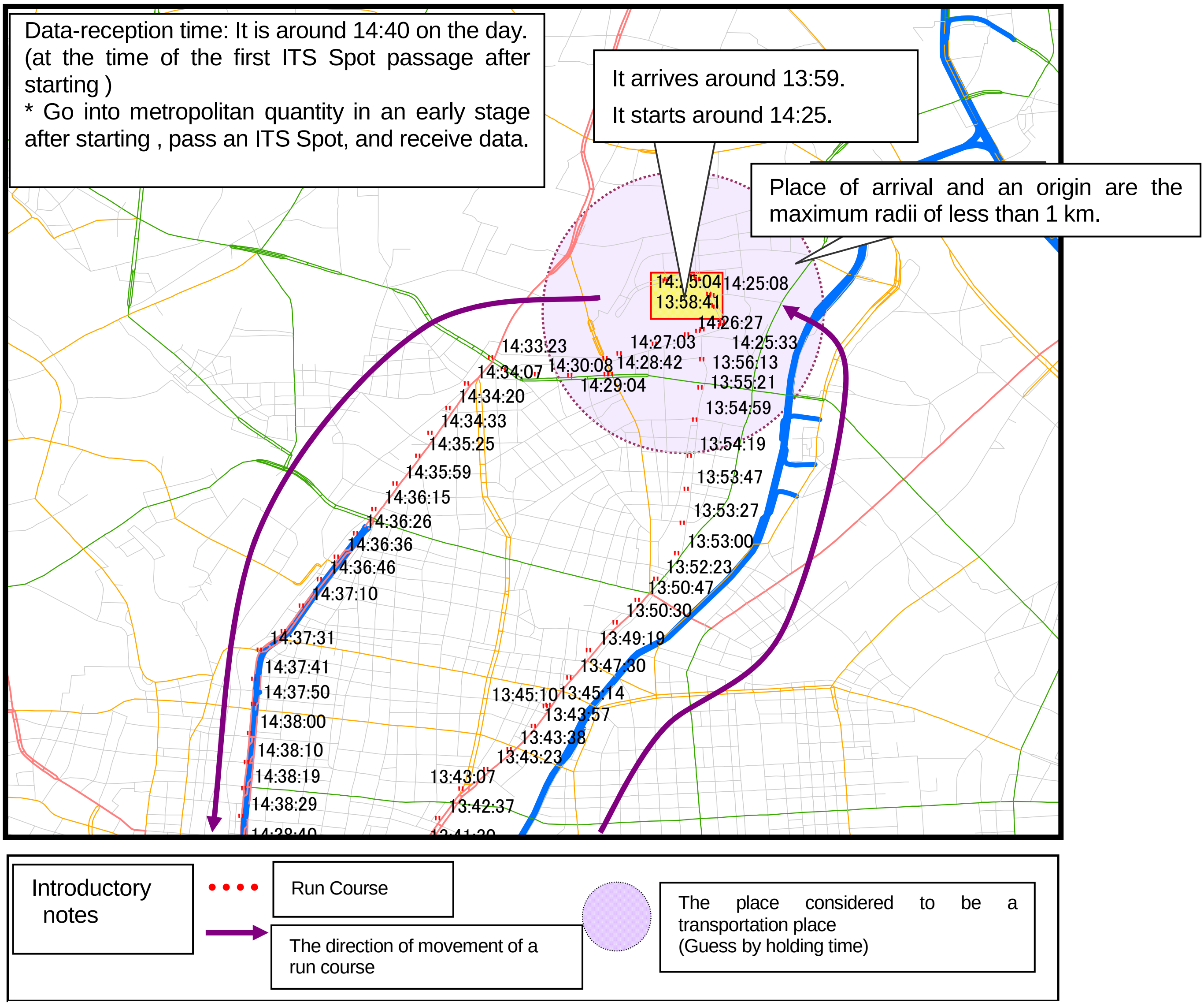


Figure 3.3.14.5 Example of Travel-route extracted Travell-records

the arrival/departure time are successfully estimated by extracting the places where the vehicle stops for more than 5 minutes.

If the specific probe information is delivered on a real-time basis, the location information and travel-ordinary roads during a large part of its travel, less frequently passes ITS Spots, and data-loss will also occur as a result of the mechanism described in 2). ①. 3).

(4) Disaster-information gathering through on-board camera

1) Introduction

Although research and development of the technologies on the detection of unordinary events through automatically processing and analyzing images provided by road-monitoring cameras and trials for their deployment have been done, such approaches using ITV images for automatic detection of unordinary events will not fully satisfy the requirements in disaster/accident-information gathering: for example, the detection will be effective only at the camera-installation sites.

On the other hand, an increasing number of cars are expected to have cameras mounted mainly for recording video at the occurrence of automobile accidents. Not only at the time of accident occurrence, those cameras have proven to work effectively, even if insufficiently, recording data even when a car is running along a route under a viaduct.

The challenges to be solved for applying video information obtained through on-board camera to gathering and utilization of disaster/accident information will be shown below.

2) Road-management organization's activities for information-gathering

"Plan for Road Maintenance," prepared by each regional development bureau or national-highway office of the MLIT requires emergency road patrols in the incident of heavy rains or earthquakes. Table-3.3.14.1 shows the list of information required to be gathered in the "MLIT Business Continuity Plan." The plan requires collection of the following information promptly for making the first press release in an hour of the collected information and well-organized disaster information: road damages; facility damages; open/close of expressway. At the same time, "Operational Plan for Disaster Prevention" prepared by each regional development bureau and each national highway office, which describes measures against earthquakes, wind and flood disasters, volcanic disasters, snow disasters, road disasters, river-water quality disasters, massive fire disasters, and nuclear disasters, requires, as one of the emergency measures, information-gathering by information equipments such as CCTV, transmission of video information from the site of disaster through small satellite-image-transmission equipment, road-information gathering through emergency patrol, and reports from road users. Furthermore, the "Earthquake Emergency-Patrol Action Plan" requires the following: road patrols should be done with focus on passability/impassability on the outward-path, and road cracks, on-road obstacles, landslides, and rock-falls on the inward-path; the onward-patrol should be completed approximately within an hour of earthquake an occurrence, and the inward-patrol should be completed within two hours after the completion of the onward-patrol.

Table 3.3.14.1 Object for Information-gathering required in the Business Continuity Plan, MILT

Object	Responsible Organization	Allowable Hours to Report			
		1	2	3	4
1. Information required as quickly as possible					
(1) Facility Damage					
River-Facility	River Bureau	●			
Pediment Disaster	River Bureau	●			
Cost-security-Facility	River Bureau, and Ports and Harbors Bureau	●			
Expressway, National Highway, Regional Road	Road Bureau	●			
Railway Facility	Railway Bureau	●			
Port Facility, Navigation Channel	Ports and Harbors Bureau	●			
Air Port, Aviation Security Facility	Civil Aviation Bureau	●			
(2) Status of Traffic and Transportation Service					
Close / Open of Expressway	Road Bureau	●			
Railway Accident, Service Cancellation	Railway Bureau	●			
Aviation Accident, Service Cancellation	Civil Aviation Bureau	●			
(3) Situation of Government Office Building and Communication Facility					
Information and Communication Facility	Minister's Secretariat	●			
Lifeline	Minister's Secretariat	●			
Government Office Facility	Government Buildings Department	●			
2. Information required, not urgently					
(1) Facility damage					
Sightseeing tour facility (registered hotels or inns)	Policy Bureau		●		
Urban Park	City and Regional Development Bureau			●	
Building	Housing Bureau			●	
Sewage and wastewater system	Sewage and Wastewater Maintenance Department, City and Regional Development Bureau				●
(2) Status of Traffic and Transportation Service					
Commercial warehouse	Director-General for Logistics		●		
Automobile transportation business (service information of expressway-busses, and accident	Road Transport Bureau		●		

information of trucks and others)					
Marine traffic (accident / service information of passenger vessels)	Maritime Bureau		●		

3) Enhancement and improvement of road management

On the basis of what is required of road-management organizations, how, by on-board cameras on a car, the conventional measures can be improved or enhanced is shown in Table-3.3.14.

Table 3.3.14.2 Conventional measures of Information-Gathering, and Its Enhancement or Improvement enabled by using ITS Service

Conventional Measures of Information-Gathering	Enhancement or Improvement enabled by using ITS Service
Road patrol (at the time of disaster)	Prompter decision-making on open/close using visual information
Unordinary-event detection through information gathering equipments (at the time of disaster)	Event detection or visual inspection even at a place not covered by information gathering equipments
Report from road users (at the time of disaster or in normal situation)	Increase of number of reports or information volume encouraged by easiness in reporting or automatic (un-manned) reporting
	Easy finding and visualization of event-location and severity using hybrid-report with images and location report

4) Concept model

Figure-3.3.14.6 shows a schematic diagram of the concept-model explaining the scheme for applying images obtained on-board cameras to road-management; the model consists of four processes, ① to ④, as follows:

① Data gathering process: extracting and collecting images, locations, acceleration, and others from the information obtained through on-board camera on a running vehicle (service vehicle running along a fixed route such as a road-management service vehicle or a route bus or other ordinary vehicle)

②Data processing process: processing and analyzing the collected data– images, identified locations, to detect unordinary events and make a judgment on them.

③ Data transmission process: via communication-line transmitting to the center collected images, detection and judgment on events.

④ Data utilization process: the road-management organization makes decisions and actions using information of event-detection or judgment, such as ordering emergency patrols or information delivery to other management-organizations or road users.

Note that the processes ② and ③ could appear in various phases and take various forms: they could appear as preprocessing such as mapping, in on-board equipment; they could appear in the image-data processing only after the transmission to a center of the entire image data.

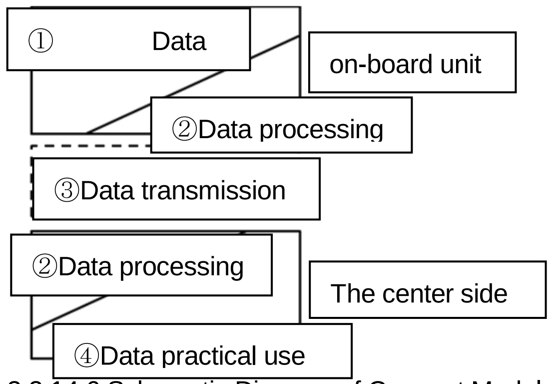


Figure 3.2.14.6 Schematic Diagram of Concept Model

5) Major managerial or operational action-items

① Data gathering process

The action-items for this process are as follows: proprietary-right of data: who owns the right; motivation of data-collection: how data-gathering action could be motivated; selection of cars: how to determine a car in which an on-board unit is installed; long-term operability: how to build a system for maintaining the performance and accuracy.

② Data processing process

In a case where the process is to be accomplished in an on-board unit, the on-board unit has to be enhanced with additional functions;

・Then, how can manufacturers be motivated to develop such enhanced equipments; how to decide applicable data-processing methods for event-detection and judgment – this would require comparison and trade-off analysis in terms of cost-effectiveness and necessity in road-management.

③ Data transmission process

As for this process, preparation or development of communication lines, and payment − who will be charged − is to be decided. In addition, because images to be transmitted could include personal information, security measures should be studied in relation to laws and regulations such as the Private Information Protection Law.

④ Data utilization process

As for this process, comparison and trade-off analysis in terms of cost effectiveness, necessity in road management, and security measures will be required on in what range the event-detection and judgment information or images could be shared and how to archive and make public such information. Especially in a case where data acquisition/transmission is performed in collaboration with social networks, roles, expenses and responsibilities should be clearly identified and allotted to involved entities. In addition, because the accuracy of the information provided by in-vehicle units could be a major issue, studies will be required on in what context in road management operation such information could be used.

6) Major Issues in Technological or System Design

① Data gathering process

One of the major problems in this process is brought about by the differences in formats or specifications of the data to be gathered. Because on-board cameras that have become available on the market adopt different specifications or standards for image devices, resolutions, frame-rates, or image-file formats, in order to integrate and utilize the image-probe information given by ordinary cars, technical considerations and solutions are required for the integration of those data. In addition, system design or technological considerations are required on the data-gathering timing — data is acquired continuously, only before and after triggers generated by accelerations, at some predetermined positions, or controlled by the driver's voice command — through technological assessments, cost-effectiveness analysis, or assessments on road managers' requirements.

② Data processing process

For this process, data processing methods must be determined to properly detect and make judgments on different types of unordinary events. The process of data gathering, combination, and integration of different images given by different on-board cameras including those by ordinary cars, dealing with different types of image-processing methods, might result in a risk of fluctuation in detection accuracy or judgment criterion. Furthermore, such a variation in processing methods could make it possible for intentional false data to pass. Therefore, certain standardization of processing methods or a performance certification system should be considered.

③ Data transmission process

In determining the data transmission method − although a method unconstrained by the data transmission timing, location, or volume is idealistic, giving great latitude in the selection of data processing methods − because the actual and available transmission channels are limited in volume and provided on a pay-basis, the transmission method should be selected through cost-effectiveness analysis and assessments on the technical requirements of the data processing method, focusing on the transmission occurrence frequency, transmission speed, and transmission channel type.

④ Data utilization process

In this process, considerations should be given to effectively setting the thresholds in the detection and judgment of abnormal events. In addition, in the case where information is shared among various managing entities, standardization of the data transmission/saving format will be required.

7) Collection of basic data for the estimation of detection accuracy

In order to estimate the accuracy of detection of unordinary events − how precisely can those events be detected −, NILIM conducted preliminary experiments using their test road.

The outline of the experiments is shown as follows:

A number of stones were placed on the test road. A drive-recorder makes shots of those stones. Those images are saved as the images supposed to be obtained through on-board camera. Image-analysis software analyzes those images to extract objects.

Table-3.3.14.3 shows the results. “OK” signs there indicate that object feature point such as corners or silhouette-boundaries were successfully detected.

At the test-distances longer than 20 meters, detections were unsuccessful. However, at distances less than 20 meters, objects were more successfully detected as the tracking number (number of feature point -detection) increased. Note that numbers shown in the photo in Figure 3.3.14.7 are the numeric-conversion of feature point.

Table 3.3.14.3 Result of Object-Detection

	Size of tracking data per frame		
	100 points	500 points	1,000 points
Distance to Object: 10m	NG	OK	OK
Distance to Object: 20m	NG	NG	OK
Distance to Object: 30m	NG	NG	NG
Distance to Object: 40m	NG	NG	NG
Distance to Object: 50m	NG	NG	NG

Tracking data numbers per frame :100units　Tracking data numbers per frame :500units　Tracking data numbers per frame :1000units

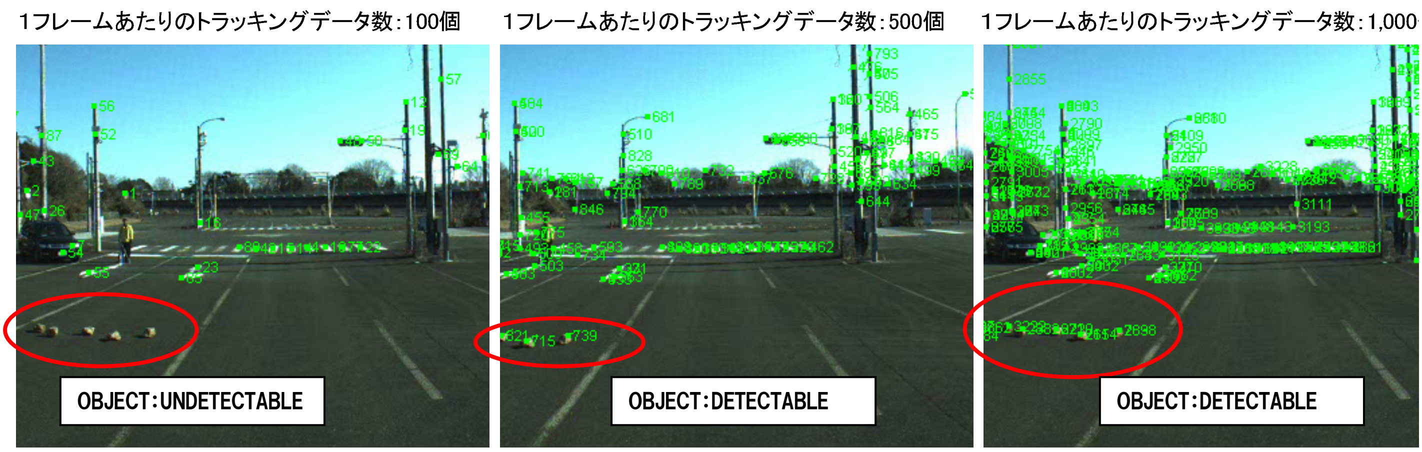


Figure 3.3.14.7 Result of Image Analysis (Distance to object: 10m)

(5) Conclusions

In this section, we reported our activities on information-provision to drivers through ITS Spots, management of heavy vehicles using probe information, and disaster-information gathering using on-board units. We are required, for expanding our activities described here, and for solving the problems our research activities have revealed, to conduct proof-of-concept experiments, accept the evaluations by road-management organizations, propose and prove the feasible services, and promote studies on the information items, their contents and their operation schemes that should be standardized.

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3.3.14.2 Correction of coordinates of road ground control points and fundamental geospatial data of roads

(1) Summary

From the viewpoint of ensuring accuracy of maps, it is also essential to revise the coordinates of maps that were changed by the large-scale crustal movement caused by the Tohoku Pacific Offshore Earthquake.

In this paper, we report on correction of coordinates following the crustal changes caused by the Tohoku Pacific Offshore Earthquake, for fundamental geospatial data of roads, which is a large-scale road map, and the road ground control points used as reference for positional information of roads, managed by the Ministry of Land, Infrastructure, Transport and Tourism.

(2) Summary & background of fundamental geospatial data of roads and road ground control points

1) Summary of fundamental geospatial data of roads

(a) Background of development of fundamental geospatial data of roads

The information handled under road management includes administrative inquiries from road users, road surface records, locations with many accidents, etc. Much of this information can be shared between operations, and having a structure for information sharing enables more efficient road management.

With the objective of supporting this kind of efficiency of road management, the Ministry of Land, Infrastructure, Transport and Tourism is developing "Fundamental Geospatial Data of Roads" which is large-scale (1/500 or 1/1,000) GIS data, that gives detailed expression of 30 types of road structure features, as shown in Figure 3.3.14.8.

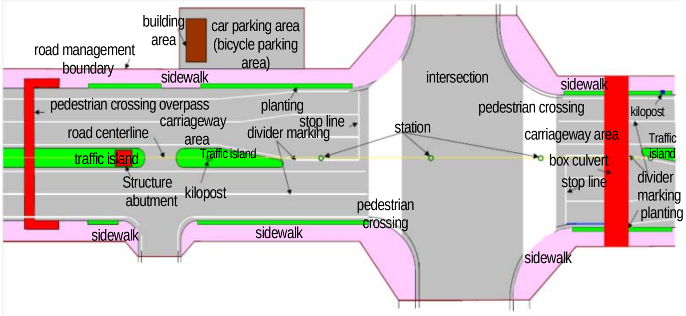

Figure 3.3.14.8 Image of Fundamental Geospatial Data of Roads

(b) Development of Fundamental Geospatial Data of Roads

The Fundamental Geospatial Data of Roads is maintained by converting into GIS data the completion drawings of road work by road offices, etc. When road work is done on subject roads, the development and update of the maps is also planned, and structures are established for carrying out the development under the minimum budget required.

Moreover, the maintenance of completion drawings of works is based on the "Manual of Completion Drawing Production for Road Works" so it is maintained with uniform accuracy.

2) Summary of road ground control points

(a) Background of road ground control points development

As described above, Fundamental Geospatial Data of Roads is created based on completion drawings of works, so they are made in the form of several hundred meter long maps as separated sections, and when using them it is necessary to join/standardize the maps using high precision latitude and longitude information.

"Kiloposts" are one of the 30 features of the Fundamental Geospatial Data of Roads used as the control points for seamlessly joined and standardized maps. The road ground control points are maintained with the main objective of providing accurate coordinates information on these kiloposts.

(b) Early-stage development of road ground control points

For the road ground control points, metal rivets are installed near the site marks created on the road shoulder etc. as shown in Fig.3.3.14.9, for measuring the coordinates. The development is carried out in accordance with the "Development Outline for Road Ground Control Points (Draft)" (hereinafter "Development Outline (Draft)," while accuracy is maintained by keeping the measurement error within about 7~8 cm for latitude and longitude, and within about 10~20 cm for altitude.

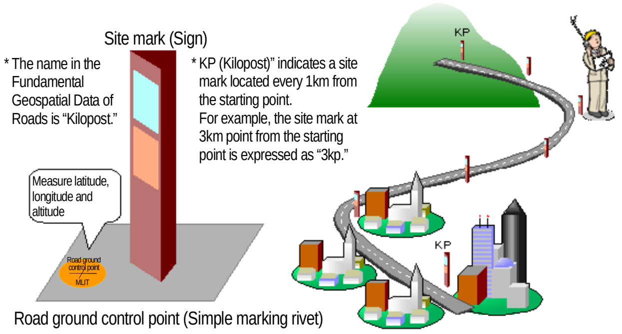

Figure 3.3.14.9 Image of road ground control points development

(3) Effects of crustal movement caused by the Tohoku Pacific Offshore Earthquake

1) Crustal movement caused by Tohoku Pacific Offshore Earthquake

The Tohoku Pacific Offshore Earthquake caused large-scale crustal movement, mainly in areas on the Pacific Coast of Eastern Japan. There was a horizontal movement of more than 20cm in the area which reaches as far as Nagano prefecture and Toyama prefecture, and also a large-scale vertical settling in areas on the Pacific Coast of Eastern Japan.[1)]

2) Provision of correction parameters

Subsequent to the aforementioned large-scale crustal movement, since October 31, 2011 the Geospatial Information Authority of Japan (hereinafter "GSI") has been providing coordinate correction parameters and altitude correction parameters for correcting the coordinate value of public control points etc., to correct the horizontal and vertical gap generated by the crustal movement.[1)]

The coordinate correction of Fundamental Geospatial Data of Roads and road ground control points managed by the Ministry of Land, Infrastructure, Transport and Tourism was decided to be carried out based on the relevant correction parameters.

(4) Coordinate correction of fundamental geospatial data of roads and road ground control points

1) Coordinate correction of Fundamental Geospatial Data of Roads

(a) Extraction of Fundamental Geospatial Data of Roads that were changed by crustal movement, etc.

Based on data released by GSI, Fundamental Geospatial Data of Roads was extracted for regions in which correction parameters were published by GSI after the changes in the crustal movement caused by the Tohoku Pacific Offshore Earthquake. The extraction also included Fundamental Geospatial Data of Roads requiring coordinate correction after previous earthquakes (Noto Peninsula Earthquake, etc.).

(b) Sorting of coordinate correction procedures

In order to implement the coordinate correction of Fundamental Geospatial Data of Roads extracted in the preceding paragraph, the coordinate correct methods and procedures were sorted based on the data published by GSI.

The Fundamental Geospatial Data of Roads GIS data is created by automated conversion of the completion drawings of works CAD data, so in order to prevent inconsistencies in the computing stage, as shown in Fig-3.3.14.10, it was decided to convert the coordinates of completion drawings of works CAD data and afterwards do automated conversion to create the GIS data.

Moreover, the application of coordinate correction parameters and altitude correction parameters in completion drawings of works CAD data enabled coordinate correction program development and batch corrections.

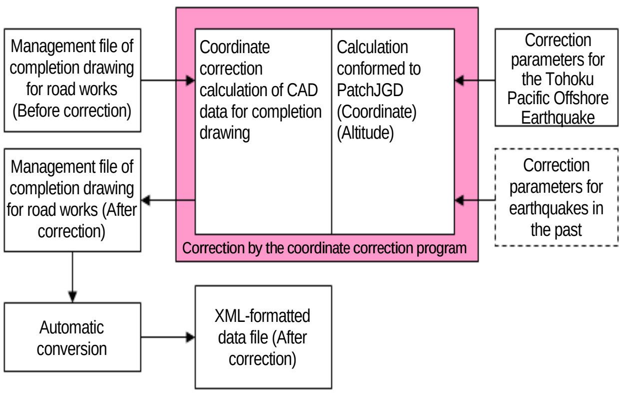

Figure 3.3.14.10 Basic operation procedure of coordinate correction

(c) Implementation of coordinate correction

Based on the aforementioned coordinate correction procedure, the coordinate correction of Fundamental Geospatial Data of Roads was done using the coordinate correction program. Fig. 3.3.14.11 is an example of correction using the coordinate correction program.

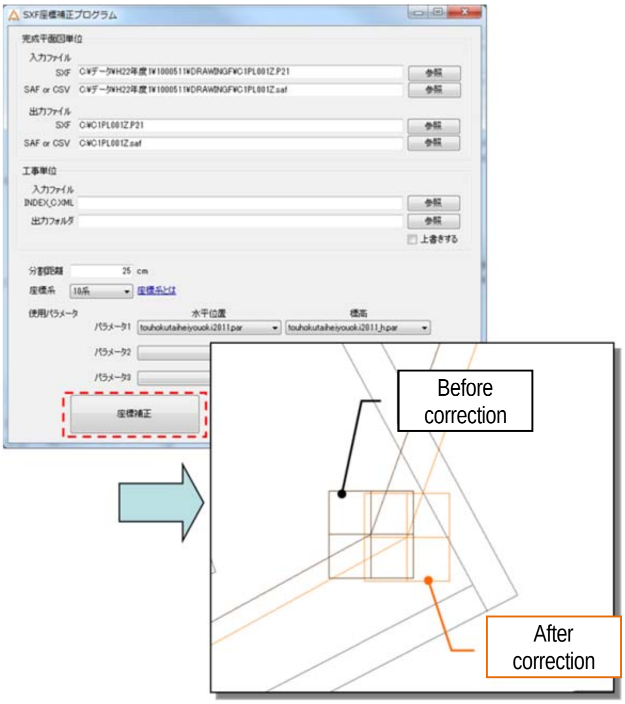

Figure 3.3.14.11 Correction by coordinate correction program (example)

For post-correction accuracy, comparative verification was done against the computation results of a coordinate correction software Patch JGD provided by GSI, to check whether the quality was maintained.

