Guide to Determining the Potential Tsunami Inundation

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(Temporary Translation)

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and

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1. Outline

1.1 About the guide

The purpose of the guide is to provide guidance for determining the potential tsunami inundation, which becomes the basis for planning and implementing measures for developing tsunami-resilient communities. The guide summarizes the tsunami inundation simulation, an effective means of fulfilling the above purpose, and how to utilize it.

<Explanation>

Preparing for a large-scale tsunami, like the one induced by the 2011 off the Pacific Coast of Tohoku Earthquake on March 11, 2011, requires a continued effort to develop tsunami-resilient communities with multiple protections, combining both structural and non-structural measures. These efforts must be based on the lesson of "disasters have no limit" and the priority of saving people's lives at all costs.[1]

Tsunami-resilient communities need to be developed not only in the reconstruction of affected areas but also at the national level. This has led to the establishment of a general system for the development of tsunami-resilient communities; namely, the Act on the Development of Tsunami-resilient Communities (Act No. 123 of 2011).

Article 8, paragraph 1 of the Act on the Development of Tsunami-resilient Communities requires prefectural governors to determine the potential tsunami inundation; that is, the area and depth of inundation deemed likely to result from a tsunami. Paragraph 2 of the Article states that prefectural governors may, when determining the potential tsunami inundation, ask the Minister of Land, Infrastructure, Transport and Tourism for information, technical advice, and other kinds of necessary support.

Based on the abovementioned aim, this guide can be used as reference material to enable prefectural governors to determine the potential tsunami inundation.

Since the guide will be updated as necessary, it is urged to refer to the latest version and the latest data, and to also consider tsunami phenomena, etc. when utilizing the guide in a flexible and appropriate manner.

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[1] The urgent recommendation by the Panel on Infrastructure Development and the Transport System Subcommittee of the Panel on Transport Policy concerning the development of tsunami-resilient communities (2011) states that many people are becoming more aware that there are no limits to how great disasters can be, and that protecting human lives at any cost through evacuations, etc. is the most important thing in the event of a greater disaster than expected. This recommendation and the Basic Guidelines for Reconstruction in response to the Great East Japan *Earthquake* underscore the importance of flexibly combining both structural and non-structural measures as a means of providing multiple protections in the development of tsunami-resilient communities.

1.2 The urgent recommendation concept of the development of tsunami-resilient communities

Upon the request of the Minister of Land, Infrastructure, Transport and Tourism following the Great East Japan Earthquake, on July 6, 2011 the Panel on Infrastructure Development and the Transport System Subcommittee of the Panel on Transport Policy presented an urgent recommendation concerning the development of tsunami-resilient communities.

This urgent recommendation established the importance of future tsunami disaster reduction based on the following principles:

・Expect that a disaster as great as the Great East Japan Earthquake can happen, and employ all structural and non-structural measures to mitigate such a disaster, with priority given to protecting human lives at all costs;

・Ensure that daily tsunami countermeasures are continued, keeping in mind the lesson of "disasters have no limit";

・Move from single-line protection using coastal levees, etc. to multiple protection, employing all structural and non-structural measures; and

・With consideration given to calls for the use of lowland, instead of imposing uniform regulations on land use, develop a flexible system that considers the safety of the location while reflecting diverse aspect and needs of the community, and the progress in the development/maintenance of protection facilities.

Along these lines, the need for developing a new legislative system was emphasized. The new system is to include regulations on land use and building construction that take into consideration, among other things, the expected area and depth of tsunami inundation determined from scientific knowledge; the creation and dissemination of a tsunami hazard map based on this determination; the details of the community; and safety.

<Explanation>

Excerpt from the urgent recommendation by the Panel on Infrastructure Development and the Transport System Subcommittee of the Panel on Transport Policy concerning the development of tsunami-resilient communities, dated July 6, 2011[2]:

○ Properly combine structural and non-structural measures to minimize damage from a disaster as much as possible while giving priority to protecting human lives at all costs, even in the event of a tsunami as large as the recent one.

○ Among these, structural disaster management measures such as coastal protection facilities should be aimed at protecting people's lives, property, industrial and economic activities, and national land against a certain scale of tsunami that is expected to occur relatively frequently, giving sufficient consideration to socioeconomic conditions.

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[2] The urgent recommendation by the Panel on Infrastructure Development and the Transport System Subcommittee of the Panel on Transport Policy concerning the development of tsunami-resilient communities, 2011
http://www.mlit.go.jp/policy/shingikai/sogo08_sg_000049.html

○ Develop a system to systematically and comprehensively implement measures to develop tsunami-resilient communities based on new ideas, such as the following:

1) Tsunami disaster management/mitigation measures based on multiple protection that flexibly incorporates and combines structural and non-structural measures, with consideration given to regional characteristics;

2) Tsunami disaster management/mitigation measures that move away from the conventional “line-based” protection by coastal protection facilities etc. in favor of “surface-based” protection, and that are within the scope of community development, combining rivers, roads, land use restrictions, etc.;

3) Effective measures to ensure swift and safe evacuations; and

4) The regeneration and revitalization of local communities through the utilization of local residents’ social infrastructure; namely, industries, urban functions, communities, and shopping streets; their history, culture, and tradition; while coexisting with the risk of a tsunami.

1.3 The Act on the Development of Tsunami-resilient Communities

Conventional tsunami countermeasures were focused on the development of structural facilities such as coastal levees. Developing greater protections against a large tsunami like the one experienced in the Great East Japan Earthquake requires basing the development of tsunami-resilient communities on multiple protections, combining structural and non-structural measures as well as the lesson of “disasters have no limit,” with priority given to protecting human lives at all costs.

Since this direction of community development is required not only in the reconstruction of affected areas but also at the national level, a general system for developing tsunami-resilient communities is necessary.

Based on these aims, the Act on the Development of Tsunami-resilient Communities (Act No. 123 of 2011) was enacted.[3]

The provisions of the Act concern, among others, the basic principles formulated by the Minister of Land, Infrastructure, Transport and Tourism, the determination of the potential tsunami inundation by prefectural governors, the creation of Facilitation Plans by municipal governments, issues concerning the special measures applicable in the areas designated in the Facilitation Plan and matters related to city planning concerning collective facilities for formation of tsunami-resilient urban area, the management of tsunami adaptation facilities, the development of an evacuation system in the Tsunami Disaster Security Zones, and measures concerning regulation of certain development and building construction activities in the Tsunami Disaster Special Security Zones.

<Explanation>

(1) Objective of the Act

To protect people’s lives, physical health, and property against tsunami-induced disasters and help secure the public welfare and sound growth of local communities by comprehensively facilitating the development of tsunami-resilient communities; namely, the development, use, and conservation of safe communities where people can feel secure for many years to come, with a significant ability to prevent or mitigate tsunami-induced disasters.

(2) Outline of the Act

[Basic Principles]

The Minister of Land, Infrastructure, Transport and Tourism lays out the basic principles to facilitate the development of tsunami-resilient communities (Basic Principles).

[Determining the potential tsunami inundation]

Based on the basic principles and the results of basic survey, prefectural governors determine the potential tsunami inundation; namely, the area and depth of inundation that is expected to result from a tsunami.

[Creation of the Facilitation Plan]

Based on the Basic Principles and the potential tsunami inundation, municipal governments may create the Facilitation Plan; namely, a plan to comprehensively facilitate the development of a tsunami-resilient community. Special provisions for land readjustment programs, deregulation of the floor-area ratio for tsunami-resistant buildings, and special provisions for promotion of group relocation are introduced in the designated areas of the Facilitation Plan.

[3] Details about the Act on the Development of Tsunami-resilient Communities http://www.mlit.go.jp/sogoseisaku/point/tsunamibousai.html

[City planning concerning collective facilities for formation of tsunami-resilient urban area]

The city planning may designate collective facilities for formation of tsunami-resilient urban area.

[Management of tsunami adaptation facilities]

Based on the potential tsunami inundation and in line with the Facilitation Plan, prefectural governors or municipal mayors manage tsunami adaptation facilities designed to prevent or mitigate tsunami-induced human injuries.

[Designation of Tsunami Disaster Security Zone and Tsunami Disaster Special Security Zone]

Based on the Basic Principles and the potential tsunami inundation, prefectural governors shall designate zones where an evacuation system particularly needs to be established, as Tsunami Disaster Security Zones ("Security Zones"). Among these zones, those necessitating limitations on certain kinds of development and construction activities may be designated as Tsunami Disaster Special Security Zones ("Special Security Zones").

1.4 Basic principles to facilitate the development of tsunami-resilient communities

The basic principles to facilitate the development of tsunami-resilient communities (hereinafter, the "Basic Principles"), laid down by the Minister of Land, Infrastructure, Transport and Tourism in accordance with Article 3 of the Act on the Development of Tsunami-resilient Communities, are designed to help prefectural and municipal governments facilitate the development of tsunami-resilient communities. The Basic Principles were decided upon on December 27, 2011, when the Act was enacted. (Ministry of Land, Infrastructure, Transport and Tourism Notification No. 51, dated January 16, 2012).

The following are the basic principles:

1 Basic matters to facilitate the development of tsunami-resilient communities
2 Guiding principles for the basic survey
3 Guiding principles for the determination of potential tsunami inundation
4 Guiding principles for the preparation of the Facilitation Plan
5 Guiding principles for designating the Tsunami Disaster Security Zones and the Tsunami Disaster Special Security Zones

<Explanation>

(1) Outline of the Basic Principles

Following are the outlines and descriptions of the Basic Principles. See 5.4 of these guidelines for the full text, which is also available on the Ministry of Land, Infrastructure, Transport and Tourism's website[4]:

1) Basic matters to facilitate the development of tsunami-resilient communities

Basic views on efficiently and effectively facilitating the development of tsunami-resilient communities are defined and outlined as follows:

- Respond in light of experiences from the Great East Japan Earthquake and the Act on Promotion of Tsunami Management Measures
- "Protect human lives at all costs" even in the event of the largest scale tsunami
- Implement multiple protection that encompass structural and non-structural measures
- Engage in effective facilitation in the course of comprehensive efforts to develop and revitalize the community
- Make efforts to ensure that local inhabitants and others maintain high levels of awareness regarding tsunamis at all times

2) Guiding principles for the basic survey

Principles for basic surveys are defined and outlined as follows:

- Conduct surveys on determining potential tsunami inundation, which serve as the basis for tsunami countermeasures

4 Basic principles to facilitate the development of tsunami-resilient communities (Basic Principles) http://www.mlit.go.jp/common/000186960.pdf

- Prefectural governments implement the surveys in a systematic fashion in coordination and cooperation with the central government and municipalities
- Conduct surveys on bathymetry and topography, geological conditions related to earthquakes and tsunamis which occurred in the past, the state of land use, etc.
- The Government conducts surveys regarding the items necessary (airborne laser hydrography, etc.) to obtain a wide area coverage

3) Guiding principles for the determination of potential tsunami inundation

Principles for determining the potential tsunami inundation are defined and outlined as follows:

- The prefectural governors determine the area and depth of inundation expected from the largest scale tsunami in a worst-case scenario
- The fault model used in determining tsunamis by the Central Disaster Management Council of Japanese Government (hereinafter "the CDMC") should also be taken into consideration in determining the largest scale tsunami
- For those marine areas for which the CDMC, etc. has not created a tsunami fault model, a fault model shall be back-calculated from the results of surveys on tsunami traces, etc.
- The fault model for the largest scale tsunami shall be determined by the central government and given to prefectural governments. A prefectural government can establish its own model prior to the provision of such model by the central government
- Local inhabitants, etc. are to be sufficiently informed through public relations activities, the distribution of printed materials, the Internet, etc.

4) Guiding principles for the preparation of the Facilitation Plan

Principles for creating the Facilitation Plan are defined and outlined as follows:

- Municipalities will combine structural and non-structural measures and draw up the development of tsunami-resilient communities based on condition of each region
- Ensure consistency with the developments of the existing policies for the communities
- Coordinate effectively between structural projects and non-structural measures such as the designation of security zones
- Develop tsunami adaptation facilities with efficiency in mind
- Form urban areas with a high degree of disaster resilience and the convenience of daily life
- Secure evacuation facilities efficiently through including the utilization of private facilities
- Coordinate with stakeholders of listed projects etc. including utilizing of the council
- Respond effectively to future crises in light of the period of time required to implement countermeasures

5) Guiding principles for designating the Tsunami Disaster Security Zones and the Tsunami Disaster Special Security Zones

Principles for the designation of Security Zones and Special Security Zones are defined and outlined as follows:

<Security Zones>

- Designated by the prefectural governor, Security Zones are designed to have especially developed evacuation systems to ensure that local inhabitants and others can escape from tsunamis
- The Standard Water Level for when restrictions will be imposed on evacuation facilities and restricted-use buildings within Special Security Zones is publicly announced
- Municipalities are to take the following measures inside Security Zones:
  - Create municipality disaster management plans which incorporate practical details and conduct evacuation drills
  - Create and disseminate tsunami hazard maps with the cooperation of local inhabitants
  - Secure of evacuation facilities based on local environments through designations and management agreements
  - Create evacuation security plans at places such as social welfare facilities and conduct evacuation drills

<Special Security Zones>

- Designated by the prefectural governor, Special Security Zones are designed to ensure that people in need for special attention at times of disasters can avoid tsunami when they are inside a building.
- Restrict specific construction and development activities
- When zones are designated, local environments are considered and efforts made to deepen the understand of local residents by means of public inspection and consultation with related municipalities

1.5 Defining and addressing the potential tsunami inundation in developing tsunami-resilient communities

The potential tsunami inundation is the basis for the development of tsunami-resilient communities, and involves the prefectural governor's determination of the potential area and depth of inundation based on the largest scale tsunami. This is estimated from the tsunami inundation simulation based on "III. Guiding principles for the Determination of Potential Tsunami Inundation, Defined in Article 8, Paragraph 1, of the Act" in the basic principles, and the results of basic surveys.