(d) Creation of coordinate correction procedure manual

The Fundamental Geospatial Data of Roads is to be maintained and updated in the future, so it is predicted that Fundamental Geospatial Data of Roads requiring coordinate correction would also be sequentially registered and accumulated in the future. Therefore, the coordinate correction method and procedures arranged this time were compiled, and the "Fundamental Geospatial Data of Roads Coordinate Correction Procedure Manual" was created.

2) Coordinate correction of road ground control points

(a) Extraction of road ground control points that were changed by crustal movement, etc.

The road ground control points that were changed by the crustal movement caused by the Tohoku Pacific Offshore Earthquake were extracted based on the data published by GSI. The extraction also included road ground control points requiring coordinate correction after the previous earthquakes (Noto Peninsula Earthquake, etc.).

(b) Implementation of coordinate correction

Coordinate correction of the road ground control points extracted above was implemented using the coordinate correction software Patch JGD provided by GSI. Fig. 3.3.14.12 is an example of coordinate correction at a site (National highway 45, site 46kp) having large coordinate parameter values.

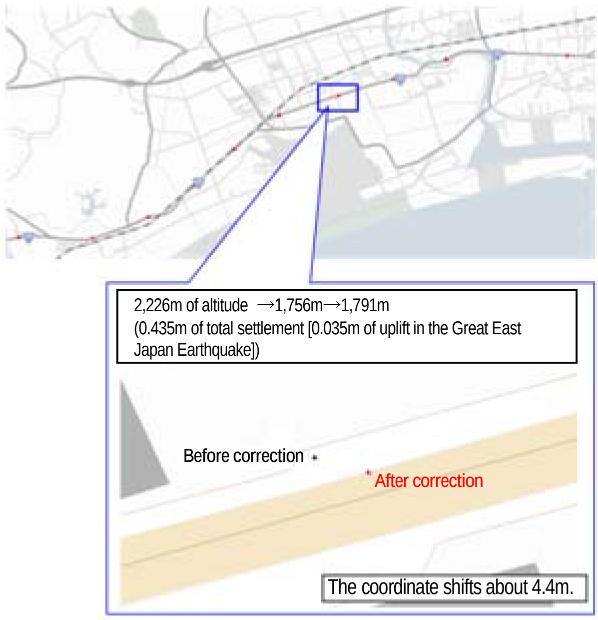

Figure 3.3.14.12 Coordinate correction of road ground control points (example)

(c) Sorting of correction operation procedures in view of future maintenance

There is a need for reinstallation/resurvey of a road ground control point in case of loss of the control point itself, and resurvey of sites for which correction parameters are not provided, so it is difficult to implement coordinate corrections in the same way using the correction parameters. Moreover, regulations for early-stage development play a central role in the Development Outline (Draft) and there were not enough description on maintenance and update after its development.

Because of this, in view of future maintenance and update of road ground control points, the Development Outline (Draft) was revised to the "Road Ground Control Points Development/ Maintenance and Update Outline (Draft)," and operation methods for handling sudden and large-scale crustal movements caused by large-scale earthquakes were also investigated, and "Road Ground Control Points Maintenance and Update Manual for Occurrence of Large-scale Crustal Movements (Draft)" was created. Fig. 3.3.14.13 is the work flow of that manual (draft).

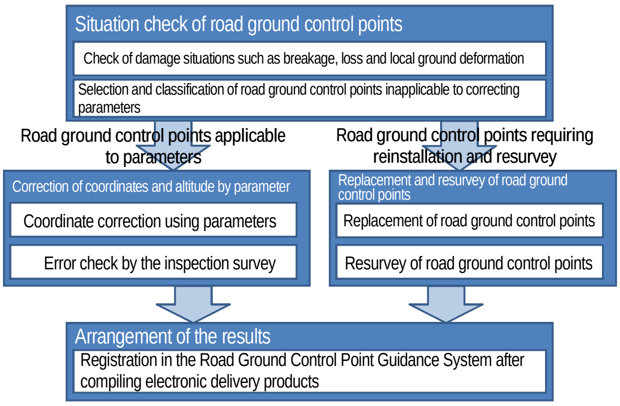

Figure 3.3.14.13 Work flow of road ground control points coordinate correction as per the manual (draft)

(d) Implementation of reinstallation and resurvey, etc.

Based on the aforementioned manual (draft), the Regional Development Bureaus will provide support for inspection surveys of road ground control points that can be corrected using parameters, and reinstallation work for road ground control points requiring reinstallation and resurvey in the future.

The results of these operations will be registered in the "Road Ground Control Point Guidance System"[3] in which the nationwide road ground control points information is centrally consolidated and managed.

(5) Conclusion

With regard to the coordinate correction of the maps that were changed by the large-scale crustal movements caused by the Tohoku Pacific Offshore Earthquake etc., the correction operation procedures were developed, actual correction work was done, and accuracy was obtained.

Henceforward, in order to consolidate and manage the results of inspection surveys of road ground control points and ensure the accuracy of Fundamental Geospatial Data of Roads and road ground control points, the plan is to continually support coordinate correcting in Regional Development Bureaus, etc.

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3.3.15 Coastal Environment

In the coastal environment, technical supports on discharge of pollutants into the coastal area, recovery and conservation of the coastal ecosystem and environmental considerations in rehabilitation and recovery constructions were conducted.

Detailed on-site information regarding the coastal environment had not been acquired after the occurrence of the disaster in spite of efforts collecting issued information from the press or involved parties [1),2)]. A month after the disaster, NILIM identified the possible problems of the environmental situation of the disaster including a discharge of pollutants into the coastal area and degradation of the coastal ecosystem[3)], and environmental considerations on rehabilitation and restorations[4)]. Seeking an understanding for these investigations and considerations, NILIM promoted awareness on the environmental considerations, notified a necessary support system to the Tohoku Regional Development Bureau through the Marine and Environmental Division of the Ports and Harbors Bureau in the headquarters of the MLIT and decided to wait for a request (Figure-3.3.15.1).

The Marine Environment Division of NILIM, on July 27, 2011

Regarding problems relating to the earthquake disaster reconstruction on the environment

- Urgent problem in the port and harbor environment as to confirm chemicals and diffusion/accumulation of sludge
  - Anticipation against secondary hazards to health and fisheries *Oil spill in Ofunato
  - Examination required on the treatment method when removing sludge
- Items to be required for an urgent survey
  - Criterion for health items in water and water bottom sediment (a few points in the port)
  - Mapping of diffusion/accumulation information with analysis of specific environmental items in sediments (inside the port or at the waterside, or in the bay at the points of decades)
- Items for which cooperation is possible as the Marine Environment Division of NILIM
  - Planning of the surveys mentioned above
  - Implementation of on-site collection of water and sediments
  - Analysis implementation (to be outsourced from the NILIM)
  - Besides the analysis described above, estimation of the sedimentation area by a simple simulation
  - Development of a wide-ranged map with high resolution using the environmental evaluation sonars
  - Necessary environmental surveys toward the future reconstruction (Possible to join organization such as the Fisheries Research Agency)
  - Proposal preparation on the items of environmental concern toward the reconstruction plan

* Assuming initial motion surveys in black letters (1-2 months), full-scale surveys in red letters (6-12 months) and later surveys in blue letters (1-a few years)

Figure 3.3.15.1 Memorandum of Problems on the Coastal Environment (July 2011)

However, the local site had not requested monitoring to grasp the current situation or researches on rehabilitation of the ecosystem because of the priority setting. An investigation of bottom sediments in Matsushima Bay was conducted as an independent survey of the National Institute for Land and Infrastructure Management (NILIM) with the support of the local office in May 2011. After the survey, NILIM had started a survey on the regeneration of eelgrass beds in Miyako Bay since November 2011, established an NPO cooperation work "the Project for Bond of Revival Connecting the Eelgrass Beds Restoration" in April 2011, and worked together through sharing the survey results.

From the end of 2011 to 2012, investigative meetings on the environmental rehabilitation for the recovery were established in Matsushima, Ofunato and Miyako Bays, respectively. NILIM is attempting to make technical cooperation and support by including the chief of the Marine Environment Division and a research officer for Advanced Port Technology in the meetings. Also, in the NHK Special "the Hidden Radioactive Pollution - an Urgent Report from the Ocean-" on January 15, 2012, the program introduced the present status of the possibility and progressive process where cesium would have transported and deposited in the river mouth areas by being transported via the air, flown into the rivers and absorbed in the grains of mud. The program also revealed problems such as radioactive pollution of earth and sand on the seabed.

In Onahama and Soma Bays, investigative meetings were conducted in order to handle such problems.

The summarized situations are reported by region as follows.

(1) Sendai and Shiogama Port and Matsushima Bay

The Gamo Tideland is located near Sendai and Shiogama Port and was an area with a higher consciousness about environmental conservation for some time[5)]. Gamo Tideland itself lost a large part of sand banks in the seaside area and experienced a drastic change in the environment of lagoons and tidelands with the coastal forest.

NILIM visited Gamo Tideland in May 2011 when conducting the aquatic survey in Sendai and

Shiogama Port and Matsushima Bay, and verified the current situation of the ecosystem by visual observation (Figure-3.3.15.2). Despite a large topographical change, the existence of benthos and birds in the new environment and strength of the reproduction power in the coastal ecosystem was observed.

(a) Seaside

(b) Landside

Figure 3.3.15.2 Gamo Tideland after the Earthquake (May 5, 2011)

In the survey at Matsushima Bay in May 2011, the sampling sites were determined after calculating the diffuse situation of effluents from the land area (Figure-3.3.15.3) and predicting the extent of expansion in advance. At the survey area, however, the sampling was not conducted as scheduled because the opening work was being conducted for floating oyster rafts or nets and the research ship could not intrude into the water areas except the seaway. Thanks to full cooperation from the local office, sampling was done within the area accessible from both the sea and land sides (Figure-3.3.15.3).

Bottom sediment sampling was done with an Ekman-Birge grab at 2cm of the surface three times or more. These samples were mixed and provided as the assay sample. The analysis result showed that five items including arsenic and its compounds, fluorides, vanadium and its compounds, mercury and its compounds and polychlorinated biphenyl were environment in Matsushima Bay, (2) Basic study on the measures for recovery of the coastal environment, (3) Basic study on the whole concept of beach development, (4) Prediction of effects on recovery of the coastal environment and (5) Others relating to the recovery of the coastal environment in Matsushima Bay. The research officer for Advanced Port

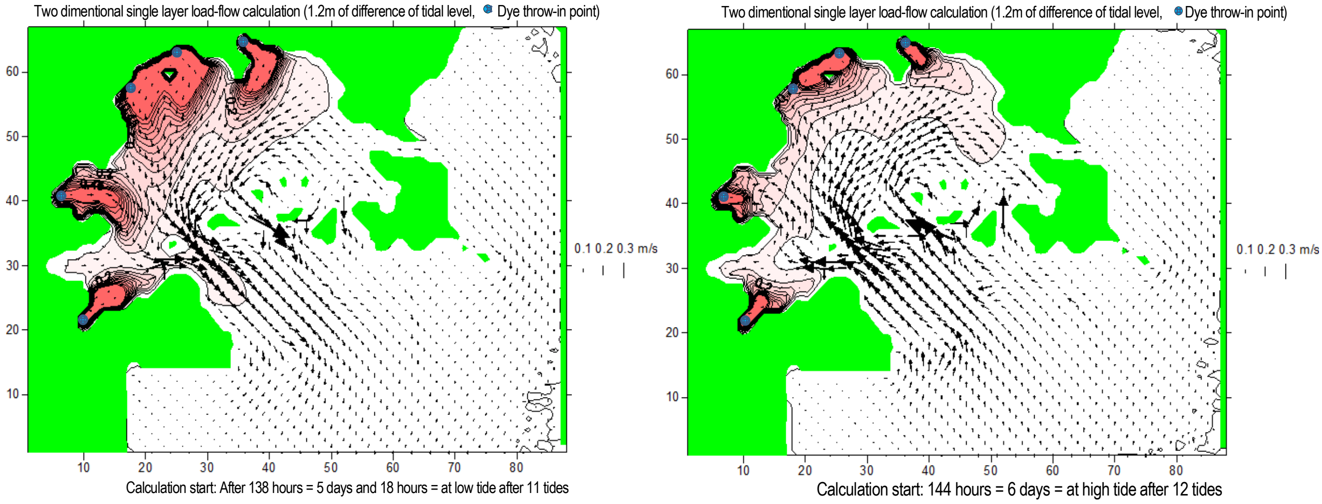
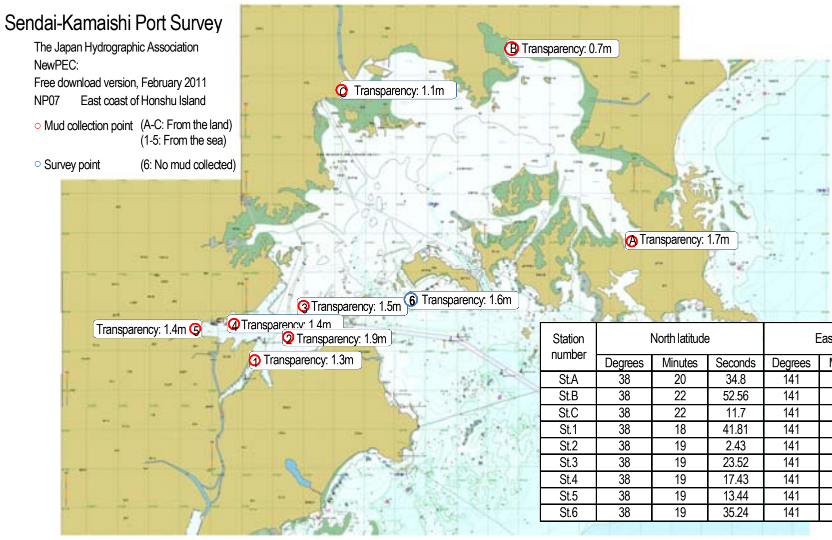


Figure 3.3.15.3 Results of Simplified Simulation for the Diffuse Situation of Effluents from the Land Area in Matsushima Bay



Station number	North latitude			East longitude			Observation schedule	
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds	Days	Hours
St.A	38	20	34.8	141	8	50.02	May 5	15:00 - 17:00
St.B	38	22	52.56	141	6	59.22		
St.C	38	22	11.7	141	3	57.36		
St.1	38	18	41.81	141	2	33.62	May 6	10:00 - 14:00
St.2	38	19	2.43	141	3	7.36		
St.3	38	19	23.52	141	3	12.99		
St.4	38	19	17.43	141	1	59.3		
St.5	38	19	13.44	141	1	43.02		
St.6	38	19	35.24	141	5	12.79		

Figure 3.3.15.4 Research Sites for Sediment Sampling in Matsushima Bay (May 2011)

detected out of 34 items of health related materials, but all of the values were largely lower than each standard and no treatments were required.

In May 2012, the investigative meeting on recovery of the ocean environment in Matsushima Bay was established and started to investigate the following items: (1) Grasp the current situations of the coastal Technology of NILIM chaired the meeting and the chief of Marine Environment Division joined as an observer.

The investigative meeting has supported some events like field observation and citizen participation types of events (Matsushima Bay beach learning with parent and child, focusing on investigation toward recovery of eelgrass beds in the bay. Moreover, in the renovation of Kitahama Green Space revetment planned in advance, in order to conduct a proper environmental consideration, NILIM has progressively conducted supports for environment recovery including the participation of the research officer for Advanced Port Technology as an expert in the forum of Kitahama Green Space revetment that was established as an opportunity to debate among the residents, Shiogama City and Miyagi Prefecture and sharing facilitation of the debates (Figure-3.3.15.5).

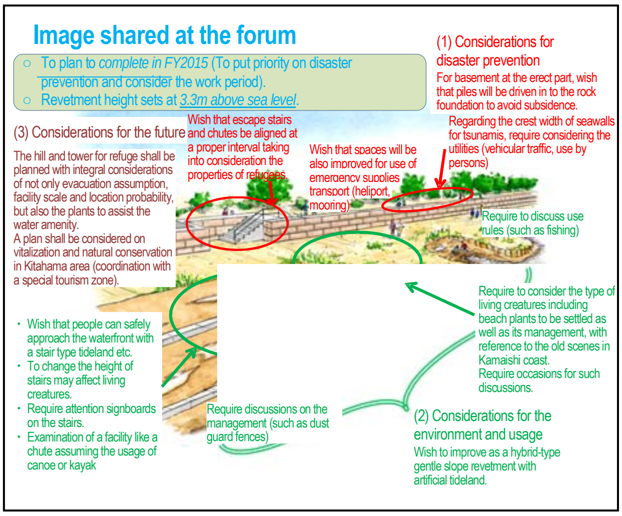


Figure 3.3.15.5 Memorandum Summarizing Discussion Results at the Forum Regarding the Rehabilitation Policy of Kitahama Revetment

(2) Miyako Bay

The closed-off section of Miyako Bay used to flourish eelgrass beds broadly[7], and has been supported the local fishing industry as rearing places of herring. The Consociation of Seagrass Beds and Tidal Flats in Miyako Bay has continuously monitored such situations[8], and conducted educational activities in the region. After the Earthquake, NILIM also conducted an observation of the fry in May 2011 and the first survey in seaweed beds on June 16, 2011, and kept records on the remaining eelgrass beds.

Mr. Suchinobu Yamane, chairman of the consociation, reported the current situation of eelgrass beds as well as damages to fishery in Miyako Bay, and asked for technical support toward the rehabilitation of eelgrass beds at "Rehabilitation from the Great Eastern Japan Earthquake - the Hearing of fresh voices along the Coastal Area in Iwate Prefecture -" hosted by the Ocean Policy Research Foundation (OPRF) on October 19, 2011.

NILIM conducted an independent survey on the bottom sediment and eelgrass beds (February and October, 2012)[9], conveyed the situations, and requested cooperation to the NPO groups having given cooperation at the eelgrass summit etc. In April 2012, "the Project for Bond of Revival Connecting the Eelgrass Beds Restoration," which is regional collaboration promoting work by the Seven-Eleven Foundation, was inaugurated as a cooperative project for the NPO entities tackling eelgrass revival throughout the country. NILIM has cooperated in the project, provided survey data, and assumed the operation of a workshop for the project.

The project held the first workshop and a field survey in May 2012 (in Miyako City) and the second workshop and technical guidance for revival of eelgrass beds in June 2012 (in Tokyo and Yokohama City), and investigated the future revival strategy (Figure-3.3.15.6).

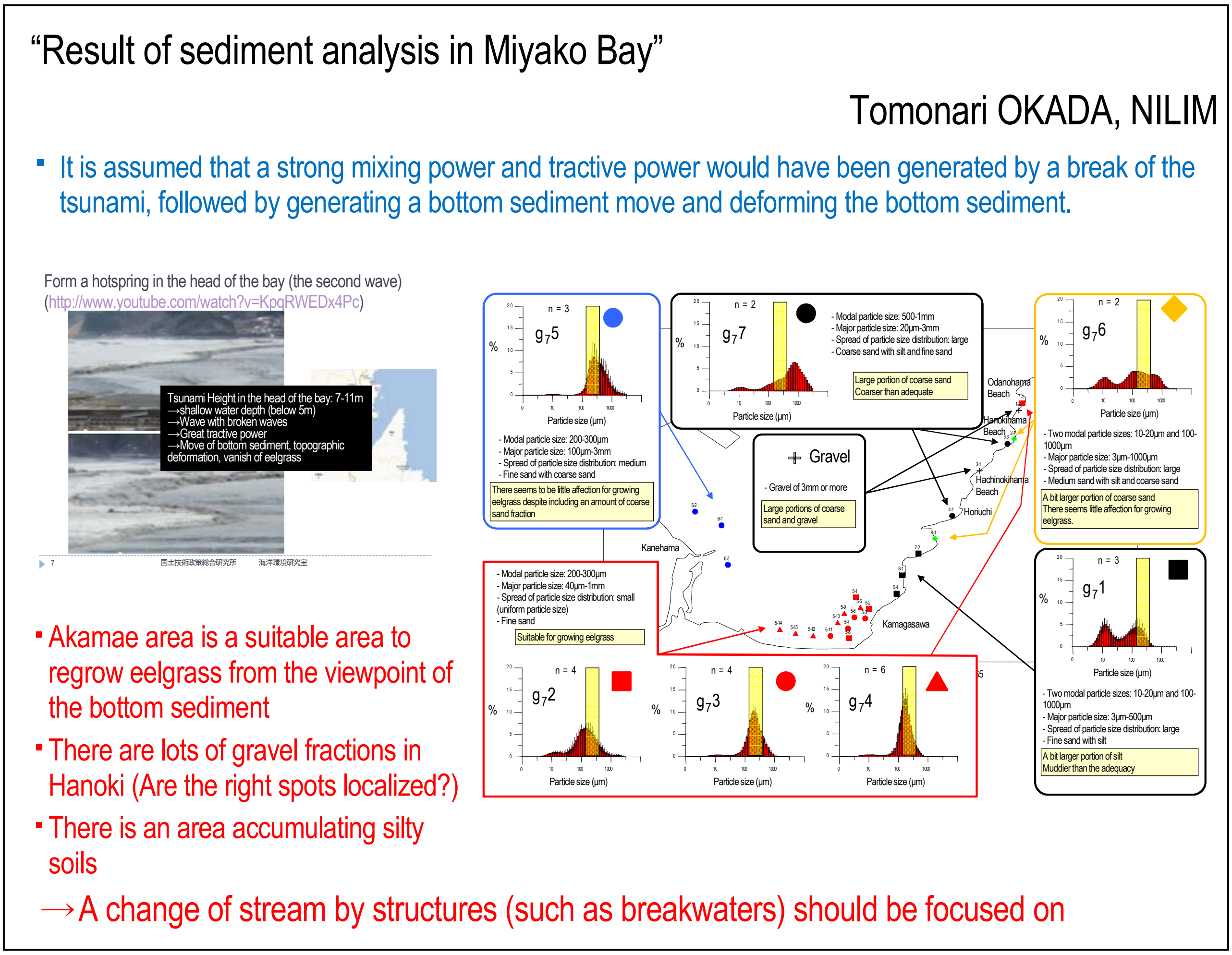


Figure 3.3.15.6 Provided Information at the Second Workshop[9)]

In the area, the reconstruction support project for sato-umi (Ministry of the Environment, MOE), has started to create the sato-umi reconstruction plan including the revival of eelgrass beds and established the development support committee for the sato-umi reconstruction plan. The chief of the Marine Environment Division and the research officer for Advanced Port Technology of NILIM joined the committee as a member and an observer, respectively, and play a coordinating role with local stakeholders for working together with NILIM's investigation and the Project for Bond of Revival Connecting the Regeneration Activity of Eelgrass Beds at present.

In the area, a newly-recruited seedling colony has now already been found as well as the remaining eelgrass beds, and the necessity of introducing prompt active revival activity has been identified as low. We have been conducting continuous monitoring and the pre-examination of revival measures to handle when needed.

(3) Ofunato Port

Ofunato Bay has been worried about environmental deterioration inside the bay by breakwaters at the baymouth for a long time[10, 11)].

In December 2011, the Water Quality Control Measures Study Committee regarding Breakwater Diffusion at the Baymouth was established. In order to recover the devastated breakwater at the baymouth of Ofunato Bay, the committee was determined to discuss the measures of seawater exchange considering the water quality inside Ofunato Bay as well as to ensure protective effects against tsunamis and the stability of the breakwater when hit by a tsunami. Currently, the chief of the Marine Environment Division of NILIM joins as a member and attended the meetings on February 13, 27 and March

16, 2012, respectively, and has conducted understandings of the current situation of Ofunato Bay and investigation of measures for seawater exchange.

(4) Soma Port and Onahama Port

An explanation was provided on the situation of seaweed beds in Misaki Area around Onahama Port in November 2011 (Figure-3.3.15.7). This area had been pointed out for a long time in that accumulation and movement of the sand would relate to a degeneration of the surrounding rocky seaweed beds. Seaweed colonies after this tsunami were said to have maintained a good condition and the phenomenon was inferred from the effects of sand movement or boulders by the tractive power of the tsunami. Conducting information exchanges was determined again after the results of the ongoing seaweed survey were submitted.