Based on the potential tsunami inundation, the following actions shall be appropriately and comprehensively carried out according to the conditions of the region, in order to efficiently and effectively implement measures against the largest scale tsunami:

1 The municipal government shall create the Facilitation Plan, as defined in Article 10, paragraph 1 of the Act
2 The projects and administrative work outlined in the Facilitation Plan shall be implemented
3 The special measure in the designated area of the Facilitation Plan defined in Chapter 5 of the Act shall be implemented
4 The tsunami adaptation facilities defined in Chapter 7 of the Act shall be managed, etc.
5 To develop an evacuation security system, the Security Zone defined in Article 53, paragraph 1 of the Act shall be designated
6 To restrict certain kinds of construction and development activities in the Special Security Zones defined in Article 72, paragraph 1 of the Act, these Special Security Zones shall be designated

<Explanation>

(1) Potential tsunami inundation

The "potential tsunami inundation" is the area and depth of inundation that is expected to result from the largest scale tsunami. This shall be determined by the prefectural governor, who is in the best position to better understand the region.

Determining the potential tsunami inundation involves running a tsunami inundation simulation to accurately reproduce and predict the area and depth of inundation.

The prefectural government will conduct the basic surveys necessary to obtain the abovementioned estimate in accordance with the Basic Principles laid down by the Minister of Land, Infrastructure, Transport and Tourism. To obtain a wide area coverage, the central government will conduct an airborne laser hydrography, etc. and provide the results to prefectural governments.

(2) Consideration of the potential tsunami inundation in the development of tsunami-resilient communities

The potential tsunami inundation, typically determined according to scientific findings, will provide the basic information to effectively combine different measures such as developing an evacuation system and creating regulations regarding land use. The formulation of Facilitation Plans, the management of tsunami adaptation facilities, etc. and the designation of Security Zones and Special Security Zones will be based on the potential tsunami inundation.

- Conduct surveys on bathymetry and topography, geological conditions related to earthquakes and tsunamis which occurred in the past, the state of land use, etc.

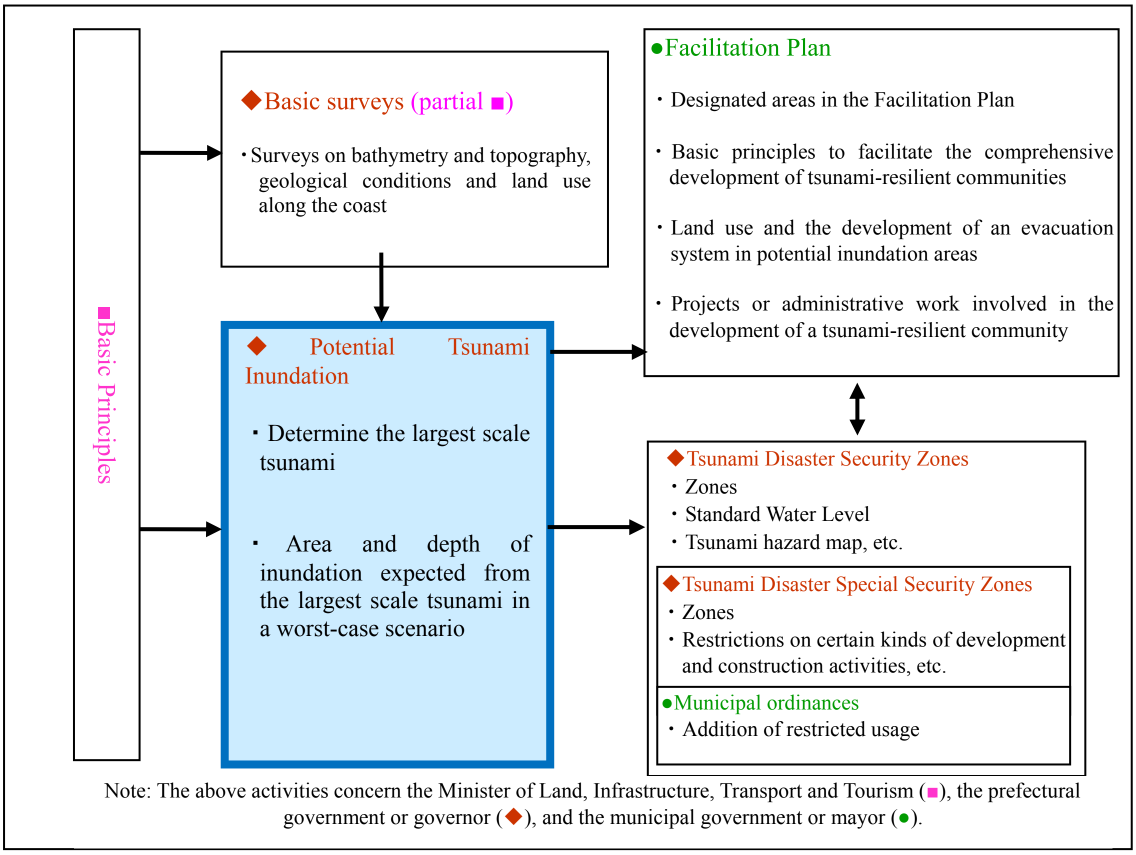


Figure 1 Outline of the development of tsunami-resilient communities in response to the potential tsunami inundation

(3) Utilizing the potential tsunami inundation

1) Facilitation Plan

The Facilitation Plan is aimed at comprehensively promoting the development of a tsunami-resilient community. The municipal government, the principle body for disaster management and community development, which is well-informed about the region, shall formulate the Facilitation Plan in consideration of the potential tsunami inundation and with the goal of thoroughly combining the structural and non-structural measures taken by the many different agents and comprehensively planning the development of a tsunami-resilient community.

The level of risk, safety, potential damage, etc. for each of the region in the potential tsunami inundation shall be analyzed. The results of this analysis and the vision of the community will be taken into consideration in determining the community development policy, which will be included in the Facilitation Plan together with issues representing the basic direction of tsunami countermeasures and priority measures such as structural measures, development of evacuation systems, etc.

Specifically, the Facilitation Plan may include, among others, the following items:

- Basic Principles to facilitate the comprehensive development of tsunami-resilient communities
- Matters concerning the use of land and the development of an evacuation system within the potential inundation area
- Matters concerning the projects and administrative work undertaken to facilitate the development of tsunami-resilient communities
  - ① Matters concerning the development and maintenance of coastal protection facilities, port facilities, fishing port facilities, etc.
  - ② Matters concerning the development and maintenance of tsunami adaptation facilities
  - ③ Matters concerning the development and maintenance of collective facilities for formation of tsunami-resilient urban area, land readjustment, urban area redevelopment, etc.
  - ④ Matters concerning the development and maintenance of evacuation routes, evacuation facilities, parks, etc.
  - ⑤ Matters concerning the promotion of group relocation

These measures, mentioned in the Facilitation Plan, will be carried out in an integrated manner as the development of a tsunami-resilient community is effectively facilitated.

Special measures for powerfully promote development of tsunami-resilient community, as shown in Table 1, shall be carried out in the designated areas of the Facilitation Plan, namely those areas where the Facilitation Plan is applicable.

The formulation of a Facilitation Plan requires consideration to be given to managing tsunami disasters, as well as the revitalization of the regional economy, the stabilization of the daily lives of local inhabitants, the improvement of their welfare, and community development.

Table 1 Special Measures

Utilization of special provisions in the designated areas of the Facilitation Plan	・**Special provision for land readjustment** The zone for concentrating residential and public facilities—namely, the tsunami-resilient housing construction zone—may be designated in the area within the land readjustment zone where measures to manage tsunami disasters have been or will be taken. Owners of the residential and public facility sites may apply for rezoning within the relevant zone. ・**Floor-area percentage exemption for buildings used for tsunami evacuation** It is recommended that buildings used for tsunami evacuation be equipped with an emergency stockpile warehouse, a standby power generator room, etc. Buildings that satisfy certain requirements for ensuring evacuation safety may not have to include in their floor-area percentage the area of these less-frequently-used floors if they receive an exemption from the floor-area percentage authorized by the relevant administrative agency. In this case they would not require an agreement from the building review council.

	・**Special provisions for the Promotion of Group Relocation** The prefectural government may formulate a plan to promote a group relocation project if the relevant municipal government reports that it would be too difficult for it to formulate such a plan because it would require a broader coordination that would go beyond a single municipality.
Development and maintenance of a collective facilities for formation of tsunami-resilient urban area	・**Collective facilities for formation of tsunami-resilient urban area** With the aim of developing disaster-resilient urban areas that would function as a hub for the maintenance of urban functions at times of disasters, housing complexes, specific project facilities, public-interest facilities, and public facilities may be collectively specified in city planning as collective facilities for formation of tsunami-resilient urban area. This makes it possible to restrict the construction, etc. of buildings that could obstruct the development of any of these facilities within the site of the relevant facility, facilitating the development of disaster-resilient urban areas in an integrated manner.
Construction or improvement of tsunami adaptation facilities	・**Tsunami adaptation facilities** Embankment structures, inland lock gates, etc. are regarded as tsunami adaptation facilities, and may be constructed or improved in the designated areas in compliance with the Facilitation Plan.

2) Designation of Tsunami Disaster Security Zones (Security Zones) and Tsunami Disaster Special Security Zones (Special Security Zones)

”Security Zones” in particular require the development of an evacuation system that facilitates such activities as the issuance or dissemination of tsunami-related forecasts and warnings, tsunami evacuation drills, the securing of evacuation areas and routes, and the creation of a tsunami hazard map. In this way, based on the potential tsunami inundation and the Standard Water Level defined in Article 53, paragraph 2 of the Act, local inhabitants can be informed of risk and safety levels in the event of the largest scale tsunami, and swiftly “escape” from a tsunami if it occurs.

The Tsunami Disaster Special Security Zones is an area within the Tsunami Disaster Security Zones where buildings could be destroyed or inundated in the event of a tsunami strike, with the possibility of a significant threat to the lives of or bodily injury to local inhabitants, etc., and where the construction of certain buildings or the development of these buildings must satisfy building codes or room elevations etc., in the event of a tsunami to ensure that local inhabitants, etc. in need of special attention at times of disasters can avoid tsunami when they are inside a building.

Both of these types of security zones may be designated by the governor of the relevant prefecture.

Further, municipal governments may enforce ordinances to strengthen regulations pertaining to the construction and development of houses and other facilities that the ordinance states would be incapable of ensuring a smooth and swift evacuation of inhabitants if a tsunami occurred in the Special Security Zones.

1.6 Potential Tsunami Inundation

1.6.1 Process of determining the potential tsunami inundation

Potential tsunami inundation is determined in the following order: ① determining the largest scale tsunami; ② determining calculation conditions; ③ running the tsunami inundation simulation; and ④ outputting the area and depth of inundation.

<Explanation>

In general, the procedure shown in Figure 2 is followed to determine the potential tsunami inundation.

Since the potential tsunami inundation depends on the building location, the status of embankment structures, etc., any changes that would affect the outcome of tsunami inundation must be determined by re-running the tsunami inundation simulation, which should be revised whenever necessary.

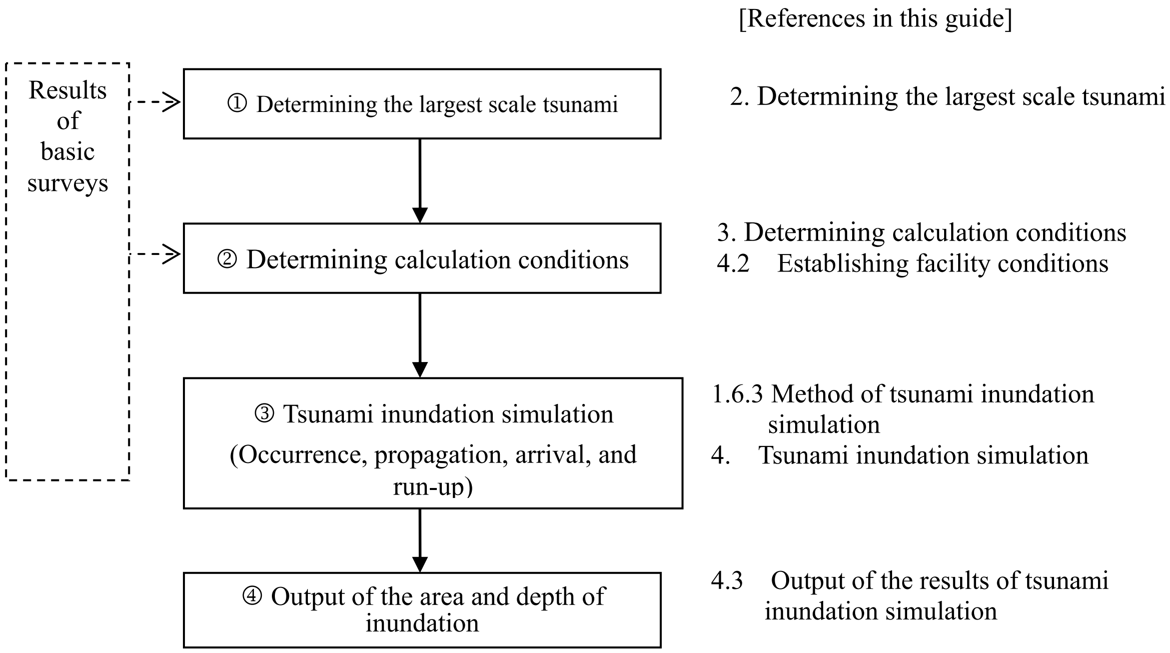


Figure 2 Process for determining the Potential tsunami inundation

1.6.2 Effectiveness of a tsunami inundation simulation

To determine the Potential tsunami inundation requires the use of a method to accurately estimate the inundation caused by a tsunami.

A tsunami inundation simulation helps determine the series of events such as tsunami generation in the source area, tsunami propagation, tsunami arrival at the coast and tsunami runup and inundation, through numerical computation. This is an effective method of determining the area and depth of inundation that should be defined as the potential tsunami inundation.

<Explanation>

(1) Effectiveness of a tsunami inundation simulation

With regard to recent tsunamis, a relatively large amount of data on tsunami inundated areas has been collected, but scant data on tsunamis up to the Meiji period is available. Traces of tsunami inundation are the most reliable record of past tsunamis.

However, tsunamis traces only reveal certain points of inundated areas, and are not enough to get a complete picture of inundation in terms of spatial distribution of water levels, velocity, etc.

Understanding the tsunami-related safety and hazards across coastal areas requires the assumption of areas that would be prone to tsunami-induced inundation. Determining the potential tsunami inundation in the development of a tsunami-resilient community also requires a method to accurately estimate the level of tsunami-induced inundation.

In recent years, tsunami disaster management measures are more frequently being planned based on the earthquake that possibly induces a tsunami.

Therefore, a tsunami inundation simulation helps determine the series of events such as tsunami generation in the source area, tsunami propagation, tsunami arrival at the coast and tsunami runup and inundation, through numerical computation. In this regard, it is an effective means for determining the area and depth of inundation that should be defined as the potential tsunami inundation.

(2) Output of a tsunami inundation simulation

A tsunami inundation simulation determines:

・The maximum area of inundation

・The maximum depth of inundation

These indicate the potential tsunami inundation. In addition, the following may also be determined:

・The Standard Water Level defined in Article 53, paragraph 2 of the Act

・The time from the occurrence of an earthquake to the arrival of a tsunami on the coast

The time from the occurrence of an earthquake to the arrival of a tsunami on the coast may be used to formulate an evacuation plan, etc. in response to the largest scale tsunami. However, it should be noted that some tsunamis may arrive earlier than the largest scale tsunami.

1.6.3 Method of tsunami inundation simulation

A tsunami inundation simulation uses the initial water level condition based on the tsunami generation process calculated from the earthquake fault model and is designed to continuously calculate a series of events of ① propagation of tsunami through the ocean and arrival at the coast, and ② tsunami runup from the coast into inland.

A tsunami inundation simulation is in principle based on the nonlinear long wave theory—namely, the shallow water theory—which considers ocean bottom friction and the advection terms. The theory of long linear waves may apply in deep water.

<Explanation>

(1) Process of tsunami inundation simulation

Figure 3 shows the process of the tsunami inundation simulation.

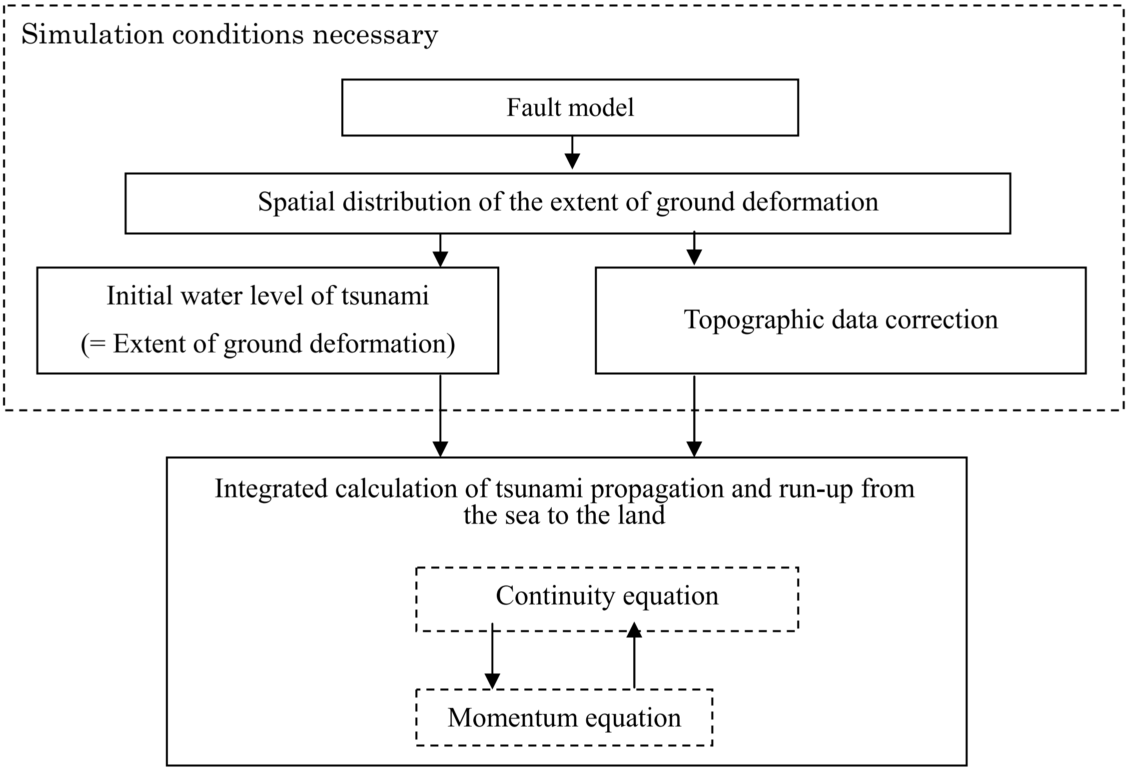


Figure 3 Process of tsunami inundation simulation

(2) Governing equation

The long-wave theory may be applicable to long-period waves, like a tsunami, which are less dispersible. The linear long wave theory and the nonlinear long wave theory are used as standards for estimating a tsunami in 50-meter or deeper seas and shallower seas, respectively.

The long-wave theory consists of the continuity equation found in the principle of mass conservation and the momentum equation found in the principle of momentum conservation. Both of these involve the following governing equations for an integration model that can be found by performing integration from the bottom of the water to the water surface in a vertical direction.

[Continuity equation]

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

[Momentum equation]

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2} = 0$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2} = 0$$

η means changes in the water level from the still-water level. *D* is the total water depth from the bottom to the surface. *g* is the acceleration of gravity. *n* is Manning's roughness coefficient. *M,N* represents the discharge flux in the direction of *x,y*. Horizontal flow velocity (*u,v*) , can be integrated from the bottom of the water (*h*) to the water surface (η) as the following:

$$M = u(h+\eta) = uD, \quad N = v(h+\eta) = vD$$

This equation assumes that horizontal flow velocity is uniformly distributed in a vertical direction.

The first term in the momentum equation is referred to as the *local acceleration term*, the second and third terms as the *advection term* (non-linear term), the fourth term as the *pressure term*, and the fifth term as the *bottom friction term*.

These terms may be omitted where the water is 50 meters or deeper because of a lesser influence from the advection term (the second and the third terms) and the bottom friction term (the fifth term) in the momentum equation.

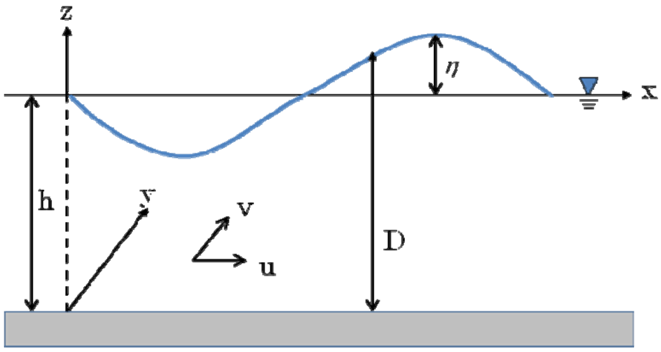


Figure 4 Coordinate system for the governing equation

Near-field tsunamis concern a 1,000-kilometer by 1,000-kilometer or smaller sea area. Using the rectangular coordinate system is sufficient for this. However, far-field tsunamis propagating over a long distance in the Pacific Ocean, etc. require the use of the governing equation with the following polar coordinate system. This type of tsunami also requires the dispersion term and Coriolis effect[5] to be considered.

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial}{\partial \theta}(N\cos\theta)\right]=0$$

$$\frac{\partial M}{\partial t}+\frac{gh}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}=-fN+\frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left[\frac{h^3}{3}F\right]$$

$$\frac{\partial N}{\partial t}+\frac{gh}{R}\frac{\partial \eta}{\partial \theta}=fM+\frac{1}{R}\frac{\partial}{\partial \theta}\left[\frac{h^3}{3}F\right]$$

$$F=\frac{1}{R\cos\theta}\left[\frac{\partial^2 u}{\partial \lambda \partial t}+\frac{\partial^2}{\partial \theta \partial t}(v\cos\theta)\right]$$

$$M=u(h+\eta)=uD,\quad N=v(h+\eta)=vD$$

In this equation, λ is longitude, θ is latitude, and M and N are the discharge fluxes in the directions of λ and θ, respectively. R is the earth's radius, f is the Coriolis coefficient ($f=2\omega\sin\theta$), and ω is the angular velocity of the earth's rotation (7.29×10^{-5}rad/s).

(3) Boundary conditions

1) Onshore boundary

In a tsunami inundation simulation, the inland tsunami run-up and the land exposure after backwashing, etc. must be calculated. Calculating the wave front condition of the tsunami requires determination of whether the computational grids have water for each of the time step in the calculation

5 Fumihiko Imamura, Osami Nagano, Chiaki Goto, and Nobuo Shuto, " Recalculation of wave propagation mode on ocean of Chile offshore tsunami waves in 1960 based on investigation result of Alasca tsunami wave." (collection of papers from the 34th Meeting of the Coastal Engineering Committee, pp. 172-176, 1987).

process, and calculation of flow by considering the relationship of water levels in the adjacent computational grids. The methods of Iwasaki and Mano (1979)[6] and Kotani et al. (1998)[7] are commonly used.

The parts of the coast other than the run-up area are regarded as a vertical wall, and the perfect reflection is assumed. In other words, the flow component perpendicular to the shore is regarded as 0.

$$M \quad \text{or} \quad N \quad = 0$$

2) Offshore boundary

Since the calculation area is finite, an artificial boundary is set offshore. The offshore boundary assumes no reflection.

3) Minimum water depth of wave front condition

The minimum water depth of wave front condition is to be set in the order of approximately one centimeter.[8,9]

(4) Soliton fission and undular hydraulic bore

As a tsunami propagates across a shoaling sea or river, it may be divided into short-period waves, and the wave height may increase, depending on the wave shape, the water depth, and other conditions. This phenomenon is referred to as a *soliton fission* or an *undular hydraulic bore*, since the back of a hydraulic bore takes on an undular form.

These are similar to each other in that they mainly concern the nonlinearity and dispersibility of a tsunami, and can be expressed by the nonlinear dispersive wave theory.

These were observed in the tsunami induced by the Central Japan Sea Earthquake. Using these in a simulation requires the use of such methods as the Boussinesq equation, in which wavenumber dispersion effects are considered. Once split, an undular hydraulic bore gets broken in shallower waters, thus a breaking wave model needs to be considered.

Descriptions of tsunami runup along a river can be found in "3.8 Tsunami runup along a river."[10]

[6] Toshio Iwasaki and Akira Mano, "Numerical Calculation of Two-Dimensional Tsunami Run-up Based on Eulerian Coordinates" (collection of presentations from the 26th Meeting of the Coastal Engineering Committee, pp. 70-74, 1979).

[7] Misa Kotani, Fumihiko Imamura, and Nobuo Shuto, "Tsunami Run-up Simulation and Damage Estimation by Using GIS, and the Method for Estimating Damage," *Proceeding of Coastal Engineering* 45 (1998): 356-360.

[8] Hideo Matsutomi, " A consideration on accuracy of numerical simulation with the conventional wave-front conditions on a dry bed," *Tohoku Journal of Natural Disaster Science* 26 (1990): 63-65.

[9] Yugo Imazu, Fumihiko Imamura, and Nobuo Shuto, " Examination on tip conditions for stable flood calculation," *Proceedings of the 51st Annual Conference of the Japan Society of Civil Engineers*, Part II, 242-243, 1996.

[10] Japan Institute of Construction Engineering, *Manual for Analyzing Tsunami Run-up in Rivers* (draft), 2007. http://www.jice.or.jp/siryo/t1/pdf/tsunami.pdf

1.6.4 Notes on determining the Potential Tsunami Inundation

A tsunami inundation simulation can be effective in determining the potential tsunami inundation. However, it may entail ① errors resulting from calculation conditions; ② calculation errors; and ③ errors in actual measurement values (trace height), etc. These errors should be taken into consideration by adjusting conditions whenever necessary.

<Explanation>

A tsunami inundation simulation can be effective in determining the potential tsunami inundation. However, its accuracy is limited, and some questions will remain unanswered in terms of the accuracy and reproducibility of the simulation. These questions are, among others, the validity of the fault model, the wave shape and behavior of the wave front, the behavior of the tsunami when it overtops the land boundary, and runup in rivers.

For this reason, abnormal values should be checked by outputting spatial distribution, etc. of maximum inundation depth, and calculation conditions should be adjusted when necessary.

The following are important notes regarding tsunami inundation simulations:

(1) Errors resulting from calculation conditions

1) Errors pertaining to the initial water level (fault model)

In a regular type of earthquake, the vertical displacement distribution of the sea-bottom floor may be deemed to exactly correspond to rise in the sea surface. The vertical displacement distribution of the sea-bottom floor in the fault model is determined to be the initial water level of the tsunami.

Therefore, the initial wave shape of a tsunami, the starting point of a tsunami inundation simulation, mainly depends on the fault model for the earthquake. Since determining a fault model depends on the data (e.g., the wave shape and the trace height of the tsunami) the estimation is based on, the calculation results depend on whether the correct fault model has been chosen. These points need to be sufficiently considered when running a tsunami inundation simulation.

Regarding making adjustments to the fault model, the geometric mean K, calculated from the results of the tsunami inundation simulation and the tsunami trace height, may be regarded as Aida's parameter, described in 3.1 (3), and can be used to correct slippage.