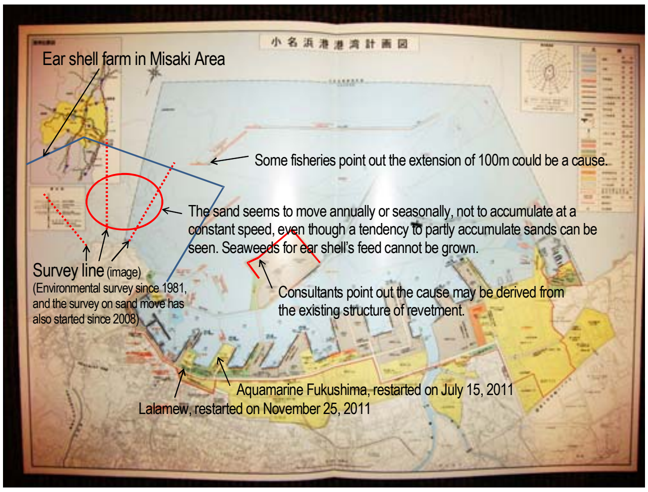


Figure 3.3.15.7 Information from Hearings at Seaweed Beds around Onahama Port (November 2011)

Following the detection of radioactive material from the seabed sand in Soma Port, the investigative meeting on the treatment of seabed sands containing radioactive materials was established in June 2012. The meeting is to conduct the development of related laws on the treatment of dredged sands generated by port construction works, the evaluation method of radioactive material concentrations in the dredged sand and the disposal method of dredged sands. Currently, the chief of the Marine Environment Division of NILIM attended the meetings on June 11, August 6 and September 30, 2011, respectively, and has made repeated investigations.

(5) Tokyo Bay

In Tokyo Bay, damages occurred including subsidence and inundation in the closed-off section of the Bay in and around Ichikawa City and Urayasu City, and collapse of laver fences or drifting ashore of spillage oil in and around Sanbanse or Banzu Tideland. Until the spring tide in May 2011 just after the Earthquake, the possibility of broad subsidence such as unusual disappearance of the tideland was pointed out. On the other hand, however, in May 2011, an abnormal tide level that surged by 10-40 cm occurred broadly on the Pacific coast because of an overlap of siphoning with the cyclonal passage and the following wind drift. Thus, NILIM could not reject the possibility that the surface elevation had induced the relative subsidence.

As for the authenticity of these geomorphic changes, in order to grasp the current situation of geomorphic change (depression) in Sambanse which was referred to through the Sambanse ad hoc meeting in which the research officer for Advanced Port Technology participated, an RTK-GPS survey was performed in the foreside of the Ichikawa Shiohama revetment where a sand adhesion test was conducted on May 16, 2011. Even locally, NILIM verified little changes in the sea bed near the revetment.

At the following ad hoc meeting held in August 2011, NILIM decided not only to spur on a broad topography survey with other experts in Chiba Prefecture which is the governing body of the area, but also to support an effective investigation by handling a part of the bottom sediment analysis at the NILIM. A wide-area sounding investigation was performed from February 3 to 16, 2012, and NILIM analyzed the particle size distribution with 22 samples gained from the investigation (Figure-3.3.15.8).

Results of the sounding investigation showed 30cm of subsidence on average and 46% of area decrease at 0m depth or less (A.P. standard). As Funabashi Seaside Park has still been an exclusion zone since the damage of land facilities, a careful watch is required on effects that these changes in the environment and utilization delivered to the ecosystem.

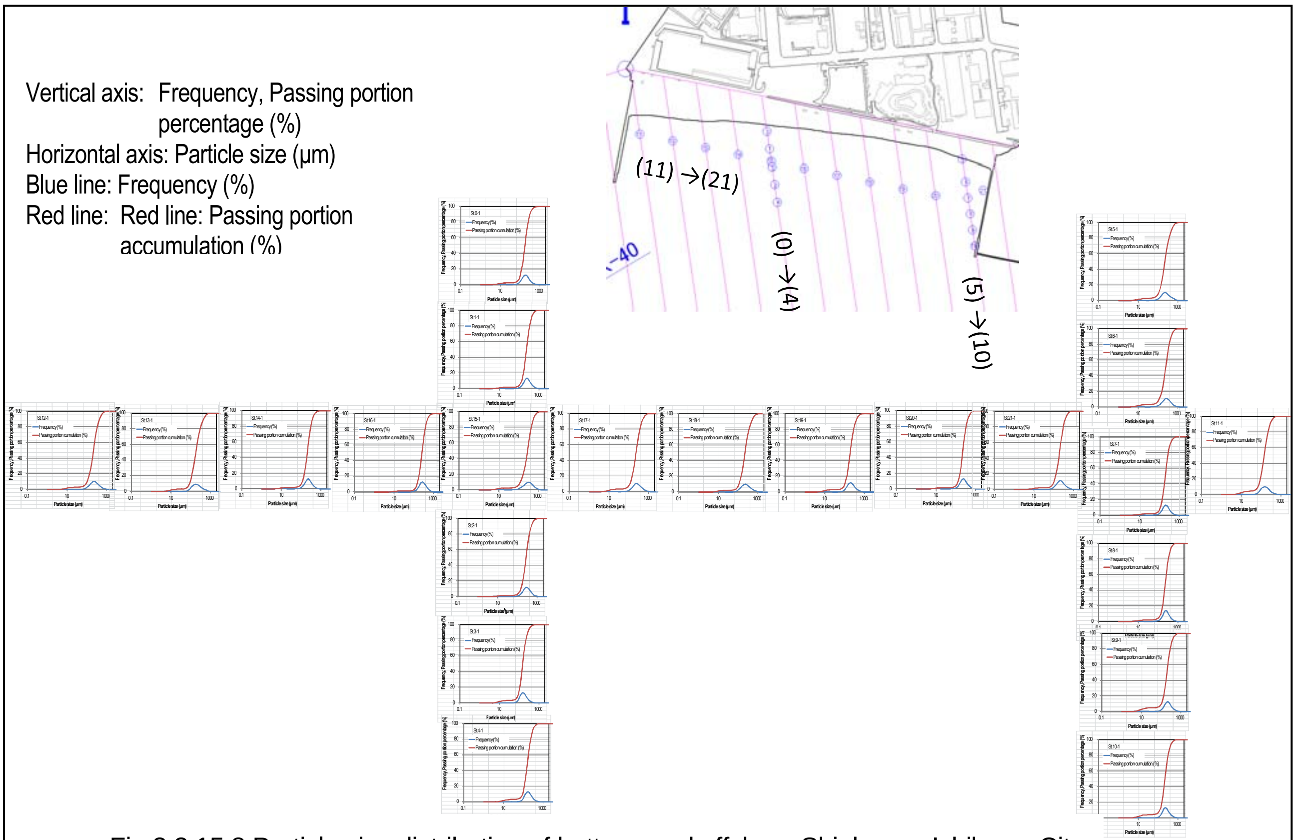


Fig.3.3.15.8 Particle size distribution of bottom mud offshore Shiohama, Ichikawa City

Acknowledgements

In the field investigations, many facilities were provided by all the persons concerned in the Marine Environment and Technologies Division, both Onahama and Kamaishi Port Offices and Shiogama Port and Airport Office of the Tohoku Regional Development Bureau and the Consociation of Seaweed Bed and Tideland in Miyako Bay. Cooperation in related data provision was made by Dr. Teruhisa Komatsu, Associate Professor of the Atmosphere and Ocean Research Institute (AORI), the University of Tokyo and the persons of the Tohoku National Fisheries Research Institute. We here express our extremely deep appreciation.

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3.3.16 River Environment

(1) Introduction

The Great East Japan Earthquake, which occurred on March 11, 2011, inflicted not only enormous damages on the Pacific coastal areas in the Tohoku region but also large impacts on the natural environment on the coast.

A noticeable impact was observed in the riverine estuaries. In the Kitakami River, for example, the habitat of reed communities was greatly changed by a large topographical change (Figure-3.3.16.1). In the Natori River, the vegetation in the riverine estuaries, which had been observed in the past, disappeared and worries have arisen about impacts on the environment in riverine estuaries by the Earthquake (Figure-3.3.16.2).

かつての北上川河口部ヨシ原　　震災後のヨシ原(H23.10.12.撮影)

Figure 3.3.16.1 Changes in Reed Beds at the Mouth of Kitakami River[1] (Before: left, after (Oct. 12, 2011): right)

Figure 3.3.16.2 Impacts at the Mouth of Natori River Before (left)/After (right) the Earthquake[2]

Thus, evaluation from a scientific viewpoint was conducted both to understand how large impacts such as the tsunami or land subsidence would have an influence on the environment in riverine estuaries and for utilization as know-how when conducting disaster rehabilitation and nature restoration[3].

In this report, findings from the investigations are introduced regarding the impact on the riverine estuaries by the tsunami focusing on results from the survey at the mouth of Kitakami River in March 2012, already about one year after the Earthquake[4]. This is just a quick report because the post-tsunami environment is still in the stage of recovery from an enormous disturbance.

(2) Outline of Investigation Area and Method[3]

The Kitakami River is a class A river with 249km of river length and 10,150km^2 of catchment area, and the present brackish water area was formed by the primary improvement work conducted from 1911 to 1935. During the primary improvement work of Kitakami River, an excavation work was done from the Yanaizu area to the Iino-gawa area (at near 15 to 25km of river distance-marks), a channel was replaced from the old Kitakami River to the Oppa River and widening of the river course of Oppa River was conducted by excavating the river course. At the upper end of the brackish water area, the final baffling was performed with the Kitakami Barrage (17.2km) placed in service in 1979. The brackish water environment possessed a good landscape and was selected as "the Scene of Sound in Japan Best 100" by the Ministry of Environment as communities of *Carex rugulosa* grew naturally around the riversides and wide reed communities were maintained at the downstream including the estuary.

The area for this survey ranged from 0kp (kilometer post) at the mouth of Kitakami River to 17.2kp at Kitakami Barrage, as shown in Figure-3.3.16.3, and the synoptic and detail surveys were conducted on March 2 to 4 and March 4 to 9, 2012, respectively. The surveyed items were topography of the river course, and vegetation and sediments inside the river course.

Figure 3.3.16.3 Map of Survey Sites at the mouth of Kitakami River

(3) Impact on Topography of River Course

An example of the river crossing of Kitakami River pre- and post-devastation is shown in Figure-3.3.16.4. The line of 2011 indicates the cross section after the devastation and the impact by land subsidence was adjusted by adding 0.601m of elevation.

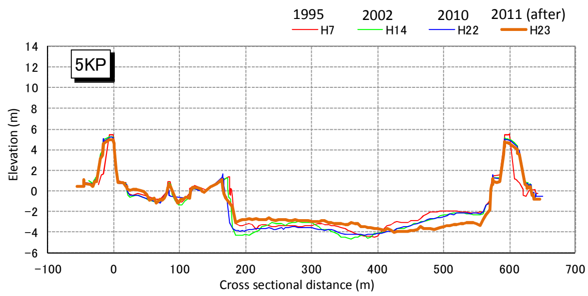

Figure 3.3.16.4 Example of Changes in the Cross Section Topography of the River (5kp)

As an overall trend, no significant changes in the shape of the river crossing have been observed though the river channel was homogenized in general as if small mounds were excavated and accumulated in the hollow.

(4) Result of Vegetation Survey Involving Reed Community

1) Result of Synoptic Survey

At first, changes in vegetation communities were grasped by the synoptic survey on vegetation. The vegetation distribution ranging from point 2kp to 9kp where the vegetation largely changed after the Earthquake is shown in Figure-3.3.16.5 (the range indicated by the yellow hatching).

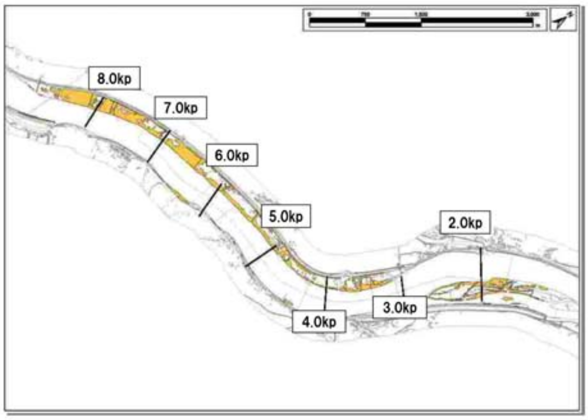

Figure 3.3.16.5 Distribution of Vegetation (Reed Community) after the Earthquake (March 2012)

The river terrace from point 2kp to 9kp was covered with vegetation before the Earthquake, which included reed communities in the main and salt marsh vegetation or Amur silver-grass communities in higher places in the marginal area of the river terrace.

In the post-devastation survey, most of the vegetation observed was reed communities, and a new small-scale salt marsh vegetation community was found only at point 6.5kp.

It is estimated that impacts by the tsunami would spread at point 0 to 9.4kp on the right bank and 0 to 8.8kp on the left bank, respectively, judging from vegetation disappearance and the existence of sediment by the tsunami. Particularly, in the island near point 2kp that may have been greatly damaged by the tsunami, most of the pre-devastated reed communities disappeared and only some parts remained on the mounds in the marginal areas (See Figure-3.3.16.6).

However, it is considerable that it was easy to observe the reeds remaining in the above-ground parts even after withering but impossible to find the species easily losing their above-ground parts or those with small amounts, because of the periods for the synoptic survey and its implementation in winter.

2) Result of Detail Survey

A detail survey was conducted on the vegetation and sediment at point 2.4kp and 6.4kp, respectively. Point 2.4kp is considered as the representative location where impacts on erosion and sediment by the tsunami as well as on the change in salinity by the subsidence could be great and point 6.4kp as a location where the impact by salinity could be small despite great impacts by erosion and sediment by the tsunami.

① Point 2.4kp

Aerial photographs before and after the Earthquake are shown in Figure-3.3.16.6. In the detail survey area at point 2.4kp in the right photo, only reed communities were observed as a vegetation type. Others include open water and natural bare lands, and places with a high tide level become surface water in the most natural bare lands. The reed community was observed in the marginal area or in the central mound part with approximately 30cm of relative elevation on the island, and the growth condition marked "Good" in the area with a relatively high elevation, and "Slightly Bad" or "Bad" in lower areas.

Furthermore, in the vegetation map created in 2008, communities of Amur silver-grass or *Carex rugulosa* were established in the mound area, but these communities could not be determined in this survey. The center of the island was covered with whole reed communities in 2008, but they have disappeared.

② Point 6.4kp

In the detail survey area at point 6.4kp, only the reed community was observed as a vegetation type. Others remained as open water and natural bare lands. Most natural bare lands are thought to be an open water place when the tide level is high. The reed community was observed at a relatively higher part of the elevation level along banks or channels, and the growth condition marked "Good" in the area which did not submerge at full tide, and "Slightly Bad" or "Bad" in accordance with lowering the elevation level. There was little vegetation in the center of river terraces.

Furthermore, in the vegetation map created in 2008, the part with the high elevation level along the channel was a salt marsh vegetation community, but had changed into a reed community after the Earthquake. There was an approach lane of vehicles upstream from the detail survey area, and a community of *Carex rugulosa* was found along the lane. The *Carex rugulosa* was observed with its recovery at point 6.4kp during the survey in June 2012 despite the small amount identified.

(5) Impact on Reed Beds by the Tsunami Sediment and Subsidence

1) Synoptic Survey of Tsunami Sediment

Sediments by the tsunami were widely observed on the river terrace after investigation of the tsunami sediment in the survey area during the synoptic survey. Figure-3.3.16.7 shows the thickness.

The tsunami sediment was deposited thickly on the

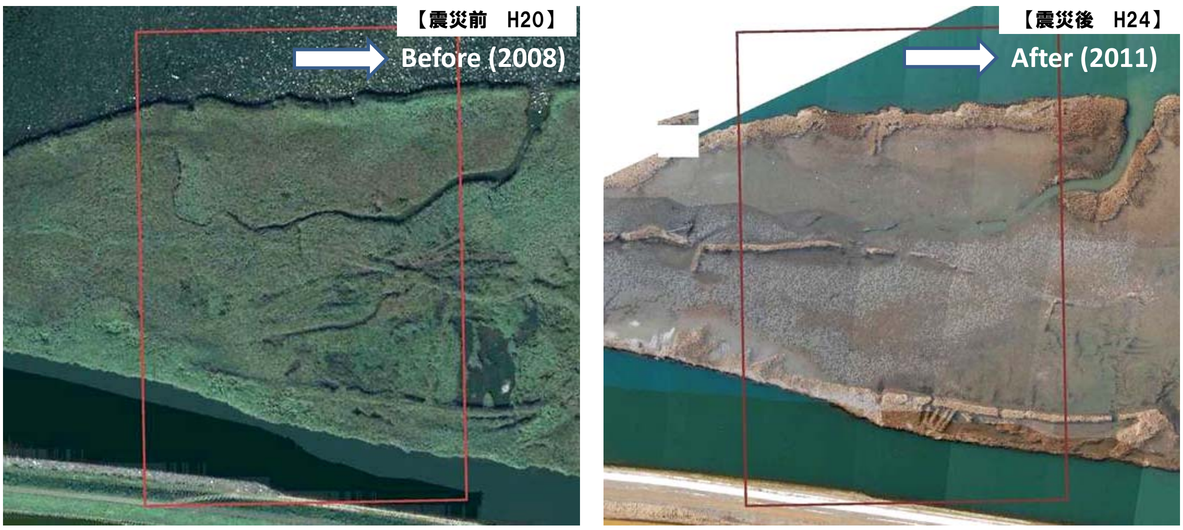

Figure 3.3.16.6 Vegetations with a Focus on the Reed Community Before and After the Earthquake (near point 2.4kp)

river terrace of both banks from point 5.0 to 10.5kp, and, among them, the sediment was thicker from point 5.0 to 7.0kp with 23cm at the thickest bed (at the synoptic survey). The sedimentary cycle which indirectly shows the number of tsunami attacks was observed by up to four times at point 5.0 to 7.0kp after estimating from grading structures.

On the other hand, the thickness of the tsunami sediment decreased downstream from point 4.5kp. The reason may be considered that a flow was disturbed by the collision of a run-up wave and a down-rush on the tsunami invasion, but the details are unclear.

Also, upstream from point 11.0kp, no tsunami sediment was observed. The detailed cause is unclear though this may have been caused by a decrease in the force to drag the sandy sediment and reduce the run-up speed of the tsunami, or by some of four tsunamis occurring without arrival to the place though detailed causes are unknown. The river terrace downstream from point 10.5kp where remarkable tsunami sediments were observed was below the elevation level of 1.0m and lower than the maximum tide level.

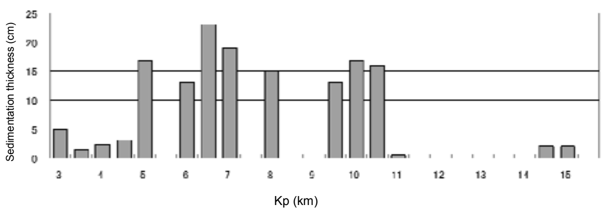

Figure 3.3.16.7 Thickness of Tsunami Sediments on the River terrace

2) Result of the Detail survey for Tsunami Sediment and Reeds

Possible impact factors on reeds in the riverine estuaries are considered as a change in the elevation level or salinity with the erosion by the tsunami or ground subsidence, or burial on land of tsunami sediments. Summarization was performed in the relation between these factors and the reed.

Relations among the elevation levels at point 2.4 and 6.4kp, bed thickness of tsunami sediments and the presence or absence of the reed are summarized in Figure-3.3.16.8. Each mark indicates the place as follows; ○: place with sprout growth, X: without sprout growth.

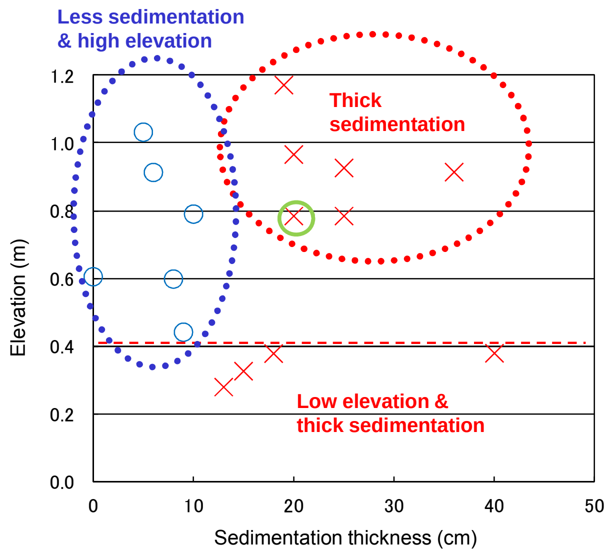

Figure 3.3.16.8 Impact on Reeds by the Elevation Level and Bed Thickness of Tsunami Sediments

At point 2.4kp of the island, reeds could be seen at approximately T.P. (or Tokyo Bay mean sea level) 0.4m or higher, and not below T.P. 0.4m. This may be due to an inhibition of growth by the salinity and sediments.

At point 6.4kp of the river terrace on the left bank, each site is at T.P. 0.4m or higher, but reeds could not be found in all sites. Regarding the place where reeds could not be found after the Earthquake in spite of the T.P. above 0.4m, some characteristics were observed on thick tsunami sediments as well as the existence of reed rhizome in a deep position before the Earthquake. In spite of the bad growth condition, however, reed growth from the rhizome in greatly deep positions was observed according to the location. The recovery from the rhizome seemed to depend on individual differences.

3) Changes in the Ground Level Before and After the Earthquake and the Vegetation

① Point 2.4kp

The states of the ground level and the vegetation were summarized. Regarding vegetation changes in the detail survey area at point 2.4kp, the summarized results including a change to the natural bare land are shown in Figure-3.3.16.9. The vertical axis indicates the elevation level, and the horizontal axis indicates the area by elevation level (the number of 5m x 5m grids settled in the survey area).

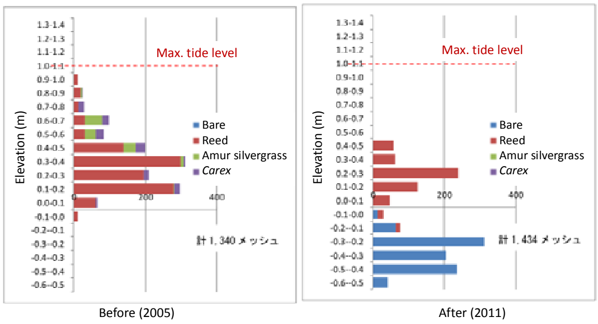

Figure 3.3.16.9 Relationship between the Elevation Level and the Vegetation Before and After the Earthquake in the Detail Survey Area at Point 2.4kp

For the vegetation before the Earthquake, although the reed community was dominant from the elevation level of 0.0 to 0.5m, evidence was observed regarding mixing growths with a salt marsh vegetation community (mixture of the *Carex rugulosa*) at 0.2m or higher and with an Amur silver-grass community at 0.4m or higher, with domination by other vegetation than the reed community at 0.6m or higher. No vegetation was found below the elevation level of 0.0m.

The elevation level with a high frequency ranged from certain 0.2 to 0.4m before the Earthquake, but from certain -0.5 to -0.2m after the Earthquake, which was lower by 0.6 to 0.7m. Considering the river terrace would have settled down in whole, an impact of the erosion by the tsunami is possible because of a disappearance of the vast vegetation bed at around the elevation level of 0.0m.

At present, a reed community is found in the area above the elevation level of 0.0m. In the area below 0.0m, however, the natural bare land remains as it was, or the condition has been bad in spite of growing the reed. For the future, in order that the reed community can be developed at around point 2.4kp as before, the elevation level should be considered being above 0.0m.

In addition, vegetation such as other salt marsh vegetation communities and Amur silver-grass communities were not observed in this investigation. In the future, however, it is sufficiently possible that other vegetation will be established by succession of entering vegetation or ingression of seeds or individuals. Studying these processes is also desirable.

② Point 6.4kp

Regarding vegetation changes in the detail survey area at point 6.4kp, the summarized results including a change to the natural bare land are shown in Figure-3.3.16.10 as well.

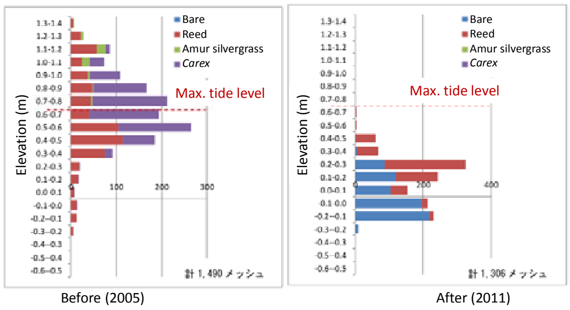

Figure 3.3.16.10 Relationship between the Elevation Level and the Vegetation Before and After the Earthquake in the Detail Survey Area at Point 6.4kp

The vegetation before the Earthquake consisted mainly of the reed and salt marsh vegetation communities (mixture of the *Carex rugulosa*). Looking at the peaks of altitude at which they appear, many salt marsh vegetation communities were observed at a bit higher level because reed communities ranged from 0.4 to 0.6m and salt marsh vegetations from 0.5 to 0.8m. The proportion of Amur silver-grass community kept high above the elevation level of 1.0m.

The vegetation observed after the earthquake is only reed communities. The high frequency of the elevation level ranged from 0.2 to 0.3m, and the same as the case of point 2.4kp, frequency distributions were polarized unlike the situation before the Earthquake.

Like point 2.4kp, no vegetation has been found in the area below 0.0m. In the area below 0.3m, reeds are sprinkled and the growth condition is bad.

However, as not only the terrestrial part but also situations of survival or growth of reed's rhizome have been confirmed, the possibility for recovery is somewhat positive for the future.

In a part, the *Carex rugulosa* and *Carex kobomugi* have been found. Vegetations like other salt marsh vegetation and Amur silver-grass communities have not been verified, but it is sufficiently possible that other vegetation will be established by succession of vegetation or ingression of seeds or individuals in the future. Grasping these processes is also desirable.

(6) Lessons for Nature Restoration

The reed community at the mouth of Kitakami River was largely eroded by the tsunami and the area has halved. In particular, the vegetation bed was lowered by land subsidence. And at point 0kp to 4 or 5kp where the salinity increased more than that before the Earthquake, it seems difficult to grow the reed due to the impact of salt levels at present. A way to raise a river terrace may be effective to get rid of these impacts.