2) Errors concerning seabed topography

Because of the shoaling effects, a tsunami will become higher as it approaches the coast (the seabed becomes shallower). When a tsunami enters a V-shaped bay, a concentration effect occurs: its energies will concentrate as the water advances inward. This will raise the height of the tsunami.

A tsunami inundation simulation will take into account the effects of seabed and coastal topographies on tsunami height. The seabed topography data used in the calculation are relatively accurate in shallow waters. In deep waters, however, data are not very reliable, and may easily lead to errors in calculation results.

3) Errors concerning the tsunami resonance phenomenon

When a tsunami surges into a bay, it may grow higher because of the bay's topographic conditions and the resonance characteristics of the bay or port. A tsunami inundation simulation requires considering small topographical features such as those of the size of a fishing port. Otherwise an error may result.

(2) Errors in calculation (numerical errors)

In a tsunami inundation simulation, numerical errors may be induced by the type of governing equations, the difference method, the calculation time steps, the size of computational grids, the minimum water depth of wave front condition, etc. There may also be errors induced by relative size of computational grid intervals and topographic inclination changes or the size of linear structures.

The time series for the inundation depth, etc. needs to be checked to ensure that the calculations are performed correctly.

(3) Errors in actual measurement values (trace values), etc.

The validity of the tsunami height calculated in the tsunami inundation simulation may be determined by comparing it with actual measurement values—namely, the tsunami trace height measured after tsunami occurrence. Since actual measurement values may not be completely reliable, possible problems with verifying the calculated values need to be recognized. Whenever necessary, the reliability of measurement values should be confirmed before assessing the reproducibility of the measured values in calculation for the overall simulation area using Aida's index, described in 3.1 (3).

2. Determining the largest scale tsunami

2.1 About determining the largest scale tsunami

> Determining the potential tsunami inundation should be based on scientific knowledge and findings, and should assume the largest scale tsunami and consider all possibilities. It also requires accurate surveys regarding information on tsunami occurrences, etc., going back as far as possible. These surveys should involve activities based on scientific knowledge and findings, such as analyses of old documents, surveys on tsunami deposits, and surveys on coastal topography.

<Explanation>

A **report from the Central Disaster Management Council's Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the 2011 off the Pacific Coast of Tohoku Earthquake**, dated September 28, 2011,[11] says that future efforts to develop tsunami countermeasures will require the expectation of two different kinds of tsunami.

One of these—namely, the largest scale tsunami—is assumed in developing comprehensive disaster management measures focused on evacuating local inhabitants. This tsunami should be determined based on the survey results of extra-long-term tsunami deposits and observations of crustal deformations. A tsunami of this scale occurs at very low frequency, but would cause devastating damage if it occurred.

The other kind of tsunami is assumed when preventing tsunamis from surging inland by coastal protection facilities, etc. This kind of tsunami occurs more frequently than the largest scale tsunami, and, despite being lower in height, can result in costly damage.

Article 8, paragraph 1 of the Act on the Development of Tsunami-Resilient Communities requires prefectural governors to determine the potential tsunami inundation based on the Basic Principles and the results of basic surveys.

The Great East Japan Earthquake taught us the lesson, "disasters have no limit." Based on this lesson, the Basic Principles give priority to protecting human lives at all costs, even in the event of the largest scale tsunami, in the context of developing a tsunami-resilient community.

By giving sufficient consideration to contemporary scientific findings and to all possibilities, the potential tsunami inundation should involve assuming the largest scale tsunami that would occur from an earthquake as great as the largest earthquake possible, and that results in a greater tsunami wave height; that occurs very infrequently; and that could induce devastating damage if it occurs.

If new findings regarding tsunami fault models are obtained, the determination of the largest scale tsunami may need to be reviewed.

Some coasts require that consideration be given to apogean tsunamis. Records of past occurrences of apogean tsunamis should be organized and analyzed. If the largest apogean tsunami created a higher tsunami than those mentioned above, the apogean tsunami needs to be established as the largest scale

[11] A report from the Central Disaster Management Council's Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis 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

tsunami, and the area and depth of inundation needs to be determined based on the actual trace height.

Determining the largest scale tsunami also requires the following to be considered:

- The largest earthquake does not always correspond to the largest scale tsunami. Note the possibility of a “tsunami earthquake” that, irrespective of its size, involves a high tsunami crest.
- Also, the results of the inundation extent expected from the largest scale tsunami need to remain consistent among adjacent prefectures in terms of the size of the inundation area and the degree of damage.
- If the largest scale tsunamis considered in adjacent prefectures is based sufficiently on contemporary scientific findings, such tsunamis should be studied and be considered when determining the largest scale tsunamis.
- Reporting the potential tsunami inundation to the Minister of Land, Infrastructure, Transport and Tourism, and reporting and disclosing it to the municipal governments concerned require that the grounds for determining the largest scale tsunami be reported and disclosed as well.

2.2 Procedure for determining the largest scale tsunami

The largest scale tsunami should be determined for each Local Coast. Determine the highest tsunamis based on the actual heights of historical tsunamis, the tsunami heights assumed in the simulation, the heights of tsunamis that are assumed to occur, etc.

<Explanation>

Follow the procedure below to determine the largest scale tsunami.

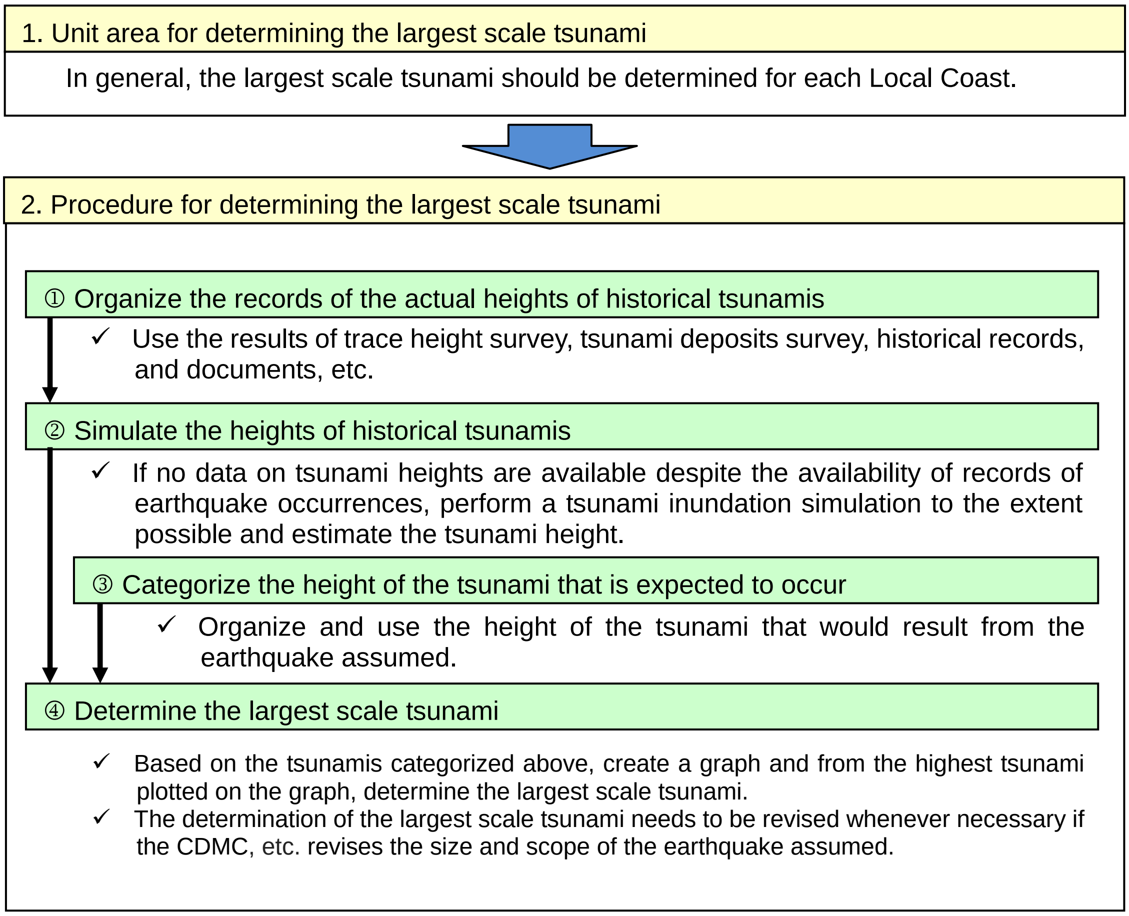


Figure 5 Procedure to determine the largest scale tsunami

(1) About Local Coast

The coastal region for which a basic coastal protection plan is developed is divided into series of “Local Coasts”. Local Coast is a unit coastal area for which it is considered reasonable to apply the same tsunami load based on the following

- Natural conditions such as the shape of the bay and coastal cliffs/mountains; and
- Actual heights of historical tsunamis obtained from related literature or historical disaster information, and tsunami heights calculated by simulations.

(2) Collecting data on the actual heights of historical tsunamis

The actual heights of historical tsunamis shall be determined from the trace heights of the tsunamis or tsunami deposits that are recorded in the surveys conducted by university research institutions, academic societies, etc., as well as historical records and documents, etc. These records shall be collected and organized as follows:

1) Collect and organize trace height data based on such documents as the Japan Society of Civil Engineers (JSCE) Coastal Engineering Committee's *Manual for Post-Tsunami Damage Survey.*[12]

   If survey results based on the manual do not exist and need to use survey results not conforming to the guide, ensure that the data is reliable.

   If the trace height near the coastline can't be obtained by surveys due to reasons such as topographical alteration, refer to other reliable data and extract data based on latitude and longitude information to obtain trace height data that is as close to the coastline as possible.

2) Concerning historical records and documents, use the data on tsunami heights used by the CDMC, etc. If the tsunami height information need to be supplemented, collect and organize published documents such as the second edition of *Nihon Higai Tsunami Soran* [A comprehensive list of the tsunamis that have hit the Japanese islands][13] and the results of existing surveys conducted by regional bureaus, prefectural governments, the Japan Meteorological Agency, etc. Use the data recorded near the coastline as much as possible, in organizing the records of historical trace heights.

(3) Assumption of historical tsunami heights by a simulation

If no data on the heights of historical tsunamis are available despite the availability of records on earthquake occurrences, refer to the results of tsunami deposit surveys, etc. and clarify the extent of inundation, etc. before trying to determine tsunami heights to the extent possible through the use of a tsunami inundation simulation, etc. In doing so, take into consideration the published results of simulations that were performed by public institutions such as the CDMC or the Headquarters for Earthquake Research Promotion.

(4) Determining the height of a potential tsunami

If a public institution such as the CDMC or the Headquarters for Earthquake Research Promotion has developed the scenario earthquakes whose possibility of occurrence have been pointed out, tsunamis expected to occur from such scenario earthquakes can be used to determine the largest scale tsunami by tsunami inundation simulation. This requires that consideration be given to determining the fault model that result in worst case tsunami height for each of the Local Coast.

(5) Determining the largest scale tsunami

For each Local Coast, create a graph with the horizontal axis representing the year in which the tsunami occurred (indicate the scenario earthquake at the right end) and with the vertical axis

[12] Fumihiko Imamura, Manual for Post-tsunami Damage Survey (Disaster Control Research Center, School of Engineering, Tohoku University, 1998).

[13] Hideo Watanabe, *Nihon Higai Tsunami Soran [A comprehensive list of the tsunamis that have hit the Japanese islands],* 2nd ed. (University of Tokyo Press, 1998).

representing the height of tsunamis along the coastline based on the data obtained in (2), (3), and (4) above that concern the actual heights of historical tsunamis, the expected tsunami height from a simulation, and the height of the tsunami that is expected from the scenario earthquakes. Plot on the graph the value representing the highest scale of tsunami, as shown in Figure 6.

The highest tsunami indicated in the graph can be determined to be the largest scale tsunami.

(6) Notes

Since the potential tsunami inundation is determined by prefectural governors, a prefecture has only one set of the largest scale tsunami which serves as the basis for determining the potential tsunami inundation. However, it should be noted that a prefecture with a peninsula and/or multiple coasts can expect to have multiple earthquakes as different earthquakes can possibly induce the largest scale tsunami in different locations within the prefecture.

Continued discussions by the CDMC, etc. may lead to reviews, etc. of the size and extent of historical earthquakes and of scenario earthquakes (e.g., earthquakes of a large magnitude or multi-segment earthquakes). In such cases, the tsunami heights should be reviewed whenever necessary.

Ensure to keep the records of determining the tsunami that generate the highest tsunami height for future reference, not only the conclusions but also the process and the grounds for the conclusion.

[Graph to determine the largest scale tsunami]

Figure 6 shows an example of a graph for determining the largest scale tsunami described in (5) above.