On the other hand, even though impacts by salt contents are not fatal upstream from point 5kp, the impact by tsunami sediments seemed enormous. In this section, gradual restoration from the reed bed remaining in the marginal part or upstream seems to be realizable in the long view. But prompt restoration is desirable as there is a region where reeds are utilized for industries. Fortunately, under tens of centimeters of tsunami sediments, it is sufficiently possible to promote the restoration of reeds by a simple method of turning over the ground as the pre-devastated reed rhizome remain. This needs a quick treatment as the life of the rhizome is limited. However, the environment in habitats or nursing areas for precious animals and plants must not be devastated only because of rushing ahead with reed restoration. A method should be implemented with as small an impact as possible while grasping the current situation. For example, it is a probable way to restore a reed bed at intervals by utilizing the underground stem and to develop it from the area.

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3.4 Research Study

3.4.1 Orientation of Research Activity for the Future Recovery

After the occurrence of the Great East Japan Earthquake, in conducting technical assistance for other parties concerned and regional development bureaus in the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the National Institute for Land and Infrastructure Management (NILIM) has recognized it as an important responsibility as a research institute to make progress in necessary studies in advance, looking at the issues that various unexpected natural disasters would bring down on the country from a medium- and long-term viewpoint, in consideration of the damage from the Earthquake. In addition, while looking ahead to social changes including aging and depopulation, NILIM has also realized it is essential to consider the ideal future vision of the country against natural disasters, define the challenges to tackle, and study the direction for issue solution by looking over issues which could occur due to an inconceivable natural disaster, from various fields and viewpoints.

As a result, the "Study session for risk management" was established on October 14, 2011, which is comprised by directors of NILIM and research directors in related fields. In the session, orientations for recognition and solution of subjects against inconceivable natural disasters by the NILIM were settled for discussion, alongside gathering know-how in various fields. The main themes in discussion at the time of the inauguration of the session were as follows:

1) Challenges that emerged on the Great East Japan Earthquake,
2) Challenges that should be tackled with regard to various natural disasters beyond existing predictions,
3) Directionality for the solution of former problems?.

At the second session on November 14, 2011, intensive arguments were continuously conducted on the three subjects above mentioned. Therefore, we recognized that "Preparation for an external force more than the limit performance which could not be assumed" would be especially important in the future studies and confirmed the following issues to be examined:

1) Issues to be bolstered on the aspects of evacuation and issues for considering non-structural improvements and the remedy for "Saving human life."
2) Concentration of applicable technologies and various plan options and ideas in order to secure the facility function and recover it quickly,
3) Non-structural preparation for life rebuilding and life support after the disaster,
4) Examinations on "reconsidering the vision of acceptable risks required and limit performances and acceptable risks for facilities against external force," "Expansion of the viewpoint of planning theory" and "Widening the cross-cutting viewpoint."

Also, the "Working group (WG) on the study session for risk management" was launched on March 30, 2012, as a study session at the practical level in order to seek possibilities for practically and concretely trying issues in each research section, problem consciousness, the start and conduct of researches and additional alignments with the arguments through the study sessions.

The WG set to conduct "Information sharing of the progress of studies on various disasters regarding unforeseen external forces and their evaluation" and "Share and discuss the progress and circumstances conducted in each research from the viewpoint of risk management," which were carried out during the second meeting on June 13 and the third on September 20, 2012, respectively.

In parallel with the comprehensive discussions in these study sessions, the next researches were started, as an individual research project. an IT and information section regarding disaster prevention and reconstruction projects are summarized in section 3.4.5, and, as well, the research orientations are described regarding "3.4.2 Study on the Systems of Multiple Defenses and Disaster Mitigation from Tsunami", "3.4.3 Research on the Disaster-structured Supporting Technologies in

Coastal Cities" and "3.4.4 Study on the Risk and Crisis Management Strategy for Excessive and Multiple Actions of Natural Disasters" in relation to the newly-launched prominent investigations considering the Great Earthquake as a specific research project.

3.4.2 Research on Multiple Defense Systems and Tsunami Disaster Mitigation

(1) Introduction

The Great East Japan Earthquake, which occurred on March 11, 2011, triggered a massive tsunami of a kind said to occur only once every 500-1,000 years, far in excess of the external force that coastal protection infrastructure was designed to withstand. Including both confirmed dead and missing persons, this disaster claimed almost 19,000 lives.

In terms of the policy for recovery and reconstruction in light of this major tsunami disaster, it was proposed that an approach be adopted involving the establishment of a two-level external force system, based on Level 1 tsunami (tsunami protection level) and Level 2 tsunami (tsunami disaster mitigation level). The proposed approach would focus on protecting human life and property from comparatively frequent Level 1 tsunami, using coastal structures, and implementing disaster mitigation aimed at protecting human life by means of multiple defenses centered on evacuation in the case of Level 2 tsunami. In the report by the Central Disaster Prevention Council's Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunami Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake", A Level 2 tsunami is referred to as the largest-class tsunami, while a Level 1 tsunami is referred to as frequently-occurring tsunami.

The research conducted in this project consists of the five studies shown in the diagram below (Figure 3.4.2.1). (i) Summarizing lessons concerning tsunami countermeasures gained from surveys of the damage resulting from the Great East Japan Earthquake and new findings concerning the damage caused by tsunami; (ii) summarizing past tsunami trace data and summarizing techniques for using tsunami inundation simulations to set Level 1 and Level 2 tsunami; (iii) developing structural methods that will make seawalls more robust and considering techniques for formulating river plans that take into account the river runup of tsunami; (iv) studies concerning tsunami hazard evaluation in inland areas and the control of inundation flow; and (v) studies concerning support for evacuation and crisis management, and measures to improve safety and mitigate disaster through land use and other methods.

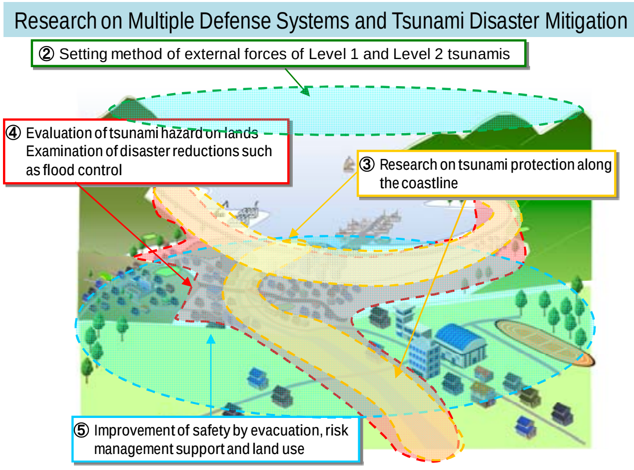

Figure 3.4.2.1 Content of Research

As well as using the outcomes of this research to support recovery and reconstruction in the aftermath of the Great East Japan Earthquake, we aim to ensure that they are reflected in tsunami countermeasures in regions where it is feared that tsunami will occur in future, such as the Pacific coast of West Japan.

(2) Support for Recovery and Reconstruction

As one of the objectives of this research is to support recovery and reconstruction in the aftermath of the Great East Japan Earthquake, research outcomes obtained by urgent surveys are progressively being published and reflected in relevant measures. The main research outcomes are introduced below.

1) Method of Setting Design Tsunami Water Level

See 3.3.5(1).

2) Guidelines on Tsunami Inundation Simulations

See 3.3.5(6). As well as being able to conduct appropriate tsunami inundation simulations quickly, this will make it possible to ensure that differences do not arise between engineers in terms of techniques and the setting of conditions.

3) Provisional Standards Concerning Structural Requirements for Tsunami Evacuation Buildings

See 3.3.9(3). In addition, in the process of considering this matter, it was necessary to make estimates for each of the damaged buildings regarding the external force resulting from the tsunami, unlike in the case of analysis of damage from seismic motion. However, there were areas where field surveys alone were not sufficient to confirm the information required for estimating the relevant external force, so even within NILIM, researchers in the River Department and the Building Department collaborated in their deliberations on this issue.

4) Resilient Structures for Coastal Dikes

See 3.3.5(2) and 3.3.5(3).

(3) Creation of Tsunami-resistant Communities and Related Research

From the tsunami resulting from the Great East Japan Earthquake on March 11, 2011, we learned the lesson that "there is no upper limit for disasters". In order to prepare for such large-scale tsunami and protect human life by all means, it is necessary to create tsunami-resistant communities based on multiple defenses, which involves mobilizing both hard and soft measures.

It is necessary not only to create tsunami-resistant communities in the reconstruction of the disaster-afflicted areas, but also to promote this endeavor nationwide. Accordingly, the Act on Regional Development in Tsunami Disaster (Act No. 123 of 2011) was enacted in December 2011[1).].

The outcomes of this research project will be the techniques that will support this endeavor, and will be reflected in relevant standards. Figure 3.4.2.2 shows what is involved in creating tsunami-resistant communities and the relationship between this and the main techniques that will support this endeavor. The outcomes that have already been published as standards or guidelines are as follows.

1) Guidelines for Setting Tsunami Inundation Assumptions

Prefectural governors set tsunami inundation assumptions (districts expected to be flooded in the event of a tsunami and the depth of the water resulting from this) based on tsunami inundation simulations. In the process of that, the largest-class tsunami is assumed, based on the results of basic surveys of past earthquake tsunami and earthquake tsunami assumptions.

The tsunami inundation assumptions set on the basis of scientific knowledge form the basic information for effectively combining a range of measures, in the form of putting in place warning and evacuation systems, and regulations concerning land use. This then forms the basis for the compilation of municipal plans, the management of tsunami protection facilities, and the designation of caution zones and special caution zones.

Progressive revisions are being made to the *Guidelines on Designing the Assumptions of Tsunami Inundation*, which was compiled in February 2012, expanding upon the content of the *Guidelines on Tsunami Inundation Simulation* referred to in (2) 2) above and setting forth the standard procedures and methods for designating tsunami inundation assumptions stipulated in law[2)]. Technical support is being provided in the same way as for the *Guidelines on Tsunami Inundation Simulation*, by establishing a consulting service. For further details, see 3.3.5(7).

2) Method of Setting the Standard Water Level

The standard water level is the water level obtained by adding the rise in the water level (swell) resulting from the collision of a tsunami with buildings and other structures, to the water depth stipulated in tsunami inundation assumptions (this does not take into consideration the effects of individual buildings). This water level forms the standard for judging the necessary height of evacuation areas and living areas in Specified Buildings (social welfare facilities, schools, and medical facilities, etc.) in special caution zones.

In the tsunami inundation simulations used when setting the tsunami inundation assumptions referred to in 1) above, set up of water level at individual buildings is not taken into account, as consideration is given to the impact on buildings in terms of roughness in overall land use. The height of set up resulting from individual buildings can be calculated by taking buildings into account as walls or topographic data. However, there would be an endless amount of work if calculations were made to take every case into account when considering regional development and developing regulations for buildings. Accordingly, we have proposed a convenient, yet hydraulically-rational calculation method based on the results of tsunami inundation simulations. For further details, see 3.3.5(7) and the *Report on Technical Review Concerning the Regional Development in Tsunami Disaster*[3]. This calculation method was reflected in the enforcement notice *Concerning the Enforcement of the Act on Regional Development in Tsunami Disaster* [4], dated March 9, 2012.

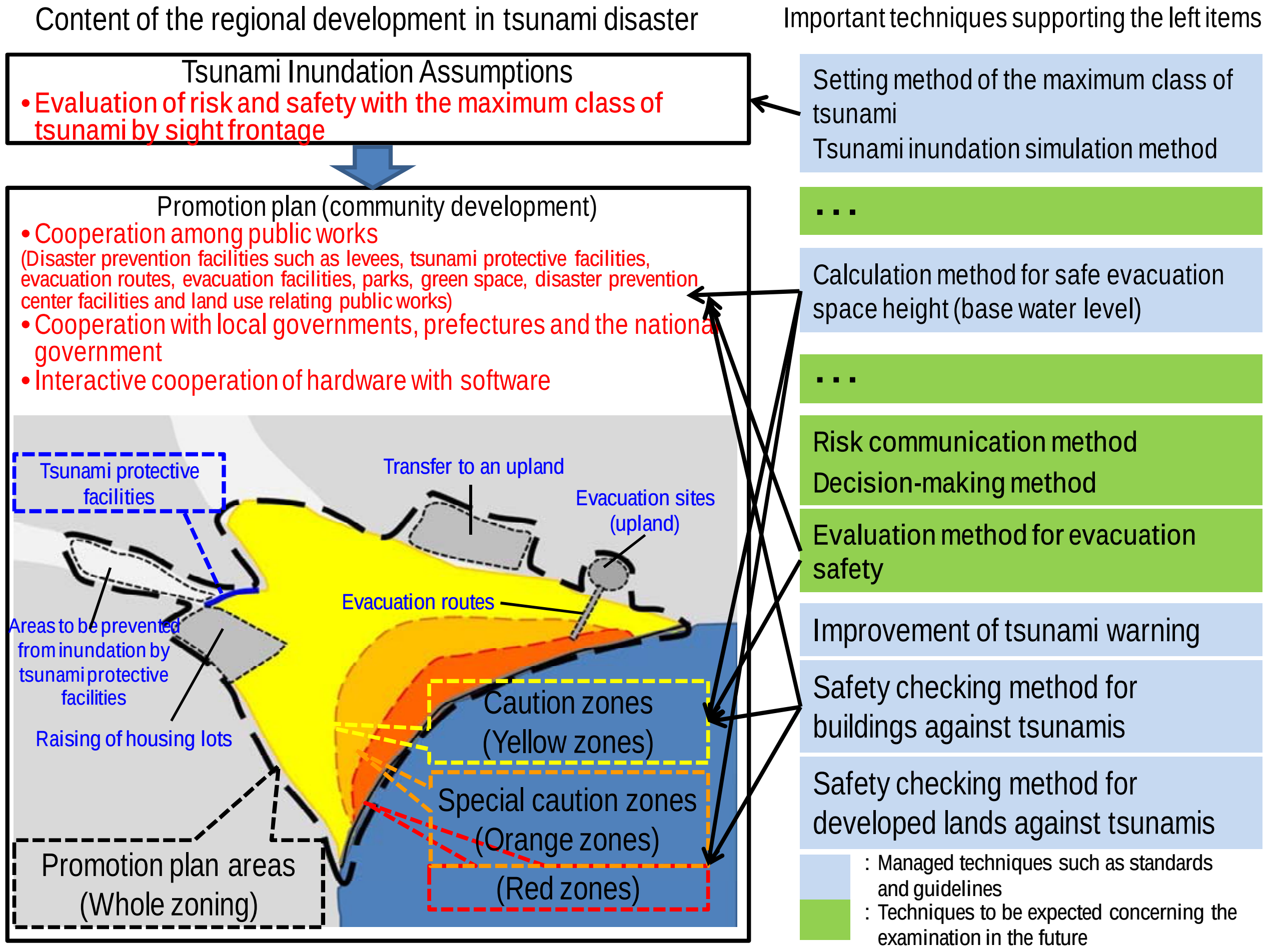

Figure 3.4.2.2 Details of the Regional Development in Tsunami Disaster and the Techniques to Support This

3) Technical Standards Concerning the Structure of Designated Tsunami Facilities, etc.

See 3.3.9.5(3).

4) Technical Standards for Tsunami Protection Facilities

Tsunami protection facilities are disaster prevention facilities newly positioned in the Act on Regional Development in Tsunami Disaster. Tsunami protection facilities are facilities established inland to prevent the expansion of inundation as a result of a maximum-level tsunami having runup on land. This assumes that it is possible efficiently to put in place infrastructure such as small-scale mounds; such facilities are not intended to be an alternative to seawalls that prevent actual tsunami on the coast.

The Technical Review Committee on the Regional Development in Tsunami Disaster (Secretariat: Water and Disaster Management Bureau, City Bureau, NILIM) examined the external forces, performance requirements, and verification methods that should be taken into consideration in the design of tsunami protection facilities. For details of the results of their deliberations, see 3.3.5(7) and the *Report on Technical Review Concerning the Regional Development in Tsunami Disaster*[3].

5) Technical Standards for Specified Development Activities

The special caution zone (Orange Zone) is the zone within the caution zone (Yellow Zone: zone in which a warning and evacuation system has been put in place) in which regulations require that Specified Buildings and development activities be made safe against tsunami.

Specified Buildings are social welfare facilities, schools, and medical facilities used by elderly people, small children, or those who are sick, for whom it is difficult to escape from a tsunami. Making buildings safe against tsunami involves securing living areas at a height that a tsunami will not reach, on developed land and in a building structure that is safe even in the face of a largest-class tsunami.

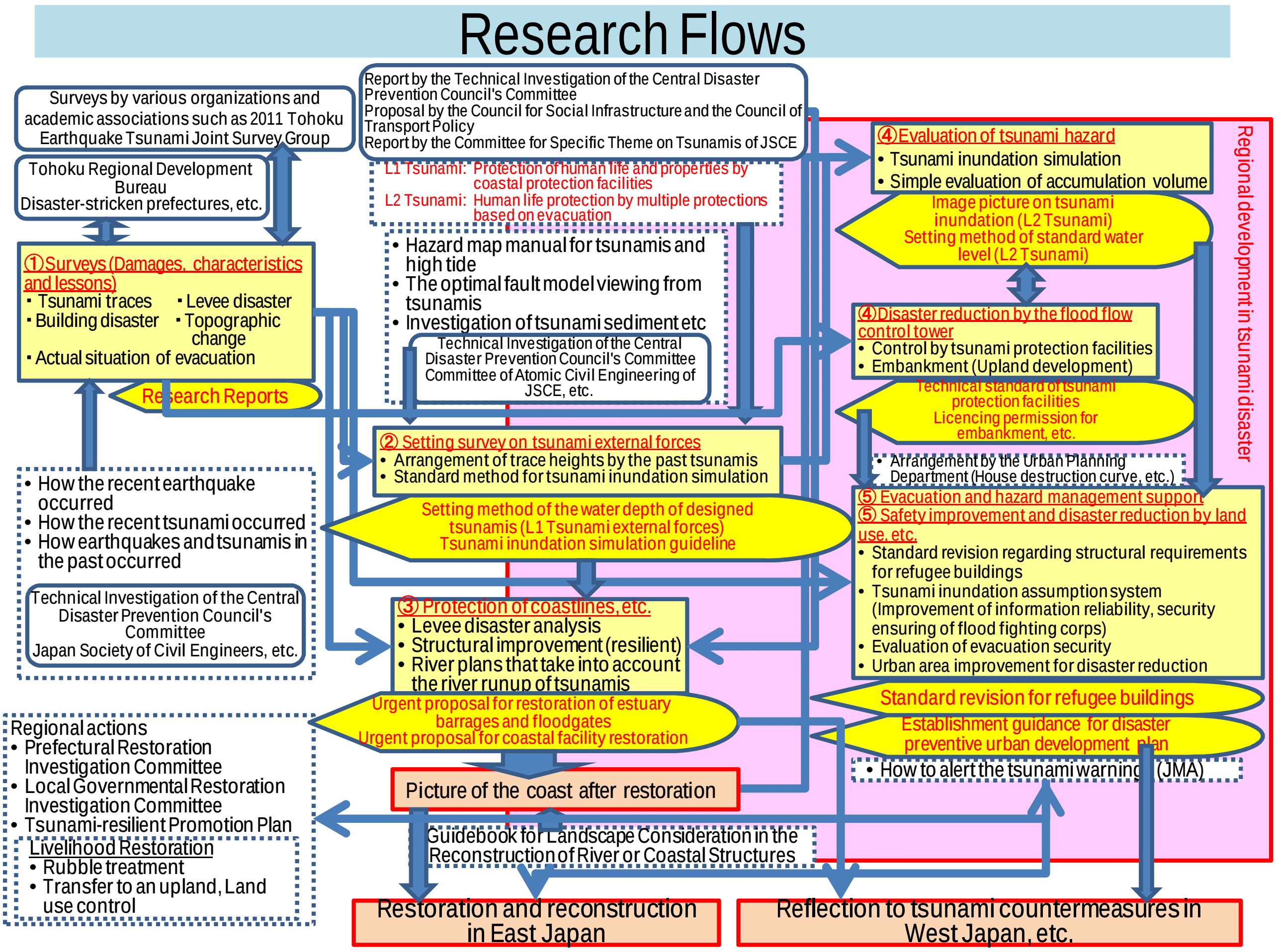

Figure 3.4.2.3 Flow Diagram of Research in This Project

Within the special caution zone (Orange Zone), it is possible to use municipal ordinances in the same way as described above in order to regulate construction and development activity to ensure that houses and residential land that are safe against tsunami are developed (Red Zone) .

Similarly to the methods for setting standard water level and the Technical Standards for Tsunami Protection Facilities, the Technical Review Committee on the Regional Development in Tsunami Disaster also considered techniques for verifying the safety of developed land against tsunami in the process of specified development activities. As this involved collaboration among multiple fields, it was necessary to engage in wide-ranging deliberations concerning not only tsunami engineering, coastal engineering, hydraulics, and hydraulic engineering, but also geotechnics and soil mechanics. The details are reported in 3.3.5(7) and the *Report on Technical Review Concerning the Regional Development in Tsunami Disaster*[3], and the outcomes were reflected in a ministerial ordinance that entered into force on June 13, 2012. In addition, as stated above, the standards in 3) are applied as standards for building structures.

6) Development of Evacuation Safety Evaluation Techniques and Urban Development Planning

Techniques for Disaster Mitigation

From FY2012, as part of the "Research concerning techniques to support the development of disaster prevention structures in coastal cities" project, studies are being conducted on urban development planning techniques based on evacuation safety and planning techniques for ensuring redundancy in the functions of disaster prevention bases (see 3.4.3).

7) Content of Future Deliberations in the Field of Rivers

Following the recent tsunami, river tsunami have been positioned as the focus of systematic measures, alongside flooding and high tides. The basic policy and approach for this are set forth in *Concerning Measures to Counter River Tsunami* (September 2, 2011; Notice from the Director, River Planning Division and Director, River Improvement and Management Division). Moreover, as stated in 3.3.2(2)-(6), the Committee has set forth its approach to considering measures tailored to individual river structures and hazard mechanisms. These advanced new policies and approaches will be translated into reality as measures focused not only on rivers affected by the Great East Japan Earthquake, but also rivers nationwide, taking into account the attributes of individual rivers and tsunami conditions.

In the process of conducting numerous rounds of deliberations about such measures and reflecting in these deliberations the outcomes of research conducted in parallel in a timely fashion, it will be vital to ensure that surveys and calculation techniques tailored to river and tsunami conditions are refined in order to improve the quality of measures, and that these are reflected in various relevant standards.

Furthermore, if the perspective is broadened from measures for river areas to include the creation of disaster-resistant communities, assumptions about the flooding that would occur as a result of various degrees of "tsunami beyond the facility plan", including the largest-possible tsunami, will form the basic information for undertaking various deliberations. It is surmised that the extent of the flooding could change depending on the behavior of river structures when acted upon by tsunami beyond the facility plan. Accordingly, important tasks for the future include compiling a summary of techniques for setting assumptions concerning the behavior of various types of river structure, such as in the event of a river embankment breach, with the techniques tailored to different purposes, for example, soft measures including urban development and evacuation.

Based on an awareness of this issue, the River Division is examining the following matters.

(i) Analytical Techniques Focused on River Tsunami

In estimating river tsunami water levels and runup sectors, conditions are set in regard to such factors as river channel shape (low-water channel or flood channel, mouth bars, river channel traits (bend or straight line), etc.), river bed evolution, embankment overflow or breach, and river flow, but the changes that occur in these conditions - for example, how acutely these are expressed as fluctuations in the water level - are not necessarily clear. This is a fundamental technique that is closely related to the structural design of river embankments, so as well as developing a more profound understanding of this matter, it is important to reflect it in deliberations concerning tsunami countermeasures.

Accordingly, it has been decided to conduct a model experiment focused on a river tsunami, using a 1/330 scale planar model of the Shin-Kitakami River. In the model experiment, various conditions are altered systematically, including the river channel topography (including whether or not there is an embankment breach), roughness, and input waveform of the tsunami from the estuary, and the water level of the river tsunami is then measured. Based on these results, the impact of each condition on the water level is evaluated. Then, replication calculations of these results are carried out, and consideration is given to improvements to river tsunami analytical techniques and methods of setting conditions that are more closely tailored to the objective.

(ii) Behavior of River Embankments in Relation to Overflow in the Event of Tsunami Runup

At the time of the recent tsunami, there were cases in which the overflow from the river embankment caused during the runup of the first wave of the tsunami continued for up to ten minutes, with the depth of the overflow water reaching 10m in some cases. Compared with the overflow experienced during normal floods, the overflow during a tsunami is characterized by the fact that a high flow velocity acts on the embankment during a short period of time. Data concerning the recent tsunami, in relation to the behavior of river embankments when acted upon by the tsunami in this way, are being gathered and analyzed (see 3.3.3(1)). As a result, the research team has ascertained that the scale of levee body erosion can change according to the extent of the flooding within the area protected by the embankment (whether or not there is a water cushion).

We will continue to conduct deliberations aimed at augmenting knowledge concerning such cases and erosion mechanisms, but at the same time, for example, in the case of river embankments, we will also examine ways of using knowledge about such matters as how to set the various conditions that affect the extent of flooding (including the tsunami water level that causes embankment breaches, and the locations and length of those breaches) in such a way as to make it possible to envisage a flood situation appropriate to the focus of deliberations.

(iii) Measures in Anticipation of Complex Disasters

River management infrastructure was also damaged by the recent earthquake and tsunami, so rapid repairs were made ahead of the flood season. However, due to various constraints, these did not necessarily restore the functions of this infrastructure adequately, and aftershocks further increased the scale of the damage and the number of places affected. We have responded to this situation by augmenting checks under normal circumstances, as well as when the rivers are in flood, dealing with issues as they arise, which has enabled us to get through the flood season without any major problems. Moreover, there have also been disasters since the recent earthquake and tsunami, including the flooding that resulted from slope failure due to Tropical Storm Talas in 2011.

In light of such events, the scope of deliberations regarding disaster prevention and mitigation - including prior measures and emergency responses in the event of disaster - will be broadened to include complex disasters in the event of flooding occurring concurrently with an earthquake, tsunami or slope failure.

(4) Conclusion

Figure 3.4.2.3 shows the process via which research was conducted in this area. One of the objectives of the research is to support responses to disaster and subsequent recovery and reconstruction, so many research outcomes have already been reflected in measures (see Figure 3.4.2.2 "Techniques already rolled out in standards and guides, etc.") In considering their reflection in tsunami countermeasures outside the disaster-afflicted areas, it is likely that the items described in Figure 3.4.2.2 as "Techniques for future consideration" will come to be more important. Of these, the Urban Planning Department will commence a study during the current fiscal year as part of this research project, focusing on techniques for evaluating evacuation safety. It is hoped that the outcomes of this study will become a technique that will support the creation of tsunami-resistant communities.

Moreover, Figure 3.4.2.4 shows the research implementation system for this project. With NILIM's River Department, Building Department, Urban Planning Department, and Research Center for Land and Construction Management as the main implementing bodies, collaboration with other departments and projects within NILIM is being sought, and findings are being shared among them. In addition, working in partnership with relevant academic societies, investigative committees, and administrative bodies, NILIM is sharing its findings and reflecting its research outcomes in various measures.

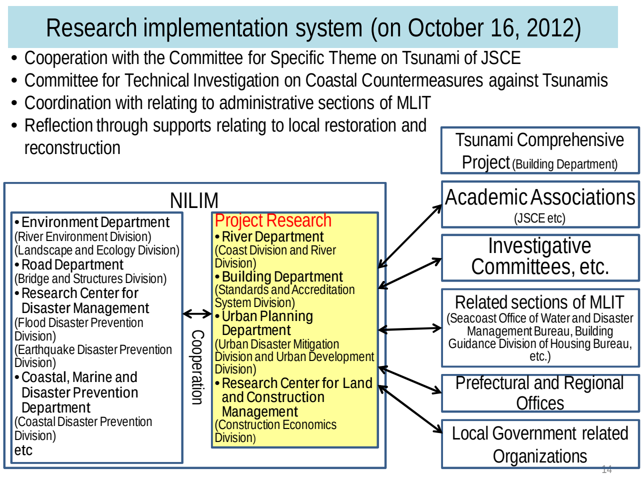

Figure 3.4.2.4 Flow Diagram of the Research Implementation System for This Project

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3.4.3 Research on technologies for disaster reduction planning in coastal cities (FY2012-2014)

In coastal cities and towns where fear for similar disasters and damages as those of the 2011 off the Pacific coast of Tohoku Earthquake has grown, there is an urgent necessity for countermeasures, such as for smooth evacuation of citizens, sustainability of urban disaster preparedness functions and against housing area liquefaction. These urban disaster mitigation measures should be reflected in the disaster mitigation structuring plan of the cities and towns.

For this reason, the following research is being conducted under a three-year plan since FY2012, with a mission to develop a planning method and technical data required for Japan's technical guidelines and technical standards on promotion of disaster mitigation structuring, including countermeasures against tsunami and widespread land liquefaction in coastal cities and towns facing risk of massive earthquakes in the future.

(1) Urban development planning method based on evacuation safety

A multi-agent tsunami evacuation simulator is developed, to predict the evacuation behavior of residents in various disaster scenarios.

In addition, this simulator can be used in identifying districts which would have many people who have trouble evacuating and districts with insufficient evacuation areas, and extracting important evacuation routes, to establish a method of drafting the urban development plan for improving the evacuation safety of residents.

(2) Planning method to secure redundancy of urban disaster preparedness functions

For disaster preparedness facilities such as local government offices, shelters, medical and emergency facilities, firefighting and rescue facilities, methods of planning their locations, designating substitute facilities, linking facilities, and flooding countermeasures are studied. The aim is to ensure their essential functions in the required phases leading to post-disaster emergency correspondence, recovery and restoration for the entire city and towns, although some of the facilities may be damaged and temporarily fail, depending on the intensity and form of the disaster such as tsunami.

(3) Data preparation for technical standardization of soil liquefaction countermeasures

To establish the numerical criteria for housing site disaster reduction, the targeted required performances are established, and for corresponding specific target levels (such as index of allowable amount of land subsidence), the basic data is collected and arranged. Also the basic data is analyzed and arranged for setting the specification standards for each ground characteristics and construction method.

Figure 3.4.3.1 Image of disaster mitigation structuring of coastal city

3.4.4 Research on Risk and Crisis Management Strategy for Excessive and Multiple Actions of Natural Disasters (FY2012-2014)

The Great East Japan Earthquake struck on March 11, 2011. It caused a huge tsunami far beyond previous estimations, along with strong shaking over a wide area from the Tohoku region to the Kanto region. The disaster devastated a wide area. Subsequent Typhoons No.12 and No. 15 also caused floods and sediment-related destruction while the area was still reeling under the quake damages. Important lessons learned from these disasters are shown in two points below.

It is essential to:

- prepare for natural disasters of sizes previously not experienced nor forecast
- prepare for multiple disasters, such as combinations of earthquakes, tsunamis, floods and landslides.

These kinds of issues were pointed out by the Central Disaster Management Council etc., and the Central Disaster Management Council's "Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the 2001 off the Pacific coast of Tohoku Earthquake"[1] recommended the following.

(1) The largest possible mega earthquakes and tsunamis should be considered from every possible angle.(2) One should be aware of the possibility of actual damage exceeding the damage expected and of the uncertainties of estimations

(3) Full preparations need to be made against a mega ocean trench earthquake in the Nankai trough and Tokyo Inland Earthquakes should also be reviewed and considered

(4) It is necessary to consider such cases: Tokai, Tonankai, and Nankai earthquakes occur at the same/subsequent time: Multiple disasters such as earthquake and typhoon.

In addition, based on the recommendations of the Central Disaster Management Council, "Basic guidelines for reconstruction in response to the Great East Japan Earthquake" [2] also indicated a broad policy to create regions which are strong against disasters, from a viewpoint based on the concept of "damage reduction": full mobilization of structural and non-structural measures, construction of resilient land and infrastructure which enhances response capacity to large scale disasters, and resilient multi layered defenses.

In the light of such lessons learned, with giving the highest priority to protection of the residents' lives, there is a need to build resilient land and infrastructure which can maintain the minimum required social and economic functions, considering disaster risks which were not assumed previously.

Against this background, research project "Research on risk and crisis management strategy for excessive and multiple actions of natural disasters" over the three years from FY2012 to 2014 was started by the National Institute of Land and Infrastructure Management with the purpose to build "damage reduction" techniques by mobilizing all possible structural and non-structural measures. This study aims to clarify the occurrence and the impact of excessive and multiple natural disasters which were not sufficiently considered previously, and propose techniques to build crisis management measures against such unforeseen disasters.

As shown in Fig. 3.4.4.1, there are various disasters: earthquakes, tsunamis, floods, volcanic eruptions, storm surges, and sediment related disasters such as landslides.

Previously, countermeasure levels were set considering that these respective disasters occur independently, but this research covers the possibilities of actions of excessive force over those levels, and multiple disasters considering mutual interaction among - several disasters.

For example, multiple disasters could be landslides and flood disasters due to floods after an earthquake or due to heavy rain after volcanic eruptions. For this purpose, three broad research points have been set as shown in Fig. 3.4.4.2.

In other words, the aims are to 1) *know*, 2) have an insight into and 3) *manage* the phenomena and impacts of excessive and multiple natural disasters.

Firstly, in 1) "know," examples of disasters which actually occurred in the past are collected, and what happened in these disasters is reanalyzed. This stage will include historical and overseas disasters, and study actual damages to see how damages occurred during the disasters, how they progressed, and how each individual event in a disaster spread and made an impact on society.

In "2) insight," based on the analysis of the actual disasters, the study will look at what happens due to excessive and multiple disasters, and study techniques to develop disaster scenarios without overlooking important impacts, and methods to evaluate risk levels and impacts. The disaster scenarios shall be studied considering vulnerabilities due to characteristics of the region, such as urban and mountain areas.

Lastly, in "3) manage," methods for preparing disaster prevention facilities and crisis management measures for excessive and multiple disasters shall be studied. A menu of countermeasures including structural and non-structural measures shall be studied, these shall be applied to a model region to check what kinds of countermeasures would be effective, and the effectiveness of the countermeasures shall quantitatively evaluated. Many combinations of multiple disasters are possible, but this research will first focus on combinations with floods.

This study started in FY2012. Its research results shall be summarized as a collection of cases including the scenario development techniques and a countermeasures menu. The results will be issued in a format ready to use as a reference while studying disaster preparedness and countermeasures.

Discussions are to be carried out to gather various options and ideas, such as the approach towards preparing against excessive force over previous expectations, limitation of structural measures, framework for combining structural and non-structural measures, techniques required to boost the evacuations to save lives and the non-structural measures, applicable technologies for early recovery and maintaining the functions of facilities.

As a result, starting with the recovery and reconstruction measures for the Great East Japan Earthquake, and study of three linked earthquakes in Nankai Trough, the research shall proceed quickly so it can be used in mitigation measures which also consider future large scale disasters.

References

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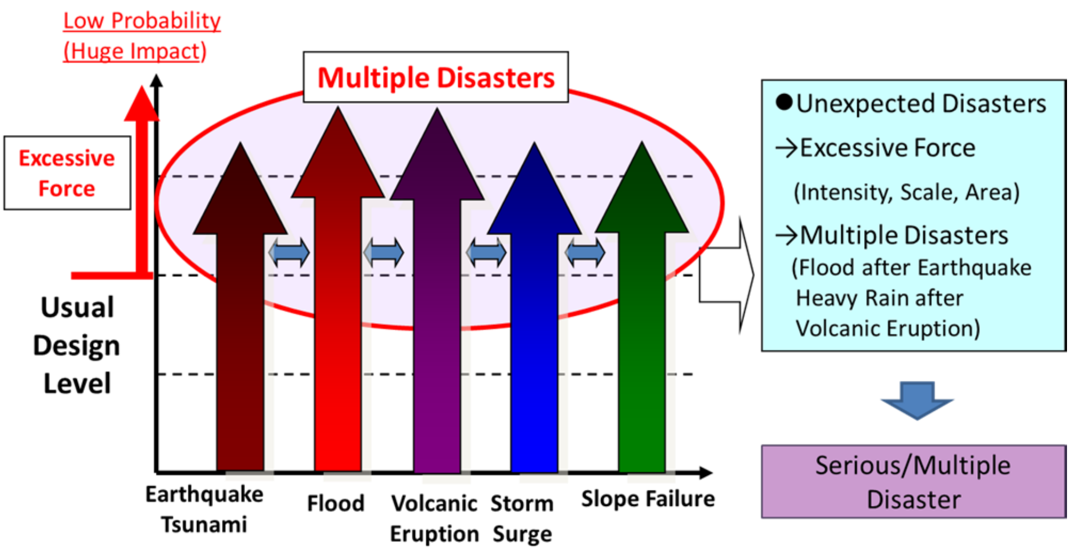

Figure 3.4.4.1 Excessive force and multiple natural disasters

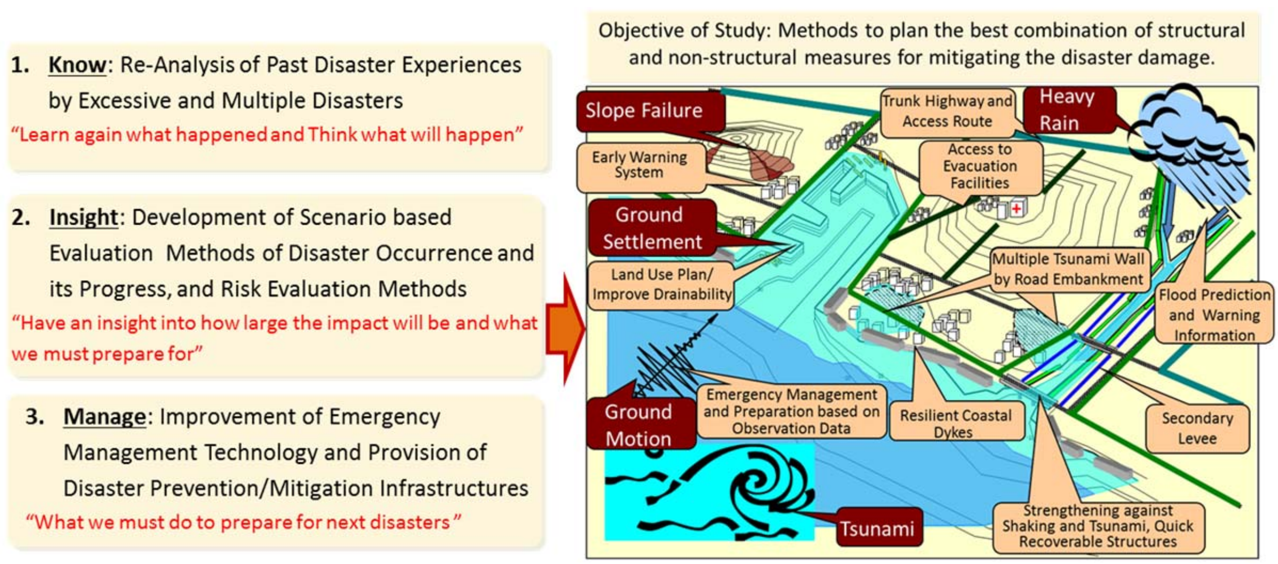

Figure 3.4.4.2 Research on crisis management for excessive and multiple natural disasters

3.4.5 Research and Development in Information and Technology Area

3.4.5.1 Research on the platform development for collecting and analyzing movement of people (FY2012-2014)

(1) Overview

The Great East Japan Earthquake caused catastrophic disruptions and interruptions in public transportations – railways, busses and others – resulting in more than 100,000 travelers (e.g. commuters, students, etc.) having difficulty returning home. The experience made us open our eyes to the importance of having a grasp of “movement of people”, e.g. the number of stranded travelers, the status of movement of people after the earthquake, and where they are accumulated. The “Recommendation on the Reconstruction Planning” drafted in the wake of the Great East Japan Earthquake stressed the need for pointing to new directions for the construction of a disaster-resilient country in the future, where the infrastructure has the pliancy and robustness to endure disasters and to maintain the capacities for uninterrupted economic and other activities.

This section presents an outline of the measures set toward the construction of an ICT (Information & Communication Technologies)-assisted information gathering/analysis platform (see Fig.3.4.5.1). The plan was launched in 2012 to provide accurate and up-to-the-moment information regarding the movement of people.

(2) Current status of movement of people gathering

“Movement of people” as stated in this section means the history recorded of the movement passages of people: who moved, the point of departure and destination, and the purpose and means of the travel. Up to the present, several modes of statistical survey – such as a person trip survey (hereafter referred to as PT survey) and road traffic census – have been implemented for grasping human mobility information, which represent only one-day data and are conducted only sparsely, on a once-in-5/10-years basis. In addition, these surveys require a large budget. Under such state of affairs, the establishment of a novel “human mobility information” survey system is highly desired, which provides a flexible and agile means conducive to grasp the immediate aftermath of the disaster.

Thanks to the progresses in ICT (e.g. GPS mobile phones, car navigation systems, and traffic smart card for railways and buses), a huge amount of extensive and up-to-the-moment digitalized information regarding movement of people has become available 24 hours a day throughout the year. Naturally, suggestions have been made to utilize it as the source of movement of people.

(3) Combination analysis of movement of people: expectations and challenges

1) Past researches

The rapid growth of big data analysis and related technologies in recent years has produced an increasing number of applications to exploit movement of people (typically in areas such as marketing, and calculations of population distribution and economic loss caused by a traffic hold-up). For example, the information obtained from the smart card data for bus travelers enabled trend visualization in the number of bus users in the regions affected by the Great East Japan Earthquake. However, it only provides the movement of people in a single mode – i.e. incoming and outgoing number of bus users – and does not give information regarding the behavior of people using plural transport means.

The National Institute for Land and Infrastructure Management has already worked on some of the issues in preparation for use in effective traffic planning (e.g. “A supporting method for bus transportation planning and effect of road improvement by using multiple trail data”[2)]), in which an effort was made to combine smart card data for bus travelers and probe car data from private enterprises. These studies have revealed many favorable effects and knowledge obtained by analyzing sources of movement of people in combination. In addition to possible achievements (expectations) gained from the combination analysis as described in the next section, the study summarized the challenges to be overcome for implementing the measures.

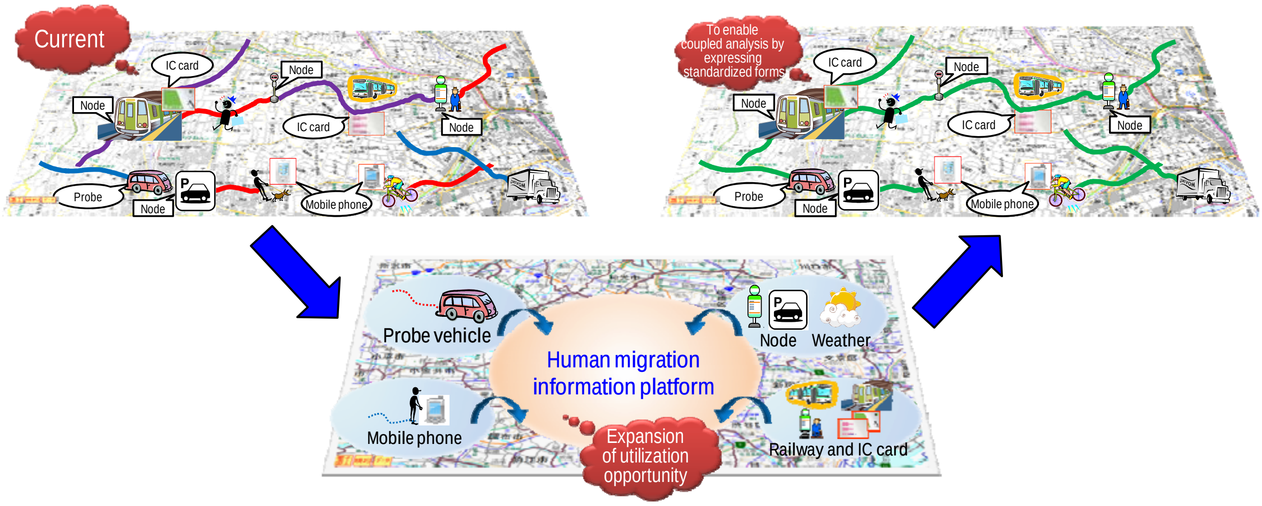

Figure 3.4.5.1 Schematic Representation of Movement of people Platform

2) Expectations for Combination Analysis

Analysis of various types of movement of people in combination enables grasping, or visualizing, the traffic behaviors (human mobility) individually in a near real-time fashion. An example of a combination analysis is the estimation of the number of travelers who had difficulties returning home due to the disaster[3], which made use of mobile phone data and PT survey data (see Fig.3.4.5.3). The mobile phone data provided "quantitative" aspects of the situation – understanding how the human flow was jammed and where people were stranded on a day-to-day and time-to-time basis. The PT survey data provided information regarding "qualitative" aspects of the situation – the purposes of travels and the means of transportation used. The approach proved effective to estimate the situation – classification of the stranded population based on their travel objectives, and the means of transportation used on a region-to-region basis – promising its applicability in disaster prevention field, i.e. support for returning home and planning of evacuation routes.

3) The Challenge of Combination Analysis

Although it seems highly likely that the combination analysis of a variety of movement of people provides a much higher level of efficiency, virtually no mechanism is in place to promote collaborative interaction among these sources, which are separately collected and managed by each organization/agency/enterprise independently. One possible cause of the situation may be ascribed to the blurred boundary between collaboration and competition in the field that is still in a growth stage, and the private sector market is very much in its infancy. As each private enterprise has its own marketing strategy, getting along under present circumstances, without a mechanism for collaborative use, will make the analysis through combined use of information sources – from organizations and enterprises on the mode of transportation basis - even more difficult.

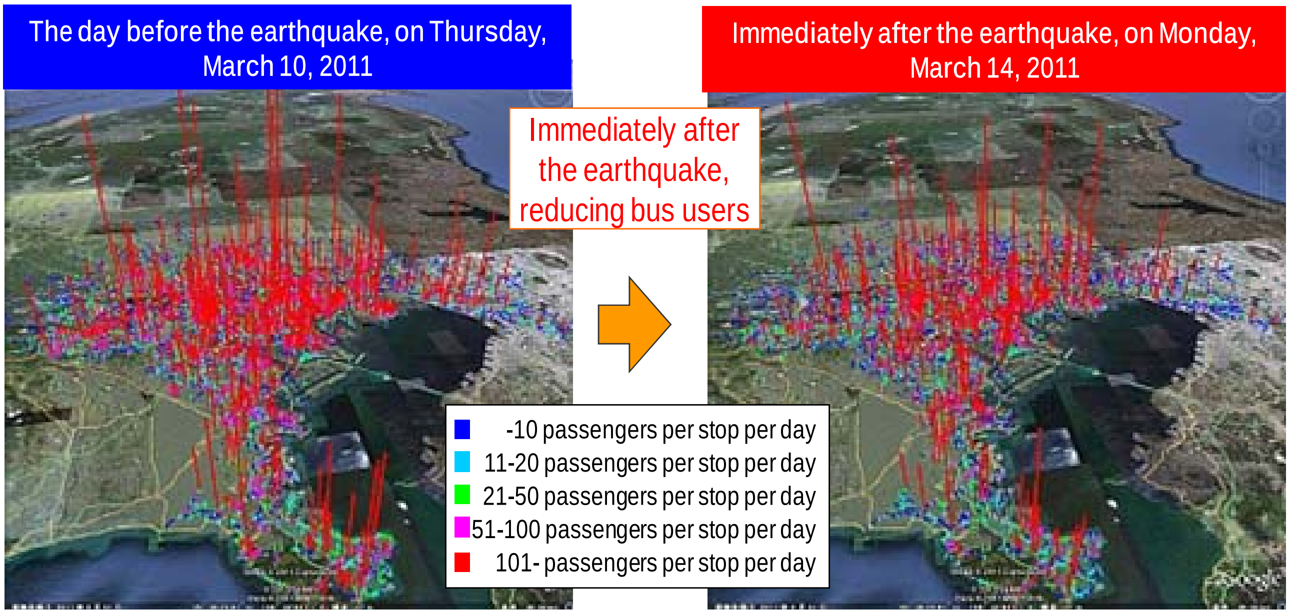

Figure 3.4.5.2 Distribution of Bus Travelers: Before and After the Great East Japan Earthquake

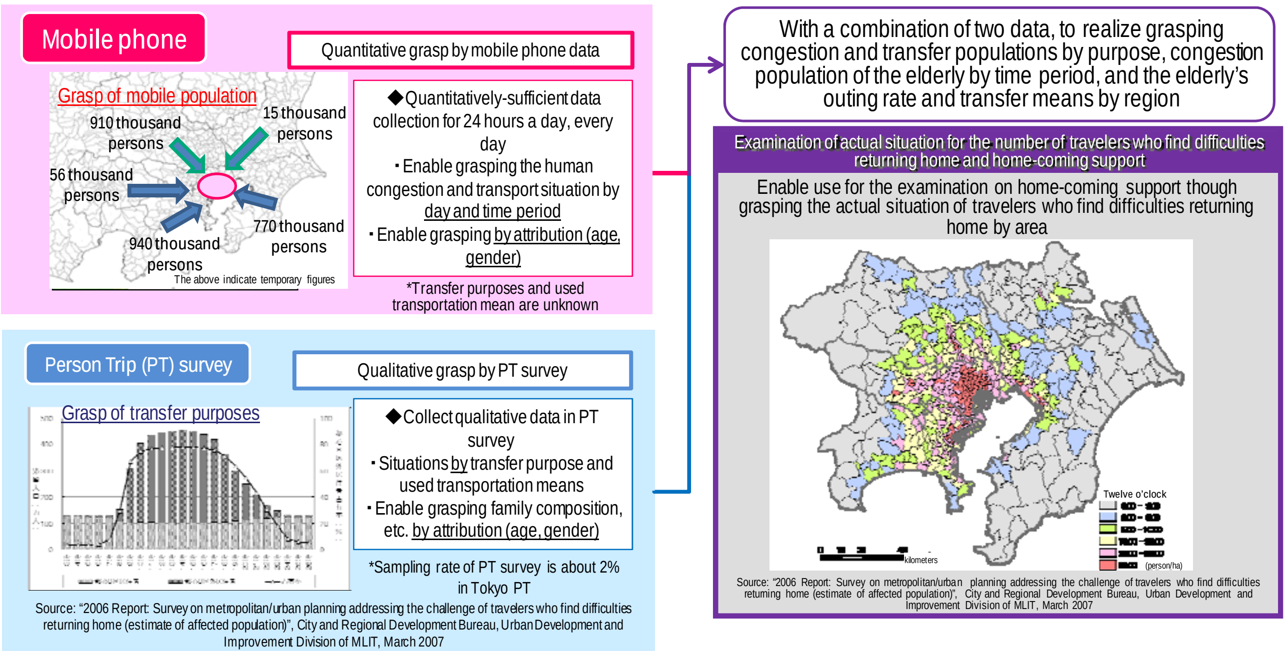

Figure 3.4.5.3 Graphical Representation of the Estimated Number of Travelers That Had Difficulties Returning Home in the Wake of the Disaster (Based on the Combination Analysis of Mobile Phone Data and PT Survey Data)

(4) Efforts toward Establishing Movement of people Platform

In light of the challenges and current status described in the preceding sections, this research aims at constructing an information infrastructure (platform) for collecting and analyzing up-to-the-moment movement of people available from ICT applications. The research project is slated to continue for three years, with the following implementation schedule for each year:

FY2012: Discussion and consultation with those organizations/agencies that own types of movement of people for the availability of the data and establishing common specifications for better exploitation, including the planning for implementation of a demonstration experiment in the next year.