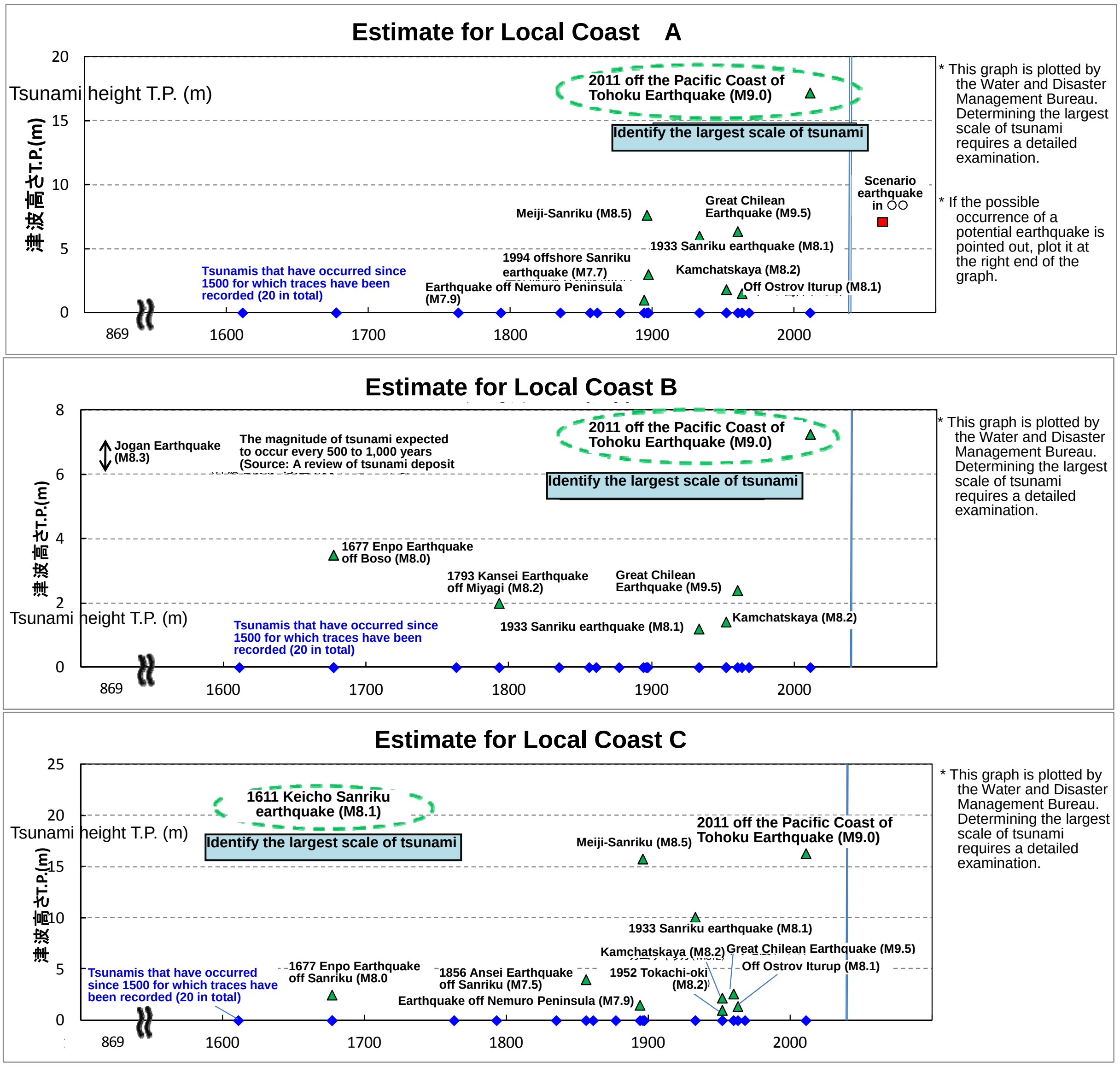


Figure 6 Example of a graph for determining the largest scale tsunami

Create the above graph in accordance with the data described in (2), (3), and (4) above. The highest tsunami plotted in the graph will be determined to be the largest scale tsunami. Note that this graph needs to be created for each Local Coast, since two or more earthquakes possibly inducing the largest scale tsunami may be expected in the same prefecture.

3. Establishing Calculation Conditions

3.1 Initial Tsunami Water Level (Fault Model)

The initial tsunami water level shall basically be calculated using a method that distributes the vertical displacement—i.e., uplift and subsidence—of the oceanic floor calculated in the earthquake fault model across the sea level. If there is a fault model that has been verified as appropriate and has been published by the CDMC, the Headquarters for Earthquake Research Promotion, or another public institution, it is permissible to use this as a reference to determine a fault model that provides the initial tsunami water level.

<Explanation>

Tsunamis are not only caused by earthquakes resulting from fault movements, but also by volcanic eruptions; irruption of sand, earth, and debris flows into the sea; submarine landslide; meteorite impacts; and many other geophysical phenomena. However, this guide focuses on tsunamis caused by earthquakes resulting from fault movements, given that these occur at a high rate of frequency and over a broad area.

The tsunami inundation simulation provides the initial tsunami water level, which means the distribution of displacement of the sea level, as a calculation condition to numerically solve the momentum equation and the continuity equation over the specified time period. Included in the simulation output, the area and depth of inundation are greatly dependent on the establishment of the initial water level.

There are two ways of defining the initial tsunami water level in the tsunami inundation simulation. One is to provide it as an initial condition and the other is to provide it as a boundary condition.

The first method is used when the tsunami source area is within the coverage area of the simulation model. It is commonly used by providing the distribution of vertical displacement of the oceanic floor computed from the earthquake fault model. This guide employs this method as a basic approach. The methods suggested by Mansinha and Smylie (1971),[26] Okada (1985),[27] and Okada (1992)[28] fall under this type of approach.

The second method is to provide the chronological changes in the tsunami's water level and flux volume at the boundary of the simulation area as the boundary condition. This is used in cases where the coverage area of the simulation model is shaped in a complex manner, or where the actual tsunami waveform observed at the mouth of a bay or in the open sea need to be used.

The initial water level condition must be revised as needed if any new knowledge about the tsunami fault model is obtained in relation to the largest scale tsunami.

(1) Establishing the initial water level or the fault model

If there is a fault model that has been verified as appropriate and has been published by the CDMC,

[26] Mansinha, L. and D. E. Smylie : The displacement fields of inclined faults, Bulletin of the Seismological Society of America, Vol.61, No.5, pp.1433-1440, 1971.

[27] Okada,Y. : Surface deformation due to shear and tensile faults in a half-space, Bull.Seism.Soc.Am., Vol.75, pp.1135-1154, 1985.

[28] Okada, Y. : Internal deformation due to shear and tensile faults in a half-space, Bulletin of the Seismological Society of America, Vol.82, No.2, pp.1018-1040, 1992.

the Headquarters for Earthquake Research Promotion, or other public institution, it is permissible to use this as a reference to determine a fault model that provides the initial tsunami water level. In this case, it is necessary to be sure to establish a tsunami fault model that constitutes an adverse condition.

For many of the sea areas for which no tsunami fault model has been published by the CDMC or other institution, there is insufficient information available at the moment.

A simulation to reproduce the height of a tsunami generated by a past earthquake shall therefore be performed, and its results shall be compared with the findings of studies on traces left by past tsunamis, on documents about them, on tsunami deposits, etc. (See "(3) Adjusting and verifying reproducibility" in this chapter) to back-calculate and define the fault model that creates the historically observed tsunami.

In this case, it is necessary to establish the conditions of various coastal facilities according to the actual damage suffered from the earthquake and tsunami being simulated. It is possible that there were no structures in historical tsunamis these facilities did not exist. With respect to those structures that require the operation of floodgates, locks, etc., the conditions shall conform to their actual open/closed state at the time of the earthquake in question, if that is known.

Materials, including studies on traces, documents, and tsunami deposits, etc., related to past tsunamis can be obtained from the results of a basic survey, according to Article 6 of the Act on the Development of Tsunami-Resilient Communities. The basic survey shall be conducted in accordance with "b. Geological and other surveys on past earthquakes and tsunamis" in "2. Guidelines for basic surveys under Article 6, paragraph 1", in the Basic Principles of the Act.

With respect to what is specified above, the fault model studied at a national public institution shall be given to prefectural governments. However, it is also stipulated that prefectural governments may create a major tsunami fault model before receiving the aforementioned fault model. It is necessary to verify that there is no inconsistency in the inundation area or the degree of damage between major tsunami flood estimates determined by the authorities of neighboring prefectures.

(2) Adjusting the initial water level or the fault model

The fault models verified as appropriate and published by the CDMC, the Headquarters for Earthquake Research Promotion, or other public institution, enable an average estimation of the entire coastline over an extensive area. They may not necessarily exhibit the best ability to reproduce tsunamis along the coast in a specific region. In view of that, if there is a detailed record of tsunami traces, such as those following the 2011 off the Pacific Coast of Tohoku Earthquake, it is possible to adjust the fault model determined in (1) in order to ensure consistency with the tsunami trace heights of the coasts in individual regions.

For any scenario earthquake or past earthquake without trace records along the coast in the region concerned, the published initial water level or the fault model may be used as is.

(3) Adjusting and verifying reproducibility

In the case of back calculating the fault model mentioned in (1) or adjusting the initial water level (the fault model) stated in (2), it is imperative to verify if the tsunami inundation simulation is capable of reproducing tsunami trace heights.

As an indicator of spatial conformity between the tsunami trace height and the calculated value, geometric average K and geometric standard deviation κ proposed by Aida (1997)[29] are commonly used.

$$\log K = \frac{1}{n}\sum_{i=1}^{n}\log K_i \qquad \log\kappa = \left[\frac{1}{n}\left\{\sum_{i=1}^{n}(\log K_i)^2 - n(\log K)^2\right\}\right]^{1/2}$$

Where,

n is the number of locational points, $K_i = R_i/H_i$, R_i is the tsunami trace height at point i, and H_i is the calculated value at point i.

Geometric average K represents the average degree of conformity between the tsunami trace height and the calculated value. As the K value gets closer to 1, the calculated value becomes more closely aligned with the tsunami trace height. On the other hand, geometric standard deviation κ represents the dispersion of the degree of correspondence between the tsunami trace height and the calculated value. The smaller κ means there is a closer relationship between the measured and calculated values. The following is generally used as a rough guide to K and κ[30]:

$$0.95 < \mathrm{K} < 1.05 \qquad \kappa < 1.45$$

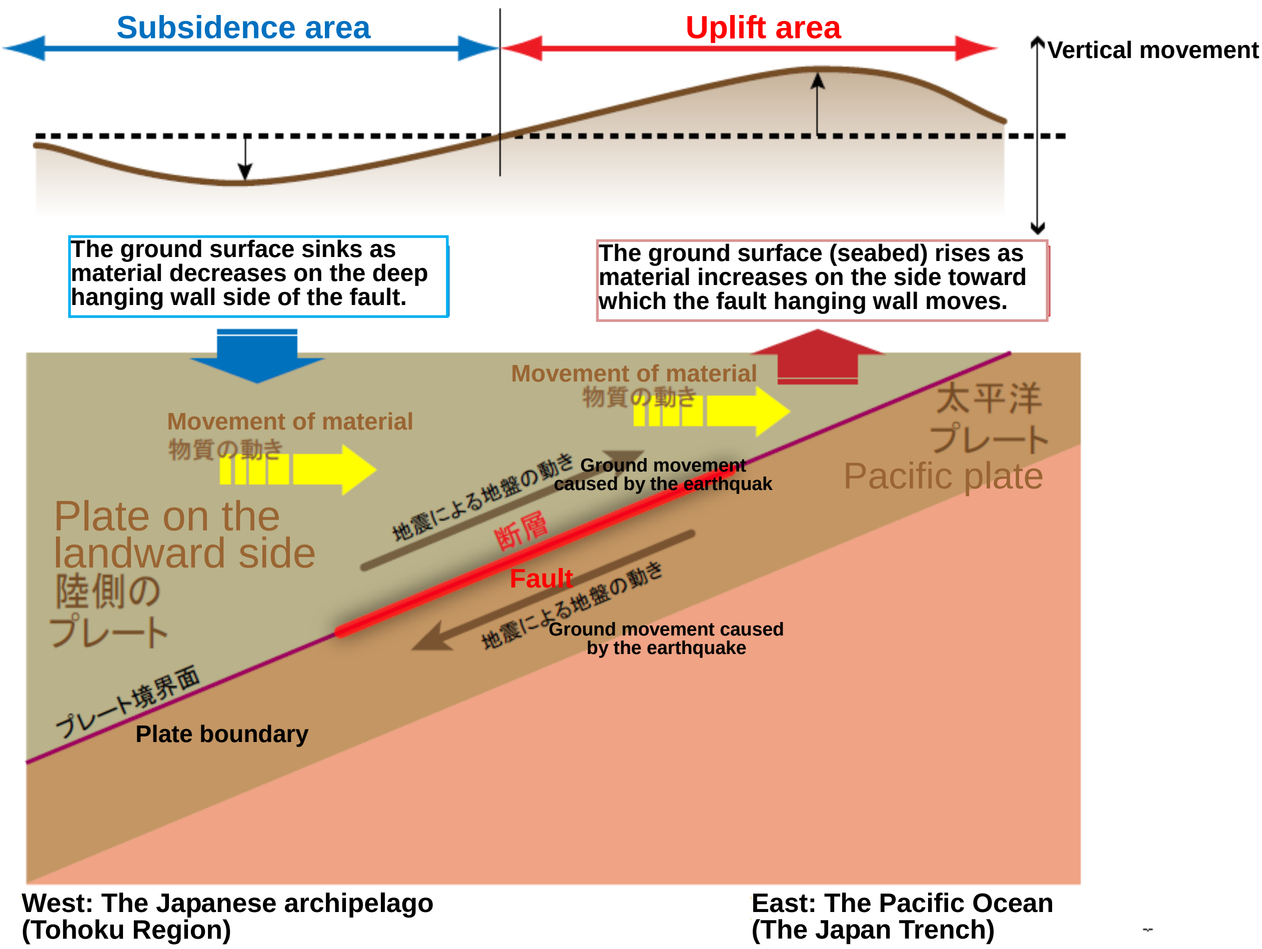
[29] I. Aida, " Simulations of Large Tsunamis Occurring in the Past off the Coast of the Sanriku District." in the *Bulletin of the Earthquake Research Institute*, Vol. 52 (1977): 71-101.

[30] The Tsunami Evaluation Subcommittee, The Nuclear Civil Engineering Committee, Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan* (2002 edition), 1-26, http://committees.jsce.or.jp/ceofnp/system/files/TA-MENU-J-01.pdf.

[Fault model overview]

The earthquake fault model expresses the mechanism behind the occurrence of an earthquake in the form of the fault movement. The model is composed of dynamic fault parameters and static fault parameters. Among these, it is mainly the static fault parameters that are required as the initial condition for tsunami calculations. In the event of a large-scale tsunami involving interactions between multiple faults, like those following the 2011 off the Pacific Coast of Tohoku Earthquake and similar, it is occasionally necessary to consider the dynamic fault parameters, such as rupture velocity and rising time. In this case, the tsunami waveform shall be given in addition to the initial water level.