FY2013: Implementation of a demonstration experiment, in collaboration with each organization/agency, for collecting and analyzing the movement of people in some model areas. The results will be evaluated for their usefulness and applicability.

FY2014: The development of a platform prototype. Institutional design, including terms of use, will be developed assuming that the system will be placed in actual operation starting in 2015.

These efforts are expected to help complement the results of current statistics surveys, and will enable, in the future, administrative services to respond more quickly and adaptively in real-time in the time of a disaster. They also contribute to establishing disaster prevention plans that address more closely to the characteristics of population groups (age, disabilities, etc.).

We forge ahead with the above-described studies continuously aiming at practical implementation of the infrastructure (platform) that addresses the challenge of collecting and analyzing movement of people.

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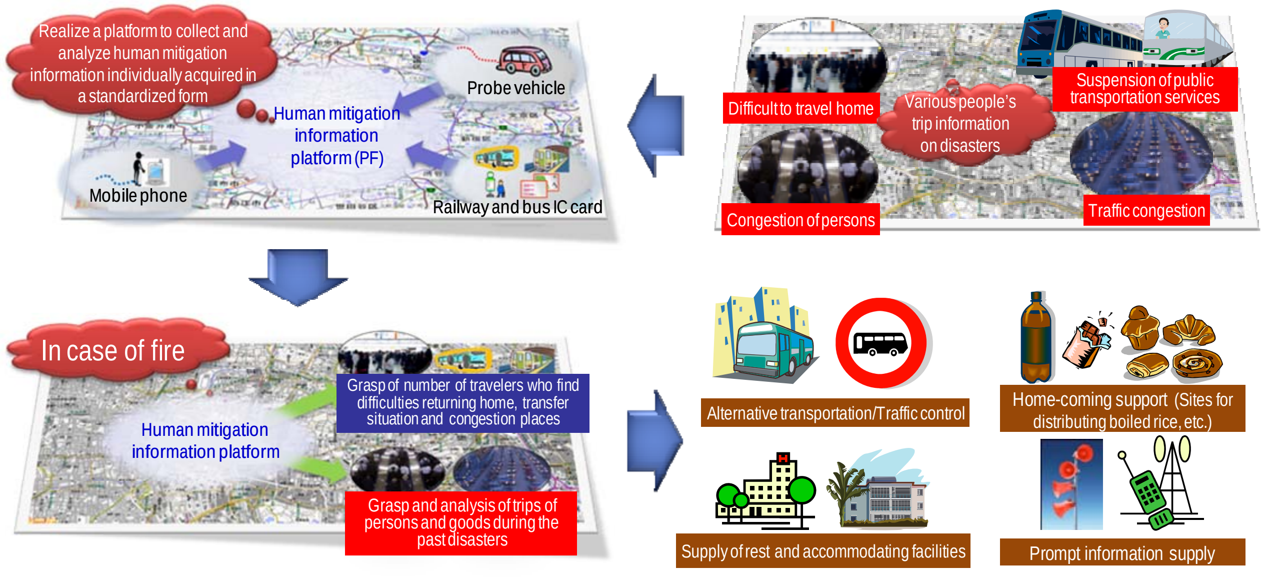


Figure 3.4.5.4 Graph depicting active use of the movement of people platform in the time of a disaster

3.4.5.2 Research on supportive use of 3D CAD data for disaster rehabilitation processes (FY2008 – FY2014)

(1) Overview

Early establishment of efficient terrain information gathering technologies and their application for rehabilitation planning have become an urgent research objective in the wake of the Great East Japan Earthquake. The relevant research areas include: grasp of the damage situation of facilities dispersed in a wide area, selection of candidate sites for provisional housing and determination of the soil volume required for their construction. To address these challenges, this research focuses on the development of technology that enables the automatic creation of 3D CAD data from existing sources of data – typically from a laser profiler (hereafter referred to as LP). In addition to disaster applications (e.g. rapid grasp of existing state of affairs and determination of soil volume and materials required for restoration works), the research also aims at establishing a method of 3D CAD data utilization at normal times, for example, computerized construction and stream management.

This report describes, as the first in the series, the results from practicality verification for 3D CAD data generation from LP data and a comparative case study pre- and post-disaster analysis of Kitakami River's downstream basin using 3D CAD data.

(2) 3D CAD data generation technique using LP

This section reviews the technique to generate 3D CAD data using LP data. The technique features the ability to automatically generate 3D CAD data for accurate trace of terrain profiles "as is" using the point cloud data provided by LP, by extracting border lines (or, break lines) where a river bank's levee crowns and slopes meet and terrain altitude changes.

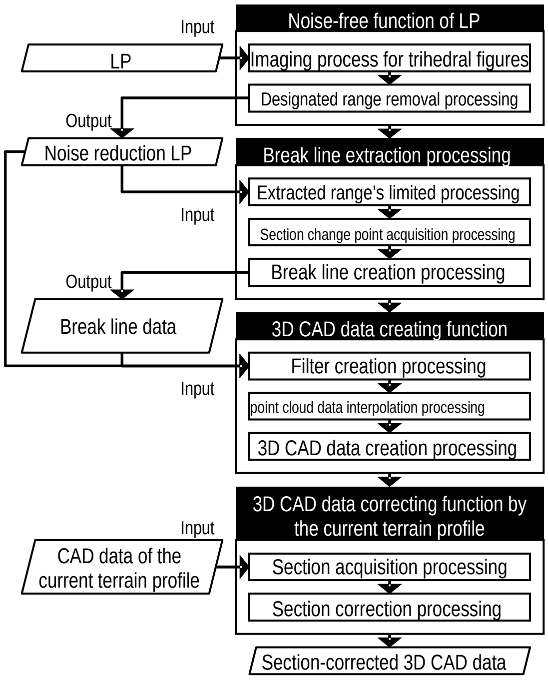


Figure 3.4.5.5 Steps to create 3D CAD data

Figure 3.4.5.5 shows 3D CAD data generation procedures using the novel technique. The first step is to remove outliers (noises) from the LP point cloud data – e.g. vegetation, etc. Then, break lines are extracted from noise-free LP data. The novel technique automatically extracts signature points characteristic of the profile from LP data using these as a clue, and determine the break lines (see Fig.3.4.5.6). Finally, LP data and the break lines are combined to generate TIN (Triangulated Irregular Network), resulting in the creation of 3D CAD data that trace the current terrain profile. The technique also support editing the 3D CAD data using information gained from measured lateral profiles. In comparison with conventional techniques, the one reported here provides 3D CAD data capable of tracing current terrain profiles much more accurately (see Fig.3.4.5.7). Note that this report does not intend to cover all aspects of the technique: see references [1) - 3)] for the details of individual functions.

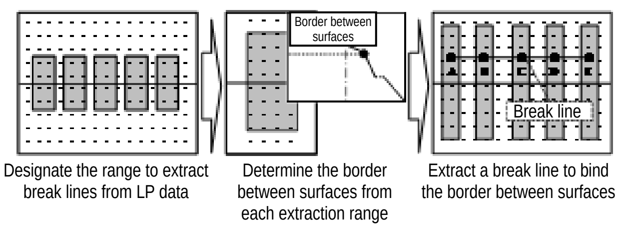
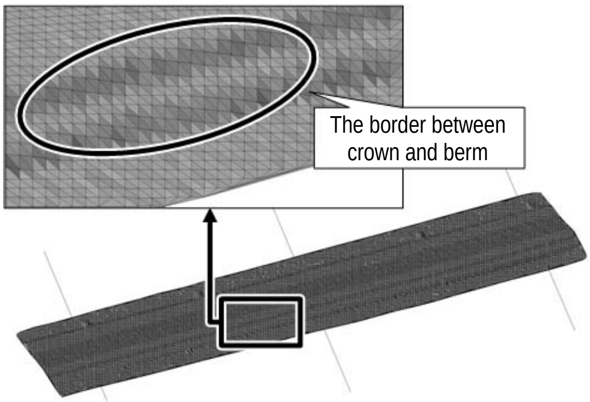
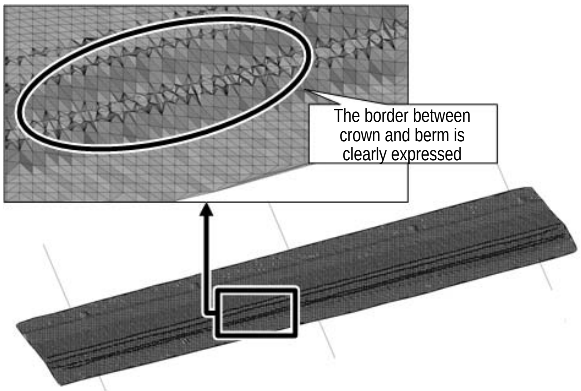


Fig.3.4.5.6 Break line extraction procedures



a) Creation of 3D CAD data by conventional methods



b) Creation of 3D CAD data by new technology

Figure 3.4.5.7 Comparison of 3D CAD data: new and old method

(3) Analysis using the pre- and post-disaster 3D CAD data: a case study

This section describes the results of a case study, in which pre- and post-disaster terrain profiles - traced based on the 3D CAD data rendered from LP data using the new technique - were used to evaluate the level of damage caused by the disaster (e.g. extraction of heavily damaged locations). The objective of the study was to evaluate the effectiveness of this technique for grasping the situations in the affected areas rapidly and accurately immediately after the disaster, and whether it is capable of providing useful information for disaster rehabilitation.

1) Target area and LP used

To reflect the post-disaster situations, the three criteria listed below were set for selecting target areas. In addition, existing sets of documents, including the flooding area map, were examined as along with the knowledge gained through performing on-site explorations. Based on these preliminary considerations, the target of this study was defined as the area, stretching over 1,800m, shown in Fig.3.4.5.8. Note that the flooded area map, provided by the Geospatial Information Authority of Japan, is overlaid onto the figure.

・ A flooded area in the downstream of Kitakami River
・ A location severely affected by the disaster
・ A location that require urgent rehabilitation because of a heavily deformed dike

The 3D CAD data was generated from two sources of information: pre-disaster LP measurements combined with the aerial LiDAR data conducted for river improvement evaluation, and post-disaster LP measurements combined with the aerial LiDAR conducted by the Geological Survey Institute in the wake of the Great East Japan Earthquake.

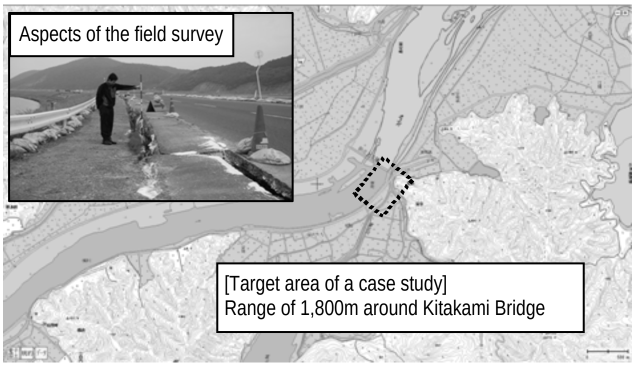


Figure 3.4.5.8 Target area of the case study

2) Comparison between pre- and post-disaster 3D CAD data

In this analysis, two sets of 3D CAD data – one for pre-disaster and one for post-disaster terrain – are superimposed for visualization, and are examined if the locations with possible damages or with large geological changes can be identified through visual inspection. Fig.3.4.5.9 shows two aerial views (before and after the disaster) and a superimposed representation of pre- and post-disaster 3D CAD data. The dike shape in two areas in the figure, labeled A and B, shows significant changes before and after the disaster. Further examination around the dike reveals that the dry riverbed near the dike, labeled B in the figure, is inundated. Pre- and post-disaster surface geometry in the area C show changes due to piled rubble. The above-described observations clearly indicate the effectiveness of the technique, i.e. superimposed drawing of pre- and post-disaster 3D CAD data and aerial views enables easy identification of locations that may have suffered large changes in terrain profile.

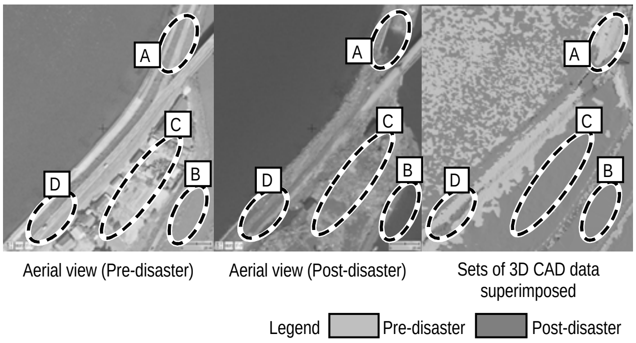


Figure 3.4.5.9 Sets of 3D CAD data superimposed

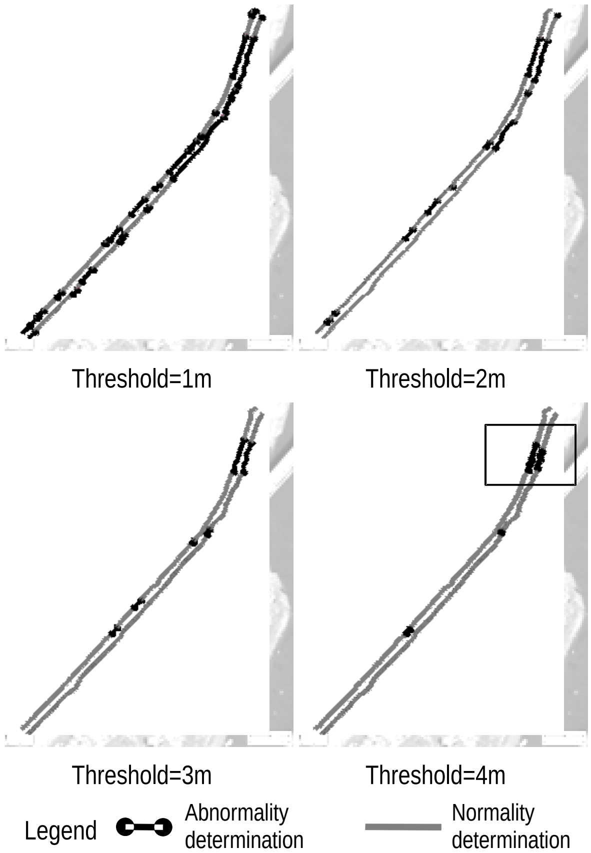


Figure 3.4.5.10 Damaged locations along the river bank

3) Comparison of arbitrary shape cross-section: before and after the disaster

Although no mention was made in the previous section (2), the new technique additionally features comparison of pre- and post-disaster break lines, enabling determination of affected locations from the level of displacement among break lines (i.e. detection of candidate locations for further analysis) [4]. Fig.3.4.5.10 shows the damaged locations detected by this function.

In this analysis, an attempt was made to compare the break lines before and after the disaster for their degree of displacement from small to large, which was considered to represent the severity of the damage.

As the river dike under review in this research has a typical convex shape with the tops of slope on both sides of the levee crown, two break lines were used to detect potentially damaged locations. In-depth examination of these locations revealed that a certain deformation length (4m in this case) provides a good threshold to distinguish large and small damages. The area enclosed by a rectangle in Fig.3.4.5.10 shows the severely damaged area, where urgent rehabilitation work was done under the initiative of the river administrator [5]. To verify if the damaged locations were properly detected, cross-sectional profiles of damaged and undamaged locations shown in Fig.3.4.5.11 were generated: the cross-sections B, C, D (severely damaged) and cross-section A (unaffected) are shown in Fig.3.4.5.12. Aerial views of two of these locations, before and after the disaster, respectively, are also shown in Fig.3.4.5.13. Examination of these figures indicates:

・ The lateral profile of location A is substantially identical before and after the disaster, and the dike around it maintained its levee crown shape almost unaffected. The aerial view around this location (upper two in Fig.3.4.5.13) also suggests preservation of the road and dike structure, despite the pile of rubble. These observations clearly indicate that the method is capable of identifying unaffected or slightly affected locations.

- The cross-sections B and C indicated changes in levee crown shapes, and especially the deformation of the top of slope, facing inward toward the dike, was substantial. This indicates that the method correctly detected local damages.
- The shape of lateral profile D showed significant change before and after the disaster, as also evidenced by the pre- and post-disaster aerial views around it. A close look into the aerial view around the location D (Fig.3.4.5.13) reveals large-scale deformation in the dike geometry. Actually, the area around the location D was found to have concentrated damages to where urgent rehabilitation works were implemented. This indicates that the method is capable of detecting the locations where the dike geometry underwent substantial localized deformation.

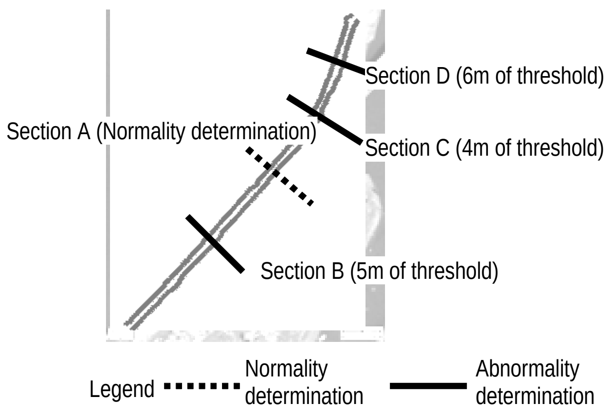


Figure 3.4.5.11 Damaged locations where lateral profiles were made

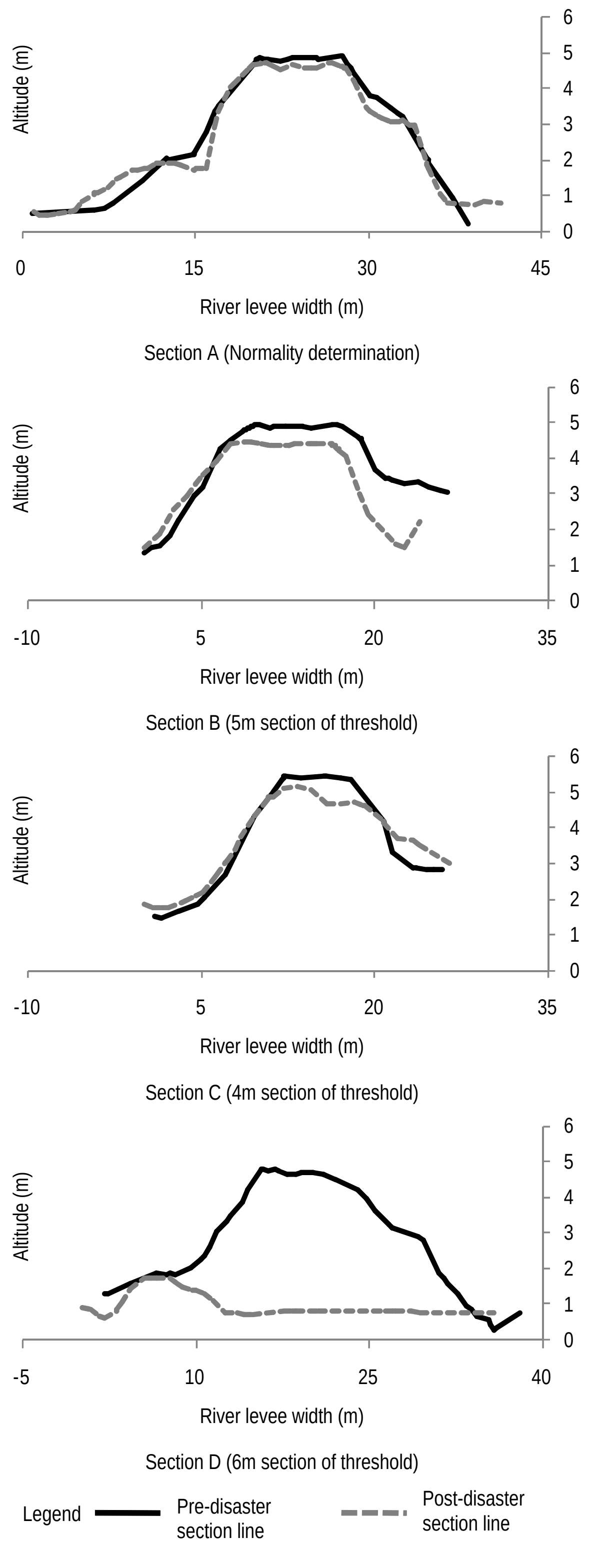


Figure 3.4.5.12 Four lateral profiles indicating varied degrees of damage

3) Differences in soil volume inside the dike: before and after the disaster

In this analysis, an attempt was made to verity if the method is capable of estimating the soil volume required for rehabilitation work. For this purpose, two sets of 3D CAD data – before and after the disaster - were generated by using the 3D CAD data generation function, and the data were analyzed along the river level to determine the difference in soil volume inside the dike. We used the soil volume calculation function of AutoCAD Civil 3D in this research, and it worked out the required values without major difficulties.

The results indicated that the rough amount of soil required to restore the pre-disaster dike can well be worked out, even in the wake of a large-scale disaster that may have accompanying crustal variations, suggesting possible use of these results as the basis for estimating the scale and cost of the rehabilitation works. Note that the calculated results were not compared with the soil volume actually used in restoration works, disabling accurate estimation of the calculated soil volume. Therefore, the calculation results are not presented in this report.

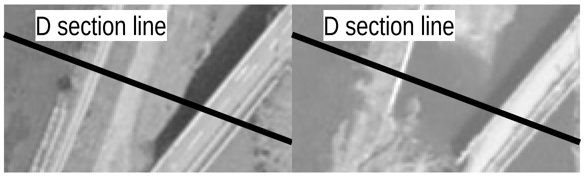


Figure 3.4.5.13 Aerial views: before and after the disaster

(4) Summary

This research focused on the method to generate 3D CAD data from an existing mass of data – typically those from laser profiling (LP) – and examined how they can be fully exploited. This report, the first in a series, describes practicality verification of the new technique (i.e. generation of 3D CAD data from LP data) and the results obtained so far from a case study targeted on the downstream basin of Kitakami River – 3D CAD data based examination of pre- and post-disaster terrain features.

Practical utility of the new technique was examined, and the results obtained through this technique proved to have accuracy on a par with the data currently in use in river projects (e.g. survey data). The following sets of knowledge were obtained through a case study that used pre- and post-disaster 3D CAD data, confirming versatility of the technique in a broad range of restoration works.

- The long shot view gained through this technique makes the grasp of terrain situations easier - surface deformation of dikes, spotting severely damaged locations, etc.
- 3D CAD data allows easy generation of lateral profiles at an arbitrarily selected location, enabling examination of important items including the changes of dike geometry, varied rate of ground subsidence, etc. These sets of knowledge contribute to rapid rehabilitation planning and setting up of construction work management.
- The new method makes quantitative estimates of damage situations easier (e.g. soil volume washed away by tsunami), enabling early grasp of the scale of restoration works (quantity survey).

Subsequent research, from FY2012 to FY2014, focuses on an automatic generation method of 3D CAD data using existing LP data, whereby the achievement presented here provides the starting point. It also aims at expanding the scope of applicability to other structures in addition to river dikes. The research will be conducted, in collaboration with regional development bureaus, with a view toward effective applications of 3D CAD data in information assisted construction and river management, leading finally to the construction of a platform for active and flexible use of existing information sources and assets in times of disaster, as well as during normal periods.

The content of this report is based on the achievements gained through the collaborative studies conducted by the researchers in the Kinki Regional Development Bureau (Ministry of Land, Infrastructure, Transport and Tourism), Kansai University (Prof. Shigenori Tanaka), and the National Institute for Land and Infrastructure Management.

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3.4.5.3 Research on the management method of buried debris using computer aided construction technology (FY2011-FY2012)

(1) Objectives and history of the research

Disposal of the enormous pile of debris in the wake the Great East Japan Earthquake (March 11, 2011) poses urgent and serious issues in the affected areas.

The approaches now under review include reclamation of debris for use as construction materials for such purposes as embankment. This approach, however, requires a management mechanism that ensures seamless monitoring throughout the process – from collecting information on the nature of the debris to long-term maintenance strategy after burial in the ground debris may contain substances different from conventional soil and is rendered invisible after the filling work has completed. The National Institute for Land and Infrastructure Management (NILIM) has been conducting researches on as-built measurement techniques using computer aided construction technology, typically TS (Total Station: a 3D surveying instrument) that is finding increasingly wide applications in earthworks. This technology, with 3D design data (3D shape information on completion) implemented in TS software, improves the efficiency of construction procedures: (1) easy navigation to a measurement position, (2) on-site display of deviation from design values, and (3) automatic report generation using measured data.

NILIM has already worked out the proposed plan “the data exchange standard for TS-assisted as-built measurement” (hereafter referred to as the “data exchange standard”), which defines specifications of “construction control data”, i.e. 3D design data and measurement data. The data exchange standard has been updated to Ver.4.0 in September 2011. In contrast to Ver.2.0, which contains only the data items directly related to earthworks, the revised version has the capacity to contain such additional information as: data relating to pavement and underground installation, date and time of measurement, and nominal designation of the work.

This research focuses on the method to facilitate management of underground burial of debris and other materials, where the as-built measurement technologies using TS (especially those implemented with the new data exchange standard, Ver.4) are brought into full use.

(2) Concept of buried object management using TS-assisted as-built measurement technology

In management of buried objects, the capacity to grasp positional information is highly desirable because they are invisible from outside after

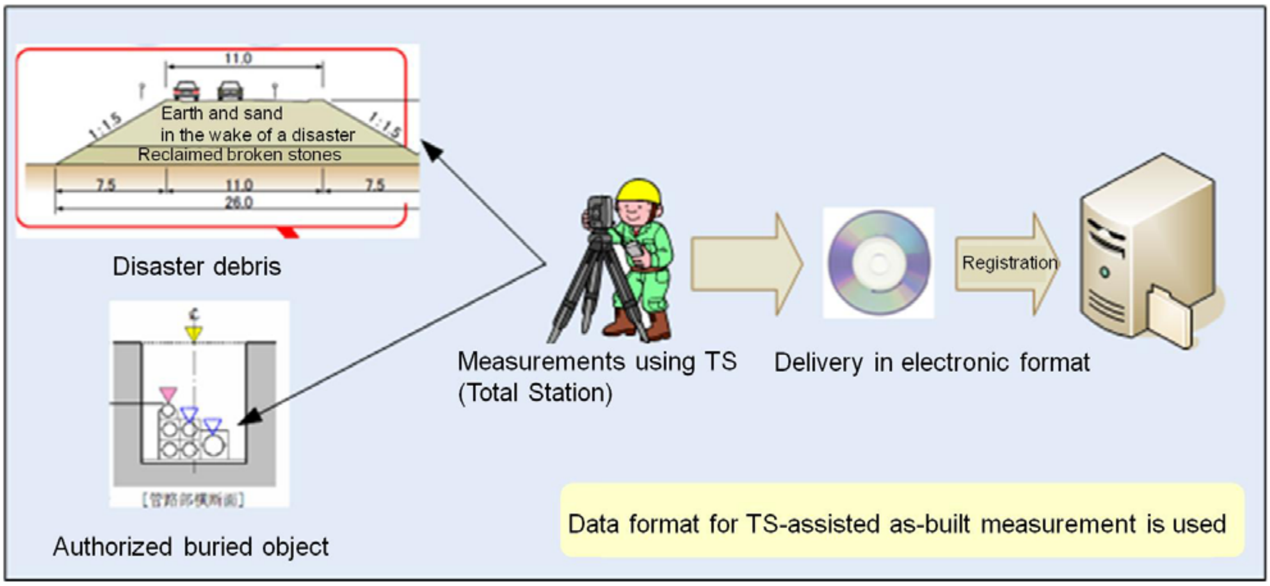


Figure.3.4.5.14 Work flow of burial object management

completion of the work. Their positions are usually determined by examining the drawings prepared at the time of burial work, but it often involves an additional task of writing in new information to the finished drawings. In addition, as conventional practice entails storage of information on a work-by-work basis, sets of separate documents are generated even for the burial works done next to each other if they are implemented separately, necessitating cross-reference of multiple documents for later use. As-built measurement is a requirement in every civil engineering work, and application of TS on as-built measurement of underground burial works is considered conducive to gain accurate positional information (i.e. high precision 3D coordinates) of buried objects. Higher efficiency is in sight if the information useful for post-construction operation and maintenance is added to the data set, enabling unified management of the buried objects.

(3) Requirements review of burial object management software

Based on the conceptual description in (1), a review was made on the functional requirements of burial object management software that uses construction control data. Required functions for this software are:

①Data registration function

This function allows registration of information required for the management of burial objects.

In the case of government's works, the data is delivered as a set of CDs. The software automatically extracts the relevant files from the CD and register them with the system. Proper management of buried objects requires, in addition to their locations, a set of auxiliary information such as the work designation and the person in charge. However, the construction control data contains only the information directly related to construction works (e.g. shape, measurement time, etc.). Therefore, additional functions were implemented to register these data in a CSV file. For easy operation for anyone to use the function, an input sheet (Excel macro) is provided to help create the CSV file. The function also provides room for addition/modification of input item definitions to accommodate itself to the management requirements – debris often defy standardized set of data items for management because of its unpredictable nature and shape.

②Data search function

This function allows the manager to retrieve necessary information to make full use of the data. It must provide a variety of searching functions using such keys as: by name, by manager, as well as by pointing to a location on the map.

The map search function allows, by pointing to a location on a map, creating the list of all objects buried on that spot, and selecting an object in the list will display all the detailed information registered for it. The construction control data allow 3D graphic display as well as data output, and the data is portable for writing in an on-site TS, enabling easy navigation to the spot where the object is buried.

(4) Summary

As described above, application of TS-assisted as-built measurement on underground burial works is expected to streamline the procedures in burial object management. Continuous research efforts – typically learning through trial and error in laboratories - will be needed to bring this technology into active use. In parallel with this, proactive field use of TS in as-built measurement is highly desirable, especially on the burial objects that may require continuous management into the future: the data thus gathered will constitute a valuable asset for future operation and maintenance.

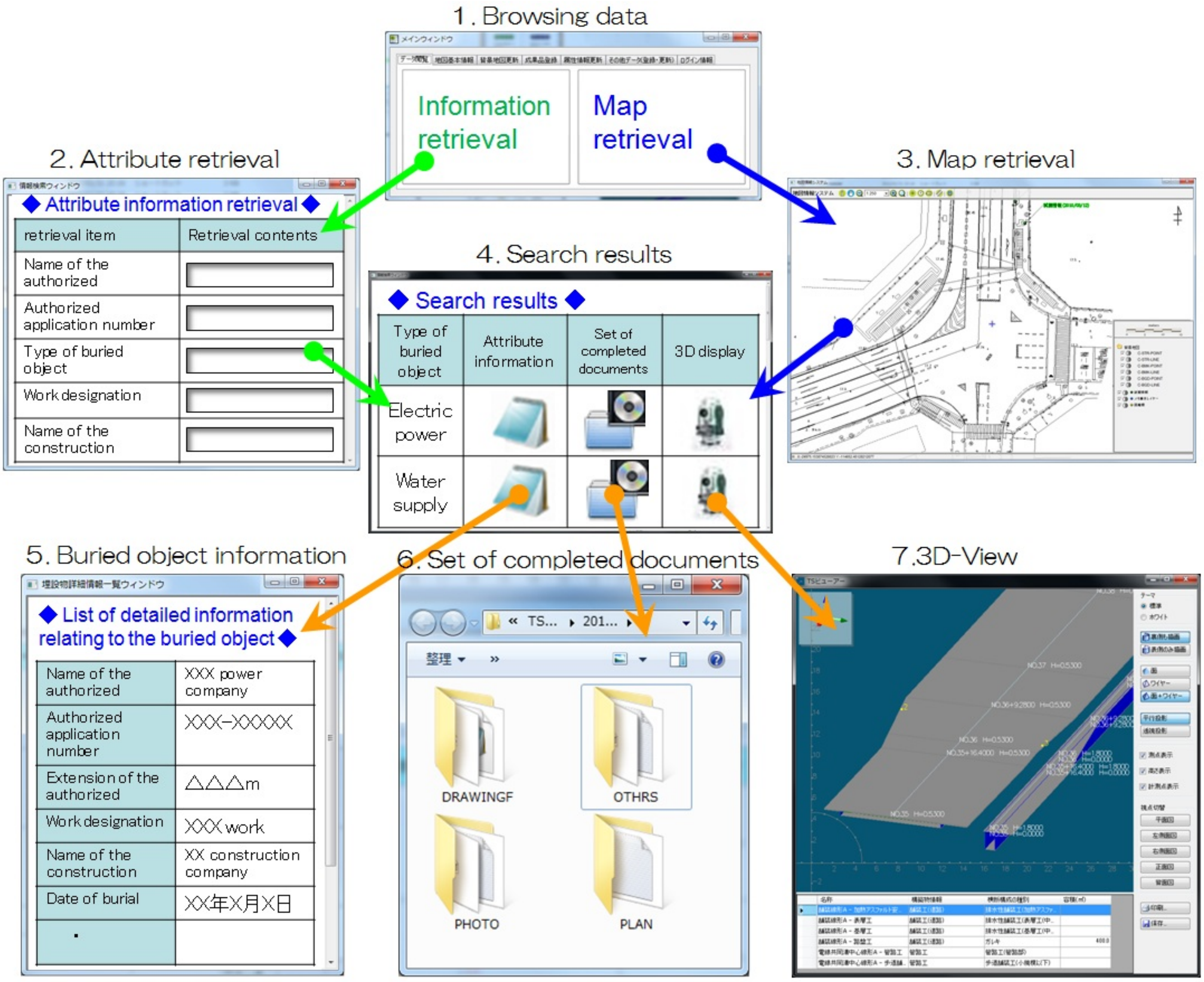


Figure.3.4.5.15 Flow of operation: Burial object management software

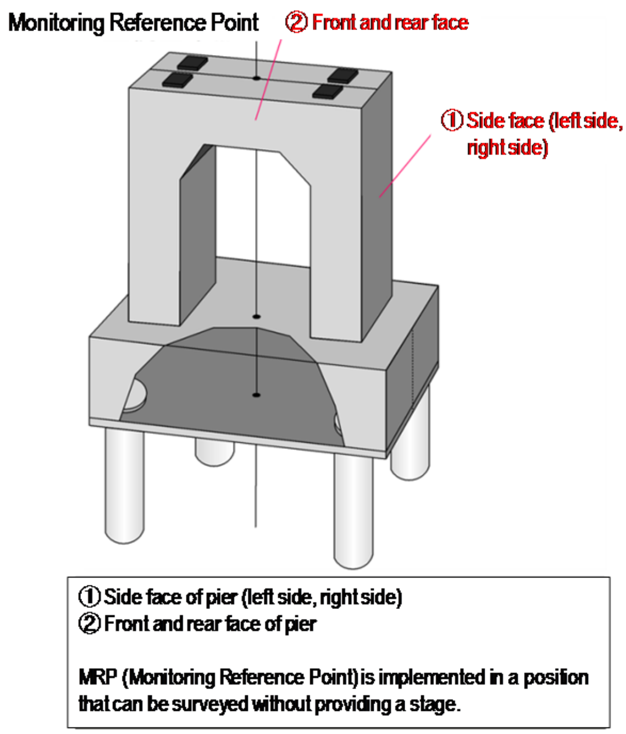
3.4.5.4 Research on Bridge Monitoring Technology using 3D CAD Design Data (FY2009 –FY2013)

(1) Research objectives

CALS/EC is a system aiming at establishing a seamless chain of data, through which each phase –from survey, design, construction to operation and maintenance – inherits necessary information from the upstream phases. The data distribution mechanism currently in place – from design to construction, operation and maintenance - is based on the exchange mechanism of 2D CAD drawing data. 2D CAD data, however, presents three-dimensional structures using a set of plane, longitudinal and lateral drawings, and is not capable of directly handling 3D data required for efficient construction, operation, and maintenance purposes. To address the current state of affairs, researches are under way to promote the flow and common use of 3D data, especially in the area of bridge design where 3D design and construction have already shown a certain level of progress. As part of these efforts, we carried out a study to promote effective use and distribution of 3D data in the time of disaster.

A disaster such as an earthquake or landslide can give rise to displacement and torsion of the base and upside of a bridge. These abnormal events, however, may remain unnoticed unless apparent damages are visible, though they can exert detrimental effects on the basis and superstructures. Therefore, displacement and translation must be determined after the occurrence of a disaster.

Certainty cannot be ascertained with regard to the displacement and torsion of a bridge if the initial positions are unclear. Therefore, we propose to measure and monitor 3D coordinate values of initial positions at the time of completion of a bridge. Our research is in progress toward establishing practical technology to implement these procedures. An attempt was made to verify the technology by applying it to the post-disaster situation in the wake of the Great East Japan Earthquake. The following section describes the interim findings from it.



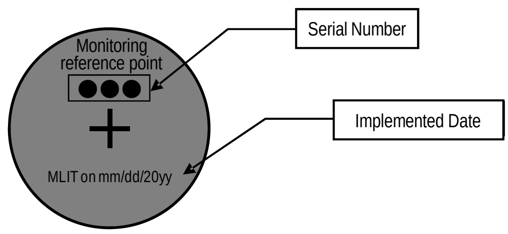


Figure 3.4.5.16 Implementing a Monitoring Reference Point

(Upper: Monitoring Reference Point placement, Lower: Survey rivet)

(2) Monitoring reference point

The experts in bridge construction have pointed out the importance of defining reference points (3D coordinate values) for continuous displacement monitoring and consistent migration of information from the construction stage to the operation/maintenance stage. In this report, we call such reference point a monitoring reference point.

A monitoring reference point represents a set of positional coordinates that should be handed over throughout the life of the structure – from construction to operation and maintenance. A set of monitoring reference points is defined in strategic spots in the bridge structure to enable early grasping of damage it suffered from a disaster.

(3) Implementing a monitoring reference point

Metallic rivets are implemented at visible strategic points – selected from the viewpoint of easy measurement of displacement, inclination, and contortion. Determination of these positions requires careful consideration on a site-by-site basis: lower positions may be hidden by plant exuberance with time, and higher positions may require a scaffold for precision measurement.

(4) Survey method

The survey for implementing observation reference points should be based on the data gained through the use of high-precision, reflecting prism Total Station.

However, the survey in the immediate aftermath of a disaster may involve danger to the operators: setting up a prism at the monitoring reference point without an adequate scaffold may require work in high places (at the top of the bridge). Evaluation of structural damage in the wake of a disaster, if the level of structural displacement is around 10mm or less, can well be done with the non-prism TS (survey precision approximately ±5mm) without causing serious compromises. From these considerations, a non-prism TS should be the basic tool for surveys conducted after disaster.

(5) Generation and distribution of data at a monitoring reference point

As a method to secure shared use of information, we propose to add the survey data of finished work – typically the monitoring reference points– to the bridge coordinate maps. The proposal represents a delivery method of job completion documents electronically, and relates to preparing a drawing that includes positional reference points (3D coordinate values) of the structures, which were handed over from the design stage to construction works. Additional writing of the surveyed monitoring reference points into the drawings constitutes an essential step of this process. This scheme brings certain advantages. For example, the contractor can easily and consistently generate monitoring reference point data from the drawings, and store the modified drawings as the job completion documents for long periods.

1) Use of a skeleton model

The skeleton model is a wireframe 3D modeling of structural reference points (handed over from the design stage to construction work) and installation reference points (handed over from the construction state to operation and maintenance) connected together. A skeleton model features 3D visualization, enabling display of the level of displacement at MRPs visually.

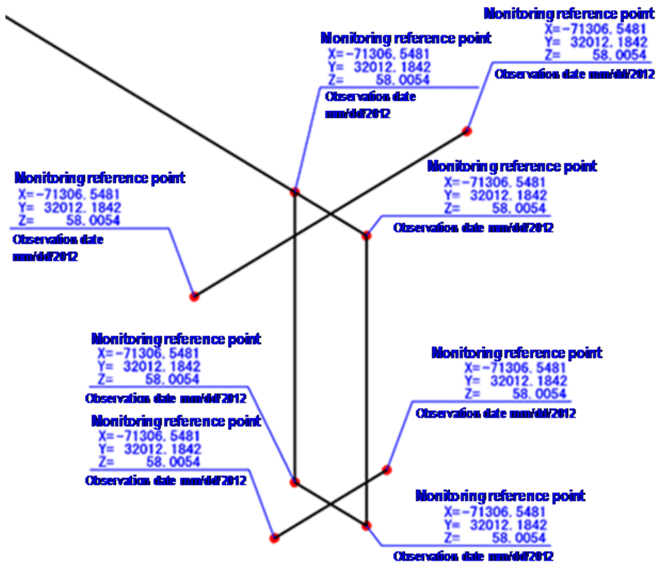


Figure 3.4.5.17 Skeleton modeling of MRP

2) Use of 3D outline model

Using 3D CAD effectively for the design of the outside shape of a bridge will be beneficial in many aspects: easy understanding of complex structures through visualization, prevention of design errors, easy selection of construction steps and procedures, and reduction of failures and moving back and forth through the steps. Consistent use of the external shape model produced in the design stage, with explicit representation of structural and monitoring reference points embedded in it, will enable visually understandable data management.

(6) Application case study in the wake of the Great East Japan Earthquake

In 2011, a survey was made again on the MRPs implemented in the interchange bridge structures of the Metropolitan Inter-city Expressway Heizogawa

Bridge (Chiba National Highway Office) to create a skeleton model to evaluate its utility for grasping changes in the entire bridge structure - displacement, contortion, etc. (The monitoring reference points were implemented, in 2010, as part of "FY 2010: Auxiliary task for utility evaluation of 3D data used in bridge construction works")

On-site survey and close examination of the data gained through the past survey revealed the loss of temporary benchmarks and reference points (used for observing MRPs), though the monitoring reference points were confirmed, by visual observation, to be "normal". Following this, a survey was conducted anew to define reference points and temporary benchmarks.

The monitoring reference point survey measurements included displacement examination of class-3 reference points (used as known reference points) caused by the crustal movement induced by the Great East Japan Earthquake (2011). The results were used to correct the coordinate values measured this year (post-disaster measurement). The skeleton (3D) model thus created using the results from the monitoring reference point survey is shown in the figure.

Based on the survey results on monitoring reference points, types of displacement detected in the bridge are summarized as below:

- The bridge, in its entirety, was displaced approximately 17cm southward, and sank 5 to 12 cm in the aftermath of the earthquake-triggered crustal changes.
- Relative displacement between each abutment base and the bridge structure was more or less naught, exhibiting no serious wrecks in abutments and bridges and deformation of the bridge as a whole.
- The skeleton model created from pre- and post-earthquake monitoring reference point measurement has demonstrated its capacity to keep track of the bridge status.

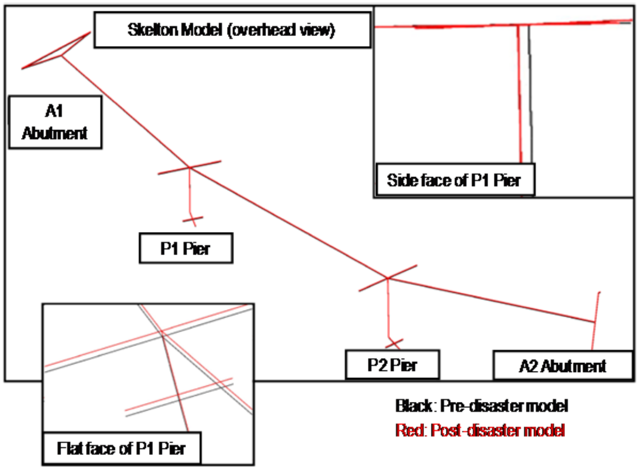


Figure 3.4.5.18 Displacement examination using the skeleton model

(7) Summary

This study focused on the method of implementation and measurement of monitoring reference points, and how we can facilitate migration of the data obtained from them. On-site examinations were also performed to confirm validity of the method.

The results obtained from these examinations well demonstrated practical utility of the method, and the opinions from the personnel in the Regional Development Bureau who cooperated in these examinations strongly support the need and validity of monitoring reference points.

Following the validity verification of monitoring reference point implementation, a set of operational guidelines (a plan) was designed based on the knowledge gained from the study, and is being placed in on-site practice for review. In the next stage, we will clarify the effectiveness and problems of the method through on-site practices, in view of further development and widespread use in the future.

4. Lessons learned and Future Tasks Concerning Disaster Countermeasures and Risk Management

In July 2012, just over a year after the Great East Japan Earthquake, NILIM formulated and published its Research Policy.

Intended to ensure that each and every staff member at NILIM shares a common understanding of NILIM's mission and the direction and perspective of its research activities, the Research Policy clarifies the technical and policy-related topics that should be dealt with and the research objectives of doing so, as well as setting forth the approach to research that should be adopted in order to achieve the Institute's goals.

In light of our experience of immense damage due to the Great East Japan Earthquake and discussions concerning the lessons to be learned from this, the policy includes research issues that should be dealt with swiftly, as a priority. Initiatives have already commenced in relation to the objectives of "achieving a safe and reliable society", "achieving a society in harmony with the environment", and "establishing comprehensive methods of supporting land and infrastructure management" set forth in the policy. From among the technical and policy-related topics aimed at achieving these objectives, the following provides an overview of the topics related to contingency planning against an earthquake disaster and risk management, the research goals thereof, and the status of research in these areas at present.

(1) Research on Risk and Crisis Management Strategy against Excessive and Multiple Natural Hazards (see Chapter 3.4.4)

As well as triggering a major tsunami far in excess of conventional assumptions, the Great East Japan Earthquake, which occurred on March 11, 2011, resulted in strong tremors over a wide area ranging from the Tohoku to the Kanto regions, causing extensive, catastrophic damage. Furthermore, subsequent flooding and landslides due to storms including Tropical Storm Talas (Typhoon No.12 in the Japanese classification system) and Typhoon Roke (Typhoon No.15) compounded the disaster, as they occurred while the damage from the earthquake was still very much in evidence. In light of such lessons, the top priority is to build the highly resilient national land that can protect the lives of the people and maintain the minimum-necessary level of socioeconomic functions even under natural hazards on a scale far beyond conventional experience and assumptions, as well as complex hazards involving a combination of earthquake, tsunami, flooding and landslides. In addition to developing methods of constructing disaster scenarios focused on major hazards due to excess external force and complex hazards, and methods of analyzing the risks and impact of these, this research will propose risk management measures that combine structural and non-structural measures to minimize the consequences of disasters, as well as approaches to the development and management of core disaster prevention infrastructure to ensure that these measures function reliably.

(2) Research on Multiple Defense Systems for Tsunami Disaster Mitigation (see Chapter 3.4.2)

In response to the Great East Japan Earthquake, the Japan Society of Civil Engineers proposed dividing the external forces from tsunami into the tsunami protection level and the tsunami disaster mitigation level. The former is used to design measures of perfectly protecting both human life and property by such means as coastal dykes, while the latter is for the design of multiple defense systems focusing on protecting human life via structural measures in combination with non-structural measures such as resilient city planning and evacuation preparation. Accordingly, this research project involves (i) summarizing the lessons concerning tsunami countermeasures that were learned from the recent disaster; and (ii) summarizing methods of setting tsunami external forces for the two levels. In addition, it involves (iii) analyzing the factors contributing to tsunami damage to coastal dykes, considering construction methods to strengthen dykes to a certain degree, so that they will not collapse easily even if tsunami overtopping occurs, and reflecting the outcomes of these studies in repair and reconstruction work. Furthermore, the research encompasses (iv) providing support for deliberations concerning city planning aimed at reconstruction and the development of disaster prevention infrastructure that also takes into account the possibility of river tsunami runup; this support takes the form of compiling a guide featuring standard methods of simulating inundation resulting from both levels of tsunami. Moreover, additional research objectives include (v) putting in place standards regarding structural requirements for tsunami evacuation buildings; developing a system for the provision of information that envisages the area and depth of tsunami inundation and can be useful in making decisions about issuing evacuation advisories; and developing a simulator that can evaluate evacuation safety and areas that constitute obstacles, as well as methods of formulating urban plans that make use of this simulator.

(3) Methods of Envisaging Damage Due to a Large-scale Earthquake and Measures Focused on Prevention, Emergency Response, and Recovery

In the event of a large-scale earthquake, it is envisaged that various events would occur that could be a major obstacle to the evacuation of citizens and the provision of emergency support, such as the destruction and collapse of road structures and buildings alongside roads due to the effects of seismic motion or tsunami, as well as the blockage of roads by rubble and vehicles abandoned on the road. This research focuses on establishing methods of envisaging the degree to which road transport functions would be reduced by such events and the damage that these reduced transport functions would cause. It also seeks to use these techniques to propose measures to prevent earthquake damage, emergency measures to be implemented in the aftermath of a quake, and effective methods of implementing recovery measures.

Moreover, in the event of a large-scale earthquake involving a large amount of damage over an extensive area, whereas there is likely to be a prolonged information hiatus until data on checks on infrastructure can be gathered, a swift initial response is absolutely vital. This research seeks to develop methods of estimating reasonably precisely the extent of the damage to facilities within the relevant jurisdiction, based on strong motion records obtained from a network of seismographs, in order to ensure that this information hiatus in the immediate aftermath of an earthquake is as short as possible, and speed up the initial response. It is also aimed at proposing a method for providing information tailored to the circumstances in which the results of damage estimates will be used, such as the consideration of extensive support measures by the Disaster Response Headquarters.

(4) Project Implementation Measures That Contribute to Improving Community Disaster-resistance

In order to ensure that soft measures such as warnings and evacuation are sufficiently effective in avoiding and reducing the damage from natural disasters, it is necessary to improve the ability of the community to prevent disasters (community disaster-resistance), including awareness of disaster prevention among local citizens and their ability to take action to prevent and mitigate disaster. Community disaster-resistance differs according to the attributes of the area and the age structure of local citizens, so this research focuses on analyzing cases from a variety of areas and establishing methods of determining each community's disaster-resistance. Moreover, using past research outcomes, it also seeks to provide public facility managers with supportive knowledge, so that they can establish schemes for improving community disaster-resistance through the implementation of projects under normal circumstances.