An ordinary natural earthquake occurs when the bedrock on both sides of an underground fault move along the fault. No fault movement takes place instantaneously throughout the fault surface. First, the movement begins at a single point. It spreads along the fault surface at a speed of around 3 kilometers per second. The fault model describes this phenomenon. It helps calculate the distribution of the vertical displacement of the oceanic floor. Assuming that the inflow and outflow of seawater above the fault is sufficiently slower than the seabed movement and the amount of seawater compression is sufficiently small, the initial tsunami water level, or the distribution of sea level displacement, is considered to be analogous to the distribution of the vertical displacement of the oceanic floor.



This diagram schematically represents the relationship between fault movements and vertical movements on the ground surface. In the case of the 2011 off the Pacific Coast of Tohoku Earthquake, a reverse fault movement occurred at the plate boundary. As shown in the diagram, an uplift took place off the coast while subsidence occurred on the landward side.

Figure 7 Relationship between Fault Movements and Vertical Movements in the 2011 off the Pacific Coast of Tohoku Earthquake (Geospatial Information Authority of Japan)

The fault model determines the distribution of the vertical displacement of the oceanic floor and the initial tsunami water level for the tsunami inundation simulation.

The fault model is expressed through parameters such as the orientation (strike) and inclination (i.e., the rake and dip) of the fault plane, the amount of displacement of the plane, and the destruction speed. Table 2 lists the parameters in the fault model. These specifications directly impact the scale of the tsunami and the amount of inundation.

Table 2 Fault Model Parameters

Reference Point: Latitude N, Longitude E	Location of the fault plane When looking at a fault plane from a position in which it dips towards the near side, the upper left-hand point is defined as the reference point of the fault. Its latitude, longitude, and depth are indicated.
Fault Top End Depth: d	
Fault Length: L	Scale of the fault plane
Fault Width: W	
Dislocation: D	
Strike: θ The azimuth angle (the clockwise angle from the north meridian) of the fault direction	Orientation of the fault plane
Dip: δ The vertical angle between the horizontal plane and the fault plane	
Rake: λ The direction of fault movement	

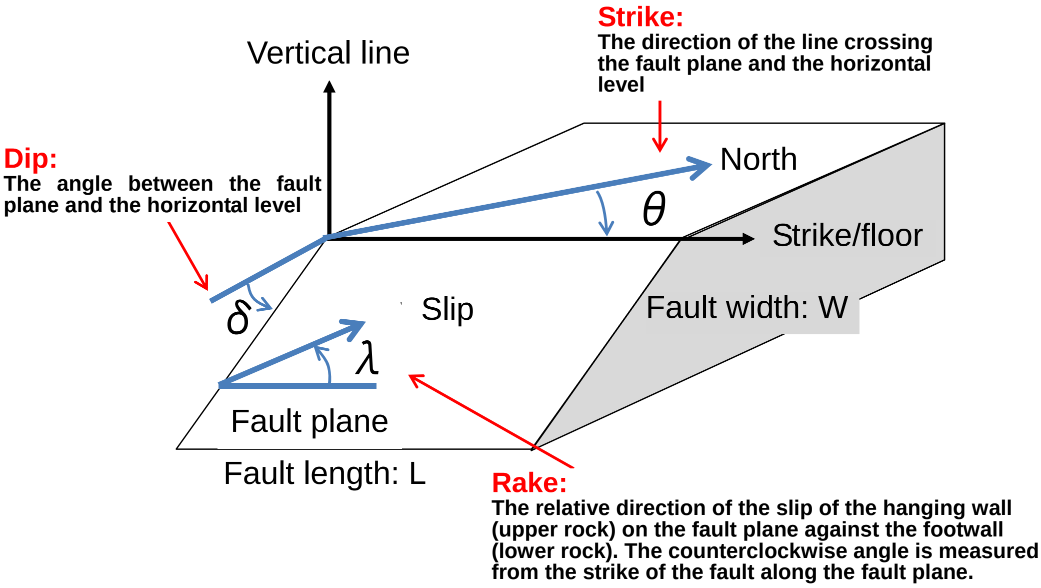


Figure 8 The Conceptual Diagram of Fault Model Parameters

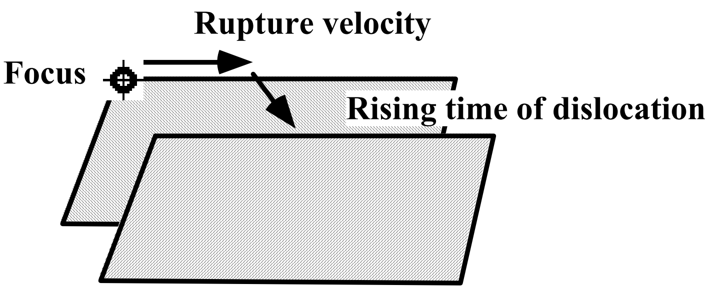
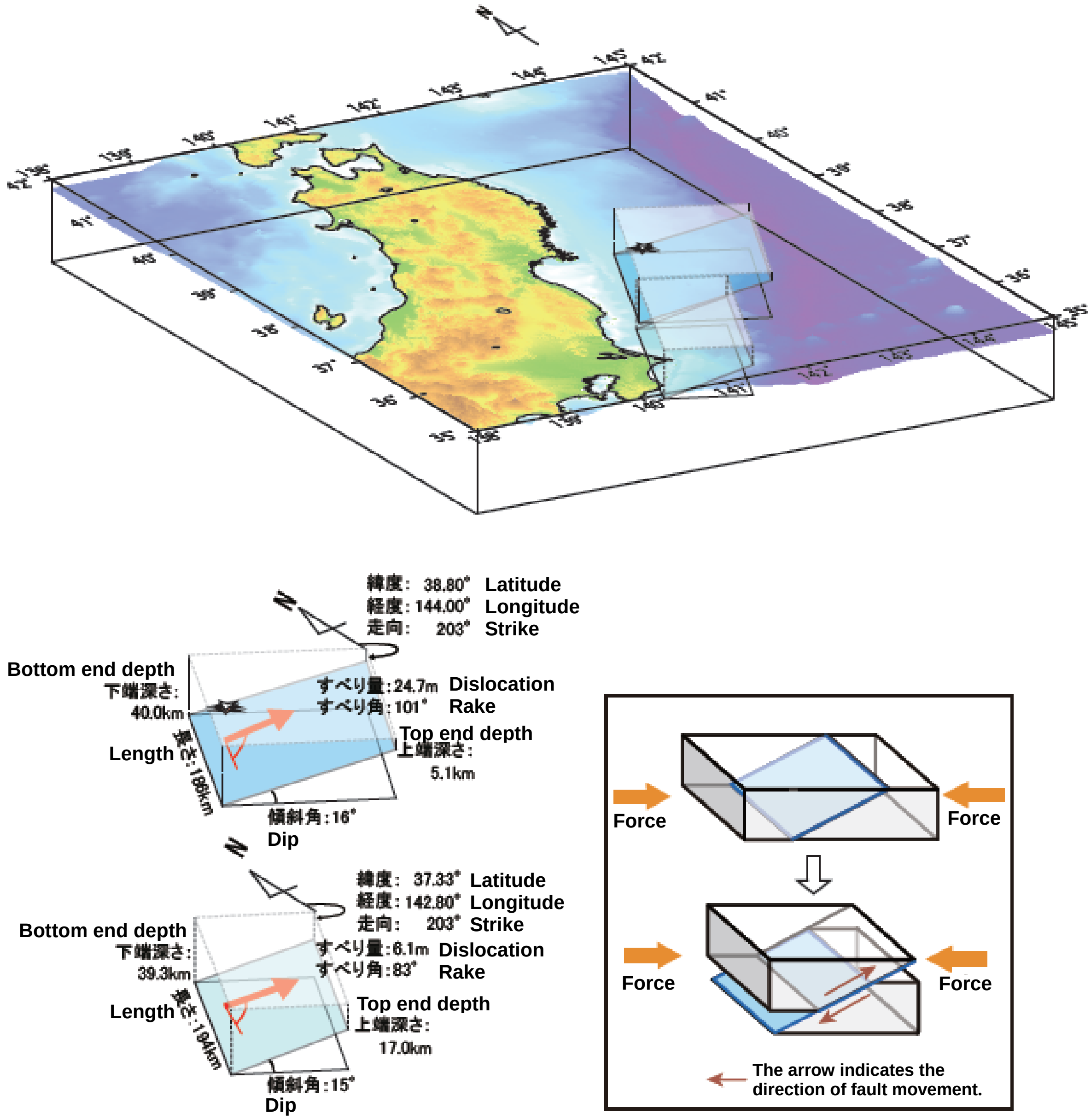


Figure 9 Dynamic Fault Parameters



Fault Model Parameters

Latitude	Longitude	Top End Depth	Length	Width	Strike	Dip	Rake	Dislocation	Moment Magnitude
38.80° N	144.00° E	5.1 km	186 km	129 km	203°	16°	101°	24.7 m	8.8
37.33° N	142.80° E	17.0 km	194 km	88 km	203°	15°	83°	6.1 m	8.3

Figure 10 Diagram of the Epicenter Fault Model of the 2011 off the Pacific Coast of Tohoku Earthquake

(Geospatial Information Authority of Japan)

3.2 Tide Level (Astronomical Tide)

To estimate the potential tsunami inundation, the tide level (astronomical tide) to be used for tsunami inundation simulation shall be in principle the mean monthly-highest water level (HWL).

<Explanation>

The higher the tide level, the more likely tsunamis are to runup on land after reaching the coast. Thus, the area and depth of inundation will accordingly be larger.

Given that, to estimate the potential tsunami inundation, the tsunami inundation simulation needs to produce a worst-case scenario for the inundation area and depth, the tide level (astronomical tide) must basically be set at the mean monthly-highest water level (HWL).

However, the recent disaster has taught us the lesson that "disasters have no upper limit." From the perspective of protecting human lives at all costs, a tide level higher than the HWL may be set.

In the case of a simulation to reproduce the height of an observed tsunami of a past earthquake, the tide level at the time that the tsunami to be compared and examined reached the area shall be set, in principle. If this tide level is unknown, the tide level (astronomical tide) can be set at the mean tide level or at *Tokyo Peil* (T.P.), 0 m.

The initial water level in a river shall be set at the water level obtained from the river flow volume in the non-uniform flow calculation, with the tide level set in this section as the downstream boundary condition near the estuary, in accordance with the *Guide to Analyzing Tsunami Runup in Rivers* (draft).[31]

The river flow volume shall be set at the normal flow volume (185 days/365 days) when determining the potential tsunami inundation and at the actual flow volume at the time the tsunami if the simulation is being conducted to reproduce or verify the actual tsunami inundation.

[31] Japan Institute of Construction Engineering, *Guide to Analyzing Tsunami Runup in Rivers* (draft), 2007, http://www.jice.or.jp/siryo/t1/pdf/tsunami.pdf.

3.3 Computational Area and Grid Size

In the tsunami inundation simulation, the computational area and the grid size shall be properly determined to obtain a highly accurate estimate of tsunami behavior in consideration of the scale of the tsunami source area, the spatial distribution of tsunami wave, the seabed/land topographical features, and the micro-topography and structures around the coastal region to be studied.

<Explanation>

(1) Computational area

In the tsunami inundation simulation, the computational area must be determined, and must include the tsunami source area to ensure a highly accurate estimate of refraction, reflection, runup, etc.

(2) Computational grid size

In the tsunami inundation simulation, the computational grid size must be set to ensure a highly accurate estimate of refraction, reflection, runup, and other tsunami behaviors.

According to Hasegawa et al. (1987), the recommended grid size is 1/20th or less of a single tsunami wavelength in space throughout the principal computational area.

In areas where the refraction phenomenon is deemed to have a significant impact, a calculation grid interval of 1/100th or less of a single tsunami wavelength in space may occasionally be required (Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan*).

In the open sea, a single tsunami wavelength is on the order of several tens to several hundreds of kilometers, but off the coast, the lower the water depth, the shorter the wavelength. Accordingly, a finer computational grid size is required. It is therefore common to use a method of simultaneously calculating multiple computational areas of different grid sizes connected according to the tsunami waveform in space and the topographical features (nesting). In such calculation, the component grid size is often reduced by 1/3, or 1/2, etc., in order to mitigate the influence of the part of the short wavelength component generated in a small area failing to propagate to the larger area and being reflected again.

On the landside, it is permissible to define the grid size (Δx) using the equation shown below, where α is the inclination of the sloping surface, T is the period, and g is the gravitational acceleration (Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan*[32]), but the minimum grid size must generally be smaller than around 10 meters so that local topographical features can be described.

$$\frac{\Delta x}{\alpha g T^2} \leq 7 \times 10^{-4} \quad \text{(in the case of Manning's coefficient of roughness, n = 0.03m}^{-1/3}\text{s)}$$

A smaller grid size leads to greater precision, but it is necessary to note that this also results in a greater computational load and higher cost for data preparation.

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[32] The Tsunami Evaluation Subcommittee, The Nuclear Civil Engineering Committee, Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan* (2002 edition), 1-51, http://committees.jsce.or.jp/ceofnp/system/files/TA-MENU-J-01.pdf.

3.4 Preparation of Topographical Data

As topographical features in the sea and on land have a considerable impact on tsunami propagation and runup, topographical data are indispensable to predicting tsunami behavior. The tsunami inundation simulation also uses topographical data, consisting of grid-shaped numerical data.

<Explanation>

Topographical data are obtained from the results of the basic survey pursuant to Article 6 of the Act. The basic survey shall be conducted in accordance with "a. Surveys of topographical features in sea and land areas" in "II. Guiding principles for basic surveys" in the Basic Principles.

To create topographical data at the highest resolution based on grids that are several meters by several meters in size, the results of aviation laser surveys conducted by the Ministry of Land, Infrastructure, Transport and Tourism and others shall be used, in general.

Topographical data in a sea area may be called "bathymetry data" or "water depth data." Topographical data in a land area may be called "topographical data" or "elevation data."

Given that topographical data have some impact on the inundation area and the water depth obtained in the tsunami inundation simulation, efforts shall be made to keep topographical data up to date, and the greatest possible consideration shall be given to the ground deformation created by the 2011 off the Pacific Coast of Tohoku Earthquake and similar earthquakes.

In the land area that underwent ground deformation following the 2011 off the Pacific Coast of Tohoku Earthquake, in general it is imperative to use grid elevation data. In areas for which no topographical data is available after the 2011 off the Pacific Coast of Tohoku Earthquake, it is permissible to use the grid elevation data before the earthquake in consideration of the amount of ground deformation caused by the quake.

In any land area where ground deformation occurred due to the 2011 off the Pacific Coast of Tohoku Earthquake and where no aviation laser surveys have been conducted since the quake, topographical data obtained by aerial photography (stereo matching) may be used.

Generally, the mean sea level of Tokyo Bay, also known as *Tokyo Peil* or T.P., shall be the reference level for the elevation in land areas, while the reference level for tide level observation, known as Datum Line (DL) shall be used as the reference level for the sea water level (tide level) in sea areas.

The tsunami inundation simulation is designed to treat the sea area and the land area in an integrated manner. Therefore, it basically uses topographical data using T.P. as the reference level. The interface between different topographical data materials shall be properly processed in view of the local topographical conditions.

When creating topographical data from grid-shaped numerical data, it is necessary to pay attention to whether or not they are reasonable in comparison with the actual topography or the map, given that the accuracy of the topographical data is a significant factor that has some impact on computation accuracy, as well as the grid size.

For topographical data on sea areas and land areas, refer to “5.2 Information on Topographical Data (Sea Area)” and “5.3 Information on Topographical Data (Land Area),” respectively, in this guide.

3.5 Coefficient of Roughness

In the case of a tsunami reaching the coastal area and running up onto the land, the resistance of the seabed and the ground surface cannot be ignored. This resistance shall basically be taken into consideration in the tsunami inundation simulation by using the coefficient of roughness.

<Explanation>

In the case of a tsunami reaching the coastal area and running up onto the land, the resistance of the seabed and the ground surface cannot be ignored. The friction term shown below shall be taken into consideration in the momentum equation used in the tsunami inundation simulation.

$$\frac{gn^2 M}{D^{7/3}}\sqrt{M^2+N^2}\ ,\ \frac{gn^2 N}{D^{7/3}}\sqrt{M^2+N^2}$$

In the term above, *n* represents Manning's coefficient of roughness. For sea areas, a value of around 0.025 ($m^{-1/3}s$) is often used. For land areas, it is common practice to adopt the method of establishing different values according to the state of land use so that the degrees of resistance such as those generated by tsunamis running through buildings in urban areas, etc. can be described.

Therefore, coefficient of roughness values defined according to the land use, such as those shown in Table 3, are being proposed.

For the purpose of establishing the coefficient of roughness, the land use can be obtained from the results of the basic survey pursuant to Article 6 of the Act. The basic survey shall be conducted in accordance with "c. Surveys on land use and others" in "2. Principles for basic surveys in the Basic Principles in Article 6, paragraph 1 of the Act."

Table 3 Example of Establishing the Coefficient of Roughness (Kotani et al. [1998])

Land Use	Coefficient of Roughness $m^{-\frac{1}{3}} \cdot s$
Residential land (high density)	0.08
Residential land (medium density)	0.06
Residential land (low density)	0.04
Factory and other land	0.04
Farmland	0.02
Forest land	0.03
Water	0.025
Other (vacant lots, green spaces, etc.)	0.025

Source: M. Kotani, F. Imamura, and N. Shuto, "Tsunami Run-Up Simulation and Damage Estimation Using GIS" in

Proceedings of Coastal Engineering, *JSCE* 45 (November 1998).

When dealing with any large-scale linear embankment structure or building that is not expressed as a coefficient of roughness value but as topographical data, it is necessary to be careful regarding consistency, for instance, by using the coefficient of roughness value for “Other (vacant lots, green spaces, etc.).”

In cases where the land use at the time of the tsunami being studied is unknown and where a large number of residential houses were washed away by the tsunami under review, it is possible to uniformly set the coefficient of roughness at the value for “Other (vacant lots, green spaces, etc.).”

3.6 Treatment of Different Facilities

Any aboveground linear structure that is in the path of tsunami propagation or runup shall basically be processed as topographical data if its width is larger than the computational grid size. If it is smaller, it shall basically be processed as a grid boundary to which the overflow conditions will apply.

<Explanation>

(1) Impact on inundation prediction results

Any aboveground linear structure that is in the path of tsunami propagation or run-up will have some influence on the tsunami's behavior. The tsunami may flow through its openings, floodgates, locks, or equivalent.

(Examples of linear structures)

- Coastal levees and equivalent
- Port facilities and fishing port facilities (seawalls and breakwaters)
- River levees and equivalent
- Embankments for roads and railways and similar structures

(2) Viewpoints on the treatment of different facilities

(i) Linear structures

Given that large-scale linear structures affect tsunami behavior, any such structure with a relative elevation of 50 cm or more from the average ground height must be reflected in the tsunami inundation simulation.[33]

The treatment of linear structures in the tsunami inundation simulation will vary, depending on their scale and on the relative size compared with the computational grid size. In general, any linear structure with a width larger than the grid size is described in the topographical data by providing its elevation data in the relevant grid cells.

However, it is common to regard any linear structure with a width smaller than the calculation grid interval as a wall between computational grid cells; i.e., a grid boundary. Its elevation is generally taken into account as part of the overflow conditions.

There is an alternative method of setting the crest height as a grid boundary in combination with the overflow conditions while processing the shape of its cross section as topographical data.

Permeable offshore breakwaters, constructed by piling up wave-dissipating concrete blocks, must be treated as non-existent facilities.

[33] River Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, *Manual for Preparing Flood Risk Maps* (2005), 13, http://www.mlit.go.jp/river/shishin_guideline/bousai/press/200507_12/050705/050705_manual.pdf.

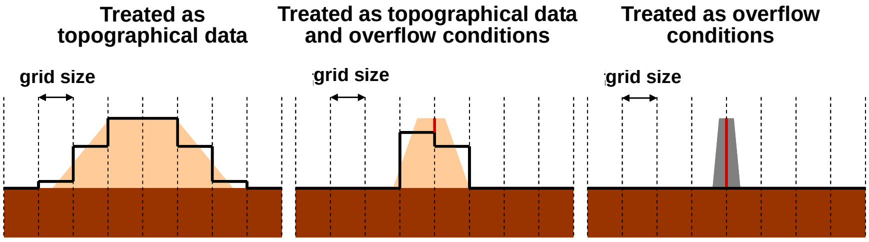

Figure 11 Examples of the Treatment of Structures in a Tsunami Inundation Simulation

(ii) Openings of linear structures, floodgates, inland lock gates and equivalent

If a linear structure has a large opening, such as a box culvert, it has to be taken into account in the tsunami inundation simulation; e.g., it may be regarded as an opening.

3.7 Ground Deformation Induced by an Earthquake

In the case of assuming subsidence in a land or sea area as a result of an earthquake, the deformation calculated from the fault model shall basically be subtracted from the height included in the topographical data for the land or sea area.

In the case of assuming an uplift in a land area after an earthquake, the uplift calculated from the fault model shall not be taken into account. However, where an uplift is presumed in a sea area after an earthquake, the uplift calculated from the fault model shall basically be taken into consideration.

<Explanation>

If an earthquake induces subsidence in a land area, the height of the ground or linear structure is reduced by the subsidence. This creates circumstances where a tsunami is more likely to runup onto land. It is therefore basically imperative to calculate the subsidence from the fault model and subtract this from the height of the topographical data for the land area.

In contrast, if an earthquake is presumed to cause an uplift in a land area, this means that a tsunami will not runup as high. However, in consideration of the purpose of determining the potential tsunami inundation, which is to calculate the maximum possible inundation area and inundation depth, the uplift shall be disregarded, as has been done by the Panel on the Nankai Trough Massive Earthquake Model[34] and as instructed in the *Tsunami and Storm Surge Hazard Map Manual*.[35]

The uplift and subsidence in any sea area calculated from the fault model shall basically be taken into consideration in order to reproduce the topography of the seabed after the earthquake. However, the interface with the land area shall be smoothed out if necessary in order to ensure continuity with the land area where uplifts and subsidence are not taken into consideration.

Table 4 and Figure 12 show the principles regarding the treatment of uplift and subsidence in land areas and sea areas.

Table 4 Treatment of Uplift and Subsidence in Land Areas and Sea Areas

	Uplift	Subsidence
Land Area	Not taken into consideration	Taken into consideration
Sea Area	Taken into consideration	Taken into consideration

34 Cabinet Office (Disaster Management), *Estimation of Tsunami Levels, Inundation Areas (Second Report) and Estimation of Damage (First Report) related to Nankai Trough Massive Earthquake*, 2012, http://www.bousai.go.jp/nankaitrough_info.html

35 Cabinet Office (Disaster Management), Rural Development Bureau and Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries, River Bureau and Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, *Tsunami and Storm Surge Hazard Map Manual* (2004), 43.

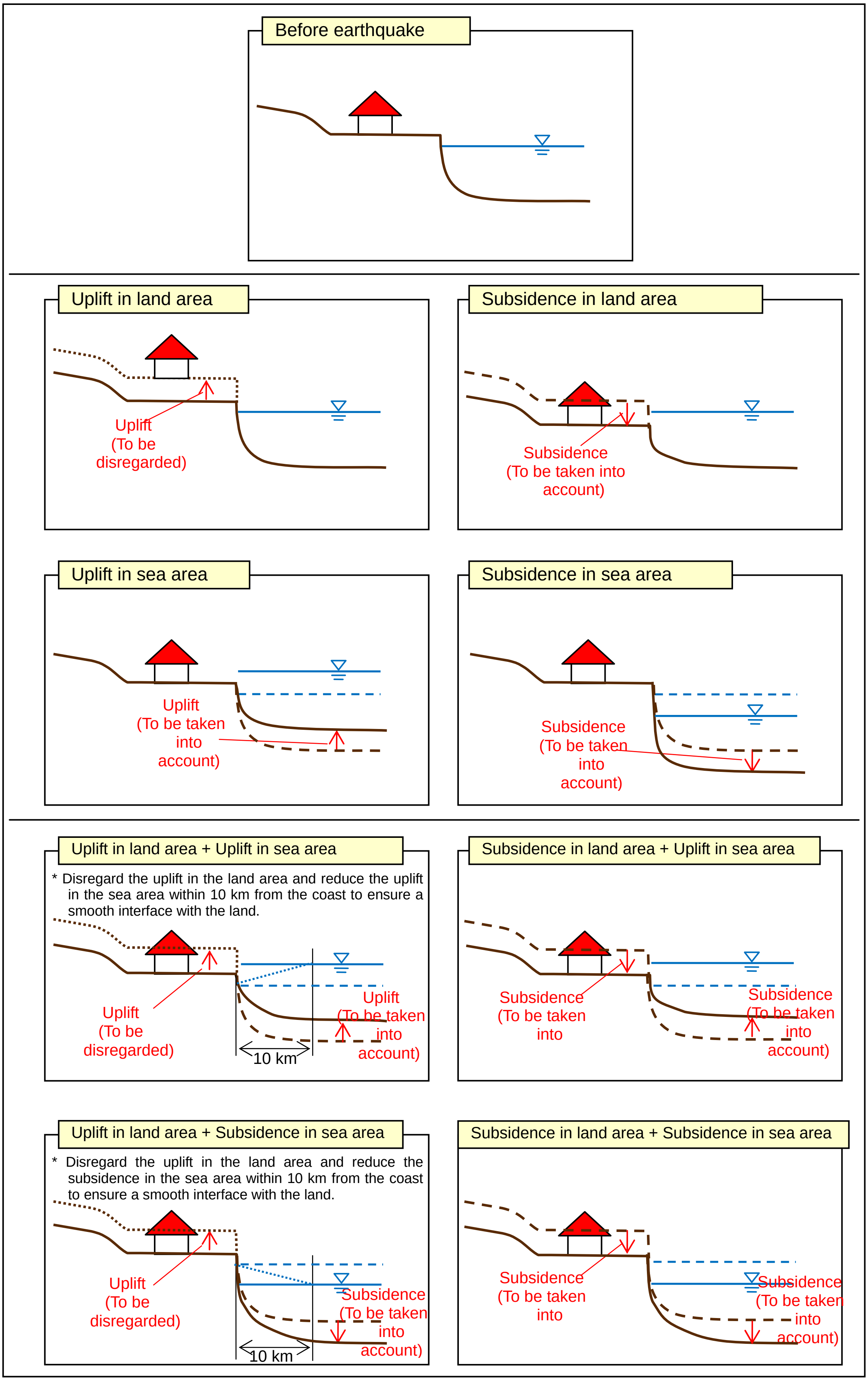

Figure 12 Conceptual Diagram of Uplift and Subsidence

3.8 Treatment of Tsunami Runups in Rivers

For treating tsunamis running up rivers, *Guide to Analysis of Tsunami Runups in Rivers* (draft) shall basically be referred to. In addition, relevant river management body shall be coordinated with for relevant rivers.

<Explanation>

Some tsunamis that originate from the earthquake epicenter and reach the coast may come through an estuary, running up a river and causing overflow, resulting in flooding.

The tsunami inundation simulation will fail to properly estimate the flooding from the river if consideration isn't given to the river's topography, such as the planform of the river channel and the river bed elevation.

Accurately describing the tsunami behavior in rivers requires establishing topographical grid data based on the cross and long profiles of rivers, held by their respective river management body. The *Guide to Analyzing Tsunami Runup in Rivers* (draft)[36] shall basically be referred to for the treatment of tsunamis running up rivers. It is also imperative to coordinate with the relevant river management body of relevant rivers.