(5) Comprehensive Coastal Disaster Prevention Techniques Related to Tsunami and High Tide Countermeasures at Ports

In order to build a society that can tenaciously withstand disaster and achieve recovery and reconstruction swiftly in its aftermath, we need to establish initiatives that blend hard measures focused on coastal protection infrastructure, with soft measures such as the provision of information and evacuation measures. Those initiatives should be based on the lessons of the Great East Japan Earthquake and the evaluation of local vulnerabilities.

Accordingly, this research is aimed at the development of comprehensive coastal disaster prevention techniques focused on port districts. For this purpose, it is necessary to understand damage spreading processes from coastal areas and to find methods for the evaluation thereof as well as evacuation simulations.

(6) Systematization of Methods for Evaluating Airport Disaster Countermeasures

In light of the Great East Japan Earthquake, this research seeks to gain deeper envisagement of disasters that require the use of airports for emergency response and disasters that affect airports themselves, and to systematize methods of evaluating exiting disaster countermeasures including emergency response plans relating to airports, while incorporating such new envisagement. It is anticipated that the systematization will encourage airport managers, whether in the public or private sector, to review and improve existing disaster countermeasures for their airports and to standardize these processes. Consequently, the above systematization will lead to the optimization of disaster countermeasures relating to airports nationwide and contribute to the development of a disaster-resistant nation.

(7) Approaches to Performance Requirements for Road Structures in Relation to Large-scale Earthquakes

During the Great East Japan Earthquake, it was necessary to impose traffic restrictions in many places, due to damage caused by the seismic motion and tsunami, including the washing away of road bridge superstructures, the collapse of the embankment behind abutments, deformation of retaining walls, extensive liquefaction, road surface subsidence, and the emergence of level differences. In the meantime variations were seen between structures in terms of the time required to carry out emergency repairs. In relation to this, in order to ensure that road network functions can be secured efficiently even in the event of a major disaster, this research seeks to systematize performance requirements tailored to the role of each road section, taking into account the period required for emergency repair, and to propose design techniques and measures that should be taken into account according to each performance requirement, such as methods of setting external forces. This will make it possible to secure road network functions systematically and rationally in the event of a major disaster.

(8) Methods of Maintaining Sewerage Services in the Event of an Earthquake or Tsunami

Following the Great East Japan Earthquake, damage to sewage treatment plants due to the massive tsunami and damage to sewerage pipes caused by liquefaction across an extensive area led to sewerage services being suspended in some areas and service levels being reduced in others. Accordingly, the goal of this project is to develop techniques that will be reflected in the business continuity plans of sewerage providers, as well as technical standards for facilities.

(9) Methods of Verifying the Safety Performance of Buildings in the Event of an Earthquake and Fire

Amid a situation in which it is deemed to be almost certain that an ocean trench megaquake will occur within the next 30 years, this research seeks to gather and analyze seismic observation records from both within and outside buildings, and to propose methods of improving the precision of seismic force evaluations, in order to reflect the more advanced seismic motion information available today in the design seismic forces for buildings. This will facilitate the development of more efficient earthquake countermeasures to prepare buildings against a megaquake. Moreover, even in the case of buildings that would have no risk of collapse due to fire or of fire spreading throughout the building under normal circumstances, it is still necessary to take into consideration the fact that such risks might arise as a result of damage due to an earthquake. Accordingly, this research involves accumulating experimental data concerning the fire-resistance of medium and high-rise buildings in the aftermath of an earthquake, and formulating guidelines for considering how those in buildings where confusion is anticipated should react. Furthermore, surveys and research will be conducted with a view to increasing the sophistication of tsunami-resistant design and seismic design in light of the Great East Japan Earthquake.

(10) Research Concerning Liquefaction

Countermeasures and Evaluation Techniques

In relation to liquefaction, there is a lack of adequate measures that can be applied in urban areas that have already been developed. Moreover, in relation to long pieces of infrastructure such as levee, it is necessary to develop more advanced methods of identifying the areas where measures are required, in order to curb the costs and time required to implement such measures. In addition, in order to ensure that measures focused on sewerage pipes are effective, it is necessary to clarify the conditions for the application of existing measures, as well as construction management standards.

Accordingly, this research focuses on (i) developing simple methods of evaluating liquefaction risk that can be applied to residential land, and building up technical data and examining integrated countermeasures for streets and residential land, with a view to measures to counter the re-liquefaction of land in areas affected by the Great East Japan Earthquake, as well as disaster prevention on residential land throughout the country. (ii) With regard to levee, research will be conducted with a view to making identification methods for sections to be strengthened more precise and summarizing the applicability of countermeasures for levee sections in various conditions, as well as developing a manual of relevant measures. (iii) In relation to roads constructed immediately on the ground (flat section), this project involves analysis of the relationship between liquefaction and geotechnical conditions of the ground and paving, and deliberations concerning measures to deal with this, as there were cases during the recent disaster in which it took a long time to reopen the roads to traffic as liquefaction had caused differences in level to emerge, even on flat sections of road. (iv) With regard to sewerage pipes, this research project involves summarizing the case in which countermeasures were not effective and the conditions of their application, and examining methods of selecting construction methods tailored to the conditions at the actual site, as well as the construction management of effective measures and quality control techniques.

(11) New Support Methods of Promoting Improvement for Disaster mitigation in Densely Built-up Areas

The "special harmonious rules for rebuilding" involves local governments giving permission for relaxing or providing exemptions from the constraints of the zoning code (obligation to ensure road abutment, setback distance, building coverage ratio, etc.) in the Building Standards Act when rebuilding in densely built-up areas that are dangerous in terms of disaster prevention. This research focuses on developing tools for simple projection and evaluation of the performance of individual districts at present and in relation to various proposals for rules on rebuilding (fire safety, performance as a living environment), and drawing up guidelines for the formulation of harmonious rules on rebuilding that can be provided to local governments, in order to promote the use of this special rules. Through this, it aims to promote landowner-led rebuilding in densely built-up areas through the use of the special harmonious rules for rebuilding, as well as increasing the disaster-resistance of such areas and improving the living environment.

(12) Conservation and Creation of the Environment in Coastal Areas

In managing coastal environments where a variety of physical, biochemical, and social phenomena overlap, it is essential to implement integrated management that takes into account the unique environmental and social conditions in that particular place. Accordingly, this research focuses on evaluating environmental phenomena in various spatial scales and assessing their mutual dependence, as well as developing evaluation techniques suited to integrated coastal management and methods of creating frameworks for cooperation and collaboration among related bodies. These outcomes will be able to be used to put together systematized techniques relating to the integrated management of coastal areas. Moreover, it will be possible to use these techniques to make proposals for multiple environmental remediation techniques that can be utilized in the reconstruction of coastal areas devastated by the Great East Japan Earthquake.

(13) 24/7 Gathering, Analysis and Use of Road Traffic Data

There are cases in which the five-yearly road traffic census is not sufficient for the implementation of focused, efficient road-related policies including effective use of our existing roads. Accordingly, this research examines methods of supplementing and integrating conventionally collected data on traffic volumes and travel speed with the data that can be gathered 24/7 from vehicle detectors, car navigation systems with communication capabilities, and ITS spots, sharing and accumulating this data efficiently, and sharing it for use in a wide range of fields, including road traffic management, with a focus on facilitating a smoother flows of traffic, a better road environment, traffic safety, and responses in the event of disaster. Through this, it will become possible to cut data collection costs substantially and carry out multifaceted, detailed analysis and evaluation of road-related policies and the priority level and effectiveness of road projects.

Thus, the content of our activities has been revised in light of our experiences of the recent Great East Japan Earthquake and our research topics cover a wide range of fields. It is necessary for us to promote initiatives in relation to these individual research topics. In addition, we have become conscious once more of the importance of initiatives aimed at sharing information in a way that transcends the boundaries between fields, and resolving common issues. Moreover, we have developed a renewed awareness of the importance of continuous technical support tailored to the situation in each area.

As well as the key topics highlighted in the Research Policy, the following initiatives will also be important tasks for the future, from this perspective.

(i) Disaster-resistant, resilient community and urban development planning that optimizes land use, infrastructure development, and soft measures.

(ii) Preparations for complex disasters involving earthquakes, tsunami, and fire.

(iii) Methods of accelerating the gathering, sharing, and provision of disaster information, as well as for risk communication with citizens.

(iv) Securing dwellings, including temporary housing, in the immediate aftermath of a disaster, establishing a housing reconstruction plan and implementing swift recovery and reconstruction in accordance with this plan, and enhancing livelihood support for disaster victims.

(v) Enhancing initial response systems in relation to complex and major disasters.

At present, measures in relation to the anticipated Nankai Trough earthquake are a matter of urgency for the government. Accordingly, developing a research system based on the lessons from the recent disaster is a vital task in promoting research activities that will assist in mitigating the damage and protecting the lives of the people, in the event of a major disaster that is expected to cause even more immense, extensive damage.

In addition, as well as gaining an accurate understanding of the technical tasks required in the field in the event of disaster, through such activities as providing technical guidance as a TEC-FORCE unit, it is necessary to strive assiduously to promote research to enable us to meet these needs.

References

1) National Institute for Land and Infrastructure Management: Research Policy, July 2012
http://www.nilim.go.jp/lab/bcg/housin/housin24.pdf

Afterword

This report provides a chronological summary of the surveys, analyses, research, and technical support in the field that NILIM implemented during the first 18 months after the Great East Japan Earthquake, as well as outlining its initiatives to tackle new challenges that became apparent in the aftermath of the disaster. The aim of compiling this information in chronological order is to be able to provide a comprehensive, multidisciplinary overview of the phenomenon-focused and practical aspects of the disaster. In conducting surveys and research, NILIM has received assistance from a great many people, especially staff from the Ministry of Land, Infrastructure, Transport and Tourism headquarters, the Tohoku Regional Development Bureau, and Iwate, Miyagi and Fukushima Prefectures. Moreover, a variety of research institutes have also assisted us in these endeavors, including the Public Works Research Institute, the Building Research Institute, and the Port and Airport Research Institute. We at NILIM would like to take this opportunity to express our sincere gratitude for their assistance.

All 14 of NILIM's departments and research centers have been involved in the compilation of this report, summarizing the aspects of the disaster on which they focused in their research. As well as covering a wide range of content, this report features as many multidisciplinary initiatives as it was possible to include. Rather than merely being a record of the disaster, we believe that this publication has a very important meaning in terms of building the imaginative abilities that we, as researchers, should have. The content is highly beneficial not only to those who were directly involved in responding to the disaster, but also to those who were not directly involved, as it will aid preparations for future disasters. We at NILIM hope that this report will be read by as many people in the world as possible.

Almost two years have passed since the Great East Japan Earthquake. The reconstruction process is expected to necessitate terrible hardship and effort. NILIM is actively providing technical support for reconstruction initiatives, and intends to continue to provide the necessary technical support.

Furthermore, preparations for a Tokai-Tounankai-Nankai earthquake and an earthquake directly under Tokyo are also an issue of the utmost urgency. In this sense as well, we at NILIM hope to learn various lessons from the recent earthquake and tsunami, and conduct the necessary surveys and research swiftly, so that appropriate front-line support can be provided in future as well.

Reference Material

Table - Reference 1: Teams Sent to Sites by TEC-FORCE, etc.

No.	Teams sent and their activity details
1	At the request of the Tohoku Regional Development Bureau, a two-member river team was sent to survey the embankment damage of Eaigawa and Narusegawa rivers (March 11-14, 2011)
2	At the request of the Tohoku Regional Development Bureau, a two-member bridge team was sent to survey bridge damage such as on National Highway No. 45 (March 11-14, 2011)
3	At the request of the Tohoku Regional Development Bureau, a two-member road disaster prevention team was sent to provide technical assistance in coordinating road disaster information for the local emergency response headquarters of Tohoku Regional Development Bureau (March 11-14, 2011)
4	At the request of the Housing Bureau, a one-member building construction team was sent to survey the ceiling of the Ibaraki Airport Terminal Building (March 12, 2011)
5	To understand the status of incidents like landslides, a one-member erosion control team was sent to Miyagi Prefecture (March 12, 2011)
6	At the request of the Tohoku Regional Development Bureau, a two-member erosion control team was sent to Fukushima Prefecture to understand the landslide situations, etc. (March 12, 2011)
7	A one-member sewer team was sent to Miyagi Prefecture to survey the sewer damage and help establish the local headquarters, etc. (March 12-15, 2011)
8	At the request of the Civil Aviation Bureau, a one-member airport team (pavement) surveyed damages to Sendai Airport (March 13-15, 2011)
9	At the request of Ibaraki Prefecture, a two-member erosion control team was sent to Mito City, to provide guidance for landslide disaster prevention facilities on steep slopes (March 14, 2011)
10	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewer damages and to help establish the local headquarters, etc. (March 14-15, 2011)
11	At the request of the Tohoku Regional Development Bureau, the Second Bridge Team was sent to examine the damaged bridges (March 14-16, 2011)
12	At the request of the Housing Bureau, a three-member building construction team did a building damages survey in Miyagi and Fukushima prefectures (March 14-16, 2011)
13	A two-member building construction team was sent to Ibaraki Prefecture, to survey building damages (March 15-16, 2011)
14	At the request of the Tohoku Regional Development Bureau, a one-member port team (tsunami, design) was sent to survey the damages to Sendai Airport and Sendai Shiogama Port, etc. (March 15-19, 2011)
15	At the request of the Tohoku Regional Development Bureau, the Third Bridge Team was sent to evaluate damaged bridges (March 16-18, 2011)
16	At the request of the Tohoku Regional Development Bureau, a three-member ports team (earthquake and tsunami) was sent to Kamaishi Port and Kuji Port etc to survey the damages (March 16-19, 2011)
17	At the request of the Ibaraki Prefecture, two bridge experts were sent for bridge evaluation in the north of Ibaraki Prefecture (March 17, 2011)
18	At the request of the Sabo Department, a one-member sediment control team was sent to survey the sediment disaster in Miyagi, Iwate and Fukushima prefectures (March 18 & 29, 2011)
19	A three-member river team was sent to survey the status of the damages to embankments near the mouth of the Shin Kitakami River, etc. (March 18-20, 2011)
20	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewer damages and to help the establish the local headquarters (March 18-22, 2011)

21	At the request of the Tohoku Regional Development Bureau, a two-member sea coast team was sent to provide technical assistance, such as a damage survey of Sendai Bay coastal embankment (March 19-20, 2011)
22	A three-member earthquake disaster prevention team was sent to Ibaraki Prefecture, to survey the disaster situation in areas around strong earthquake measurements. (March 21, 2011)
23	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewer damages and to help establish the local headquarters (March 21-25, 2011)
24	At the request of the Civil Aviation Bureau , a two-member airport team (pavement) surveyed the damages to Sendai Airport (March 21-27, 2011)
25	A one-member building construction team was sent to Ibaraki Prefecture, to survey the building damages (wooden construction) (March 23, 2011)
26	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewer damages and to help establish the local headquarters (March 24-28, 2011)
27	A two-member building construction team was sent to Fukushima, Miyagi and Iwate prefectures to survey the building damages (reinforced concrete construction, etc.) (March 24-26, 2011)
28	A one-member building construction team was sent to survey the building damages in Chiba and Ibaraki prefectures (Ground) (March 24, 2011)
29	A one-member building construction team was sent to survey the building damages in Tochigi and Fukushima prefectures (wooden construction) (March 24-25, 2011)
30	At the request of the Kanto Regional Development Bureau, a three-member sewer team was sent to Ibaraki and Chiba prefectures to survey the damages (March 24-25, 2011)
31	At the request of Iwate Prefecture, a two-member sea coast team was sent to assist in surveys of the tsunami traces height and embankment damages in Taro Town, etc. (March 27-30, 2011)
32	A one-member ports team was sent to Iwate Prefecture , to survey the tsunami damages to the port (March 27-30, 2011)
33	At the request of the Tohoku Regional Development Bureau, a one-member sea coast team was sent to provide technical guidance on survey of tsunami traces (March 28-30, 2011)
34	At the request of the Tohoku Regional Development Bureau, a two-member bridge team was sent to survey the damaged bridges in Fukushima City (March 29, 2011)
35	A two-member building construction team was sent to Iwate and Miyagi prefectures, to survey the tsunami damages to building (March 30-April 2, 2011)
36	A one-member building construction team was sent to Ibaraki Prefecture, to survey the building damages (steel frame construction under the old earthquake resistance standards) (March 30-31, 2011)
37	At the request of the Kanto Regional Development Bureau, a one-member building construction team was sent to Chiba Prefecture, to survey the housing restoration (March 31, 2011)
38	At the request of the Kanto Regional Development Bureau, a two-member sewer team was sent to Chiba Prefecture, to survey the liquefaction damages (March 31, 2011)
39	At the request the Housing Bureau, a one-member building construction team was sent to Miyagi and Iwate prefectures, to ascertain the damage and to collect basic information to consider measures such as immediate emergency restoration etc. (March 31- April 3, 2011)
40	A two-member earthquake disaster prevention team was sent to Miyagi and Iwate prefectures, to survey the damages in areas around strong earthquake measurements (April 1-5, 2011)
41	At the request of the Tohoku Regional Development Bureau, a two-member port team (tsunami, design) was sent to survey the damages to Onahama Port and Soma Port, etc. (April 5-7, 2011)
42	At the request of the Kanto Regional Development Bureau, a one-member ports team (tsunami) was sent to survey the damages to Kashima Port and Ibaraki Port, etc. (April 5-6, 2011)

43	A one-member sewer team was sent to Miyagi Prefecture, to survey the damages to sewer system (April 5-7, 2011)
44	A two-member sewer team was sent to Ibaraki Prefecture, to survey the damages to sewer system (April 6, 2011)
45	A one-member bridge team was sent to jurisdiction of the Tohoku Regional Development Bureau, to survey the damaged bridges (April 5-7, 2011)
46	A three-member building construction team was sent to Miyagi Prefecture, to survey the tsunami damages to buildings (wooden structure) (April 6-8, 2011)
47	A one-member building construction team was sent to Iwate Prefecture, to survey the tsunami damages to buildings (April 6-9, 2011)
48	A four-member sediment control team was sent to Miyagi Prefecture, to survey the risks of sediment disasters (April 7-8, 2011)
49	At the request of the Tohoku Regional Development Bureau, a two-member dam team was sent to Fukushima and Miyagi prefectures, to survey the deformations of dams (April 7-9, 2011)
50	A one-member building construction team was sent to Ibaraki Prefecture to survey the damages to the buildings (steel construction) (April 11-12, 2011)
51	A four-member sediment control team was sent to Miyagi and Iwate prefectures, to survey the risks of sediment disasters (April 11-12, 2011)
52	At the request of the Tohoku Regional Development Bureau, a one-member ports team (facility design) was sent to Kashima Port and Ibaraki Port, to ascertain the damages (April 12-14, 2011)
53	At the request of the Sabo Department, a two-member sediment control team was sent to Fukushima Prefecture, to survey the actual situation of sediment disaster (April 13, 2011)
54	A two-member sea cost team was sent to Fukushima Prefecture, to survey the damages to coastal conservation facilities (April 13, 2011)
55	At the request of the Tohoku Regional Development Bureau, a two-member bridge team was sent to Iwate and Miyagi prefectures, to survey the damaged bridges (April 13-16, 2011)
56	A two-member building construction team was sent to Miyagi and Fukushima prefectures, to survey the damages to the buildings (ground) (April 15-16, 2011)
57	A three-member building fire-safety team was sent to Iwate and Miyagi prefectures, to survey the damages to buildings (fire) (April 20-22, 2011)
58	A one-member building construction team was sent to Ibaraki Prefecture, to survey the damages to the buildings due to seismic movement (wooden construction) (April 21, 2011)
59	A three-member building construction team was sent to Miyagi and Fukushima prefectures, to survey the damages to the buildings (April 21-22, 2011)
60	A two-member building fire-safety team was sent to Aomori and Iwate prefectures, to survey the damages to the buildings (fire) (April 26-28, 2011)
61	A one-member building construction team was sent to Miyagi and Tochigi prefectures, to survey the damages to the buildings due to seismic movement (wooden construction) (April 27-29, 2011)
62	At the request of the River Bureau, a one-member team was sent to Yamagata and Miyagi prefectures, to survey the deformation of dams (April 27-28, 2011)
63	A two-member sewer team was sent to Iwate Prefecture and Miyagi Prefecture, to survey the coastal conservation facilities (May 2-4, 2011)
64	A one-member ports team was sent to Aomori Prefecture, to survey the tsunami damages to port (May 8-9, 2011)
65	A two-member sewer team was sent to Chiba Prefecture, to survey the damages to sewer system (May 11, 2011)

66	A two-member sewer team was sent to Miyagi Prefecture, to survey the damages to sewer system (May 11-12, 2011)
67	A one-member building construction team was sent to Fukushima, Tochigi and Ibaraki prefectures, to survey the damages to the buildings (reinforced concrete construction) (May 11-14, 2011)
68	At the request of the Sewerage and Wastewater Management Department, a six-member sewer team was sent to Fukushima and Miyagi prefectures, to survey the damages (May 23-24, 2011)
69	A one-member building construction team was sent to Iwate Prefecture, to survey the damages to the tsunami damages to buildings (wooden construction) (May 24-27, 2011)
70	A three-member earthquake disaster prevention team was sent to Chiba Prefecture, to survey the disaster around strong earthquake measurements (May 26, 2011)
71	A two-member sewer team was sent to Fukushima Prefecture, to survey radioactive sludge of the sewerage treatment plant (May 27, 2011)
72	A two-member sewer team was sent to Chiba Prefecture, to survey sewer system damages (March 31, 2011)
73	A two-member building construction team was sent to Miyagi Prefecture, to survey the damages to the buildings (seismic isolators) (May 31- June 2, 2011)
74	At the request of the Housing Bureau, a one-member housing team was sent to the Tohoku Regional Development Bureau, to assist in the construction of temporary housing (June 11-18, 2011)
75	A one-member ports team was sent to Ibaraki Prefecture, to survey the tsunami damage to the port (June 13, 2011)
76	A two-member sewer team was sent to Miyagi Prefecture, to survey the damage of the sewage system (June 15-17, 2011)
77	A two-member port team was sent to Iwate Prefecture, to survey the tsunami damage to the coastal conservation facilities (June 16-17, 2011)
78	A two-member sewer team was sent to Ibaraki Prefecture to survey damages to sewer system (June 21, 2011)
79	A one-member building construction team was sent to Iwate Prefecture, to survey tsunami damages to buildings (June 30-July 2, 2011)
80	A one-member building construction team was sent to Ibaraki Prefecture, to survey the damages to the buildings (gym) (July 1, 2011)
81	A one-member sewer team was sent to Fukushima Prefecture, to survey the sewerage treatment plant damages (July 4, 2011)
82	A one-member building construction team was sent to Ibaraki Prefecture, to survey the damages to the buildings (steel frame construction) (July 6, 2011)
83	A three-member sewer team was sent to Ibaraki Prefecture, to survey the damages to sewer system (July 13, 2011)
84	A two-member sewer team was sent to Chiba Prefecture, to survey the damages to sewer facilities (July 15, 2011)
85	A two-member port team was sent to Miyagi Prefecture, to survey the tsunami damage to the coastal conservation facilities (July 19-20, 2011)
86	A two-member sewer team was sent to Miyagi Prefecture, to survey the damages to sewer system (August 17-19, 2011)
87	A one-member river team was sent to Miyagi Prefecture, to survey the river and coastal sites (August 22-23, 2011)
88	A one-member building fire protection team was sent to Miyagi Prefecture, to survey the fire safety of the government facilities (August 29-30, 2011)

89	A two-member port team was sent to Miyagi Prefecture, to survey the tsunami damage to the coastal conservation facilities (August 31- September 1, 2011)
90	A four-member sewer team was sent to Miyagi Prefecture, to survey the sewage system damages and to survey the damages to quake-resistant pipes and drains (September 12-14, 2011)
91	A one-member building construction team was sent to Miyagi Prefecture, to survey the tsunami damage to public housing (September 22-24, 2011)
92	A one-member sewer team was sent to Iwate Prefecture, to survey the damages to sewer system (October 11-12, 2011)
93	A five-member river team was sent for the field survey of the Kitakami, Naruse, Natori and Nanakita rivers (October 11-13, 2011)
94	A one-member building construction team was sent to Miyagi Prefecture, to do a detailed survey of tsunami damage to private housing (wooden construction) (October 13-15, 2011)
95	A two-member earthquake disaster prevention team was sent to survey the actual condition of evacuation sites (October 13-15, 2011)
96	A one-member sewer team was sent to Ibaraki Prefecture, to survey the sewerage treatment plant damages (December 8, 2011)
97	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewerage treatment plant damages (December 8, 2011)
98	A two-member sewer team was sent to Miyagi Prefecture, to survey the sewerage treatment plant damages (December 15-16, 2011)
99	A one-member sewer team was sent to Miyagi Prefecture, to survey the sewerage treatment plant damages (January 11, 2012)
100	A one-member sewer team was sent to Miyagi Prefecture, to survey the sewage system damages (January 16-17, 2012)
101	A two-member river team was sent to do a site survey of the Kitakami River (February 5-6, 2012)
102	A two-member sewer team was sent to Chiba Prefecture, to survey the sewage system damages (February 14, 2012)
103	A seven-member earthquake disaster prevention team was sent to survey the disaster responses of the road administrators and support responders and related organizations, after the earthquake (February 29-March 2, 2012)
104	A one-member sewer team was sent to Miyagi Prefecture, to survey the sewerage treatment plant damages (March 14-15, 2012)

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