[36] Japan Institute of Construction Engineering, *Guide to Analyzing Tsunami Runup in Rivers* (draft), 2007, http://www.jice.or.jp/siryo/t1/pdf/tsunami.pdf

3.9 Computational Time and Time Steps

The computational time for the tsunami inundation simulation shall be determined to calculate the maximum inundation area and maximum water depth in consideration of tsunami characteristics and other conditions.

The computational time step for the tsunami inundation simulation shall be properly determined in consideration of computational stability and other factors.

<Explanation>

(1) Computational time

In a tsunami, the first wave is not always the biggest. Depending on the initial water level condition and tsunami's behavior along the coast, a second or later wave may possibly result in the greatest inundation area or the inundation depth. A sufficient computational time must be set to obtain the maximum inundation area and maximum water depth.

(2) Computational time step

It is necessary to set the computational time step to meet the CFL condition presented below in consideration of computational stability against the properly determined computational grid size:

$$\Delta t \leq \frac{\Delta x}{\sqrt{2gh_{\max}}}$$

Where,

Δt is the length of the time step, Δx is the grid size, $h_{\max}$ is the maximum water depth, and g is the gravitational acceleration.

However, actual calculations involve numerical errors and non-linear phenomena. It is therefore necessary to set the time step at a sufficiently small value in comparison with the aforementioned condition (Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan*[37]).

[37] The Tsunami Evaluation Subcommittee, The Nuclear Civil Engineering Committee, Japan Society of Civil Engineers, *Tsunami Assessment Method for Nuclear Power Plants in Japan* (2002 edition), 1-52, http://committees.jsce.or.jp/ceofnp/system/files/TA-MENU-J-01.pdf.

4. Tsunami Inundation Simulation

4.1 Purpose

A tsunami inundation simulation to determine the potential tsunami inundation shall be performed with the purpose of finding the maximum inundation area and the maximum water depth estimated from the largest scale tsunami.

<Explanation>

The potential tsunami inundation depends on building locations, the status of the development/maintenance of linear structures, etc. For this reason, any changes that might affect the behavior of a tsunami inundation must be followed by another tsunami inundation simulation and by, whenever necessary, a review of the potential tsunami inundation.

The potential tsunami inundation is used for such purposes as designating Security Zones. In the areas affected by the 2011 off the Pacific Coast of Tohoku Earthquake and the resulting tsunami, a tsunami inundation simulation must be performed in terms of the land use (zoning) specified in the reconstruction plan, etc. and the layout, height, etc. of the linear structures that are expected to function as secondary barriers to prevent tsunamis from penetrating further inland.

4.2 Establishing facility conditions

Based on the lesson, “disasters have no limit,” and with the priority of protecting human lives at all costs, a tsunami inundation simulation to determine the Potential Tsunami Inundation should, in principle, involve the assumption that the largest scale tsunami will occur under adverse conditions and cause inundation, and that facilities will be damaged from the earthquake and/or the tsunami.

In principle, facilities such as floodgates and land locks shall be treated as follows: Automated facilities with anti-seismic capabilities, permanently-closed facilities, and anti-seismic facilities that can be closed before the arrival of a tsunami shall be considered "closed". Any facilities other than the above mentioned shall be considered "open".

<Explanation>

Facilities satisfy safety requirements against earthquakes and tsunamis that are assumed in their design. However, they could be affected by an earthquake or a tsunami that exceeds their design capabilities. Facility conditions need to be based on the lesson “disasters have no limit,” and priority given to protecting human lives at any cost. For this reason, a tsunami inundation simulation shall in principle be performed with the assumption that the largest scale tsunami will occur under adverse conditions and cause flooding, and that facilities will be damaged from such earthquake and/or the tsunami.

Establishing facility conditions requires the effects of the facilities that have been constructed so far to be included, based on the latest scientific knowledge and findings. The effects of future earthquake-protection inspections and measures also need to be included in the future facility conditions, with the assumption that the potential tsunami inundation may be revised.

(1) Establishing facility conditions against earthquakes

Establishing conditions for tsunami inundation simulations should involve setting conditions of facility damage due to earthquakes, which can be based on the results of existing verifications, conducted in compliance with the appropriate methods of anti-seismic capacity analysis. More specifically, a facility’s resistance to an earthquake that could induce the largest scale tsunami must be analyzed. Facilities with insufficient anti-seismic capacities shall be classed as either “settled” or “failed.” The post-destruction shapes of “failed” facilities shall be appropriately set according to their structure.

Technical Standards for Coastal Protection Facilities and Their Explanatory Notes define the method for analyzing the anti-seismic capacities of coastal protection facilities as follows:

- A facility may be deemed to satisfy the required resistance to Level 1 ground motion if it is shown to be safe in terms of an anti-seismic design that is properly in accordance with the seismic coefficient method. If a facility is judged to possibly suffer from liquefaction, however, it shall be verified properly in accordance with anti-seismic capacity requirements.
- Resistance to Level 2 ground motion may be verified using methods that facilitate an accurate evaluation of deformation, stress, strain, etc.

The *Inspection Manual for anti-seismic capacities of Coastal Protection Facilities* [38] includes methods for estimating the extent of the subsidence of coastal levees, etc. resulting from Level 1 ground motion. The *Manual for Inspection of River Levees Resistance to Level 2 Ground Motion* [39] mentions inspecting the resistance of levee embankment to Level 2 ground motion. This is a useful reference for verifying the anti-seismic capacities of coastal levees.

(2) Determining facility conditions against tsunami

In the event of a tsunami, a coastal/river levee, etc. may be regarded as being "failed" from the time the tsunami begins to overtop it, with consideration also being given to the destruction of coastal and river levees from the tsunami induced by the 2011 off the Pacific Coast of Tohoku Earthquake. In general, a failed facility is considered to have completely lost its shape.

High-standard river levees (super levees) or coastal levees with particular topographical features behind such levees may not be considered as being "failed", if sufficient technical evidence is available.

In case of a river levee, etc., tsunami that runup in a river may start overtopping levees in the upstream area, and the inundation area of water depth varies depending on when and where the levee is considered to have failed. Thus, it should be noted that considering that the levee is "not failed" at the time of overtopping may result in worse condition.

Based on the above and in compliance with Article 8, paragraph 3, of the Act, prefectural governors shall obtain the opinion of the coastal/river management bodies concerned, when it is deemed necessary in terms of establishing conditions for coastal/river levees, etc. against the largest scale tsunami.

The damage conditions of linear structures such as roads and railroads, which are expected to function as secondary barriers to prevent tsunamis from penetrating further inland, shall be assessed separately based on examples of the destruction of linear structures by the tsunami induced by the 2011 off the Pacific Coast of Tohoku Earthquake, etc.

Up till now, technical knowledge and findings on the structures and shapes of park greenery and other possibly tsunami-resistant artificial embankments have been insufficiently organized. In a technical document,[40] the dissipation of a tsunami's energy was verified in an idealized model where, for example, a tsunami would not cause the corrosion of embankments.

It should also be noted that the ability of green belt such as park greenery, and coastal protection forests to dissipate energies from the largest scale tsunami is limited, and their effectiveness may

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[38] Agricultural Structure Improvement Bureau of the Ministry of Agriculture, Forestry and Fisheries; Fisheries Agency; Ports and Harbors Bureau of the Ministry of Transport; and River Bureau of the Ministry of Construction, *Inspection Manual for Earthquake-resistance of Coastal Protection Facilities*, 1996.

[39] River Improvement and Management Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, *Manual for Inspection of River Levees Resistance to Level 2 Ground Motion*, 2012, http://www.mlit.go.jp/river/shishin_guideline/bousai/wf_environment/structure/pdf/ref06.pdf.

[40] Parks, Green Spaces and Landscape Division, City Bureau, Ministry of Land, Infrastructure, Transport and Tourism, *Technical Guidelines for the Development of Park Greenery Concerning Reconstruction from the Great East Japan Earthquake*, 2012, http://www.mlit.go.jp/report/press/toshi10_hh_000097.html.

become insignificant.[41,42] However, some methods are available to consider the ability of forests to decrease momentum in tsunami inundation simulations. These methods involve adding a term representing forest resistance to the momentum equation (Harada et al., 2000)[43] and expressing forest resistance as the coefficient of roughness (Harada and Kawata, 2005),[44] among other approaches.

(3) Opening and closing of floodgates, land locks, etc.

The floodgates, land locks, etc. that would definitely remain operable from the occurrence of an earthquake inducing the largest scale tsunami until the arrival of the tsunami, shall be considered closed, while other floodgates, land locks, etc. shall be considered open.

Tidal barrages that are closed at high tide are basically considered closed. However, in case tidal barrages are open (if it has collapsed due to ground motion), the inundation area and water depth upstream of the barrage can become larger. There have been some examples where a barrage was considered open and the inundation area and depth upstream of the barrage were calculated.

<Reference> Example of establishing facility conditions against earthquakes and tsunamis (Figure 13)

Facilities that have been investigated for their risk of liquefaction in the event of an earthquake ground motion that induces the largest scale tsunami, and those that have been determined to be resistant to such earthquake and are free from the risk of subsidence, shall be regarded as ”no subsidence” against such earthquake, as shown in Pattern 1. They will however be considered to have failed when overtopped by tsunami. As shown in Pattern 2, any other facility shall consider subsistence after earthquake by incorporating quantitatively assessed subsistence into the facility condition, and will also be considered to have failed when overtopped by tsunami.

A revetment or other concrete structure that has yet to undergo such surveys shall be regarded as possibly settle to the relative elevation of zero when an earthquake occurs, as shown in Pattern 3. A coastal levee, etc. such as an embankment structure, shall be regarded as possibly settle by the relative elevation of 75% (the maximum subsidence rate observed in past records of post-earthquake river levee subsidence), as shown in Pattern 2 and based on Figure 14. This type of structure shall also be regarded as being failed to the relative elevation of zero when tsunami begins to overtop.

Due to the lack of ground motion estimates of earthquakes inducing the largest scale tsunami, it may be practically difficult at this point to analyze a structure’s resistance to an earthquake. If this is the case, for the sake of convenience, using Level 2 ground motion to set the liquefaction risk of facilities and the anti-seismic capacities of levees may be considered.

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[41] Ibid.

[42] *Panel for the Discussion on the restration of Coastal Anti-disaster Forests Concerning the Great East Japan Earthquake* (Forestry Agency), *Future Regeneration of Coastal Anti-Disaster Forests*, 2012, http://www.rinya.maff.go.jp/j/press/tisan/120201.html.

[43] Kenji Harada, Takako Aburaya, Latief Hamzah, and Fumihiko Imamura, “ Examination on Coastal Forest to Reduce a Tsunami Energy,” *Proceedings of Coastal Engineering*, 47 (2000): 366-370.

[44] Kenji Harada and Yoshiaki Kawata, “ Study on the Utilization of Coastal Forest for Tsunami Mitigation,” *Proceedings of Coastal Engineering*, 52 (2005): 276-280.

Either way, if a new ground motion is estimated or survey results on liquefaction risks and the anti-seismic capacities of levees are obtained, the classification of facilities into the patterns shown in the figure may be revised although the basic principles described above shall remain relevant.

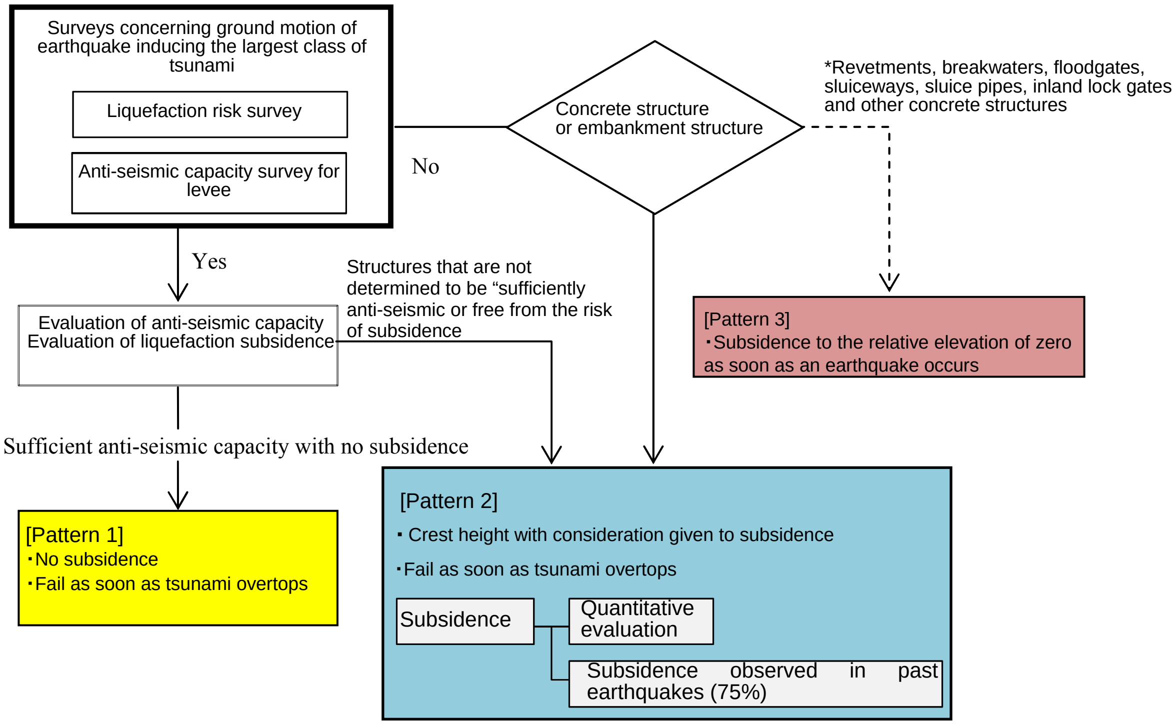

Figure 13 Example of the process for establishing facility conditions against earthquakes and tsunamis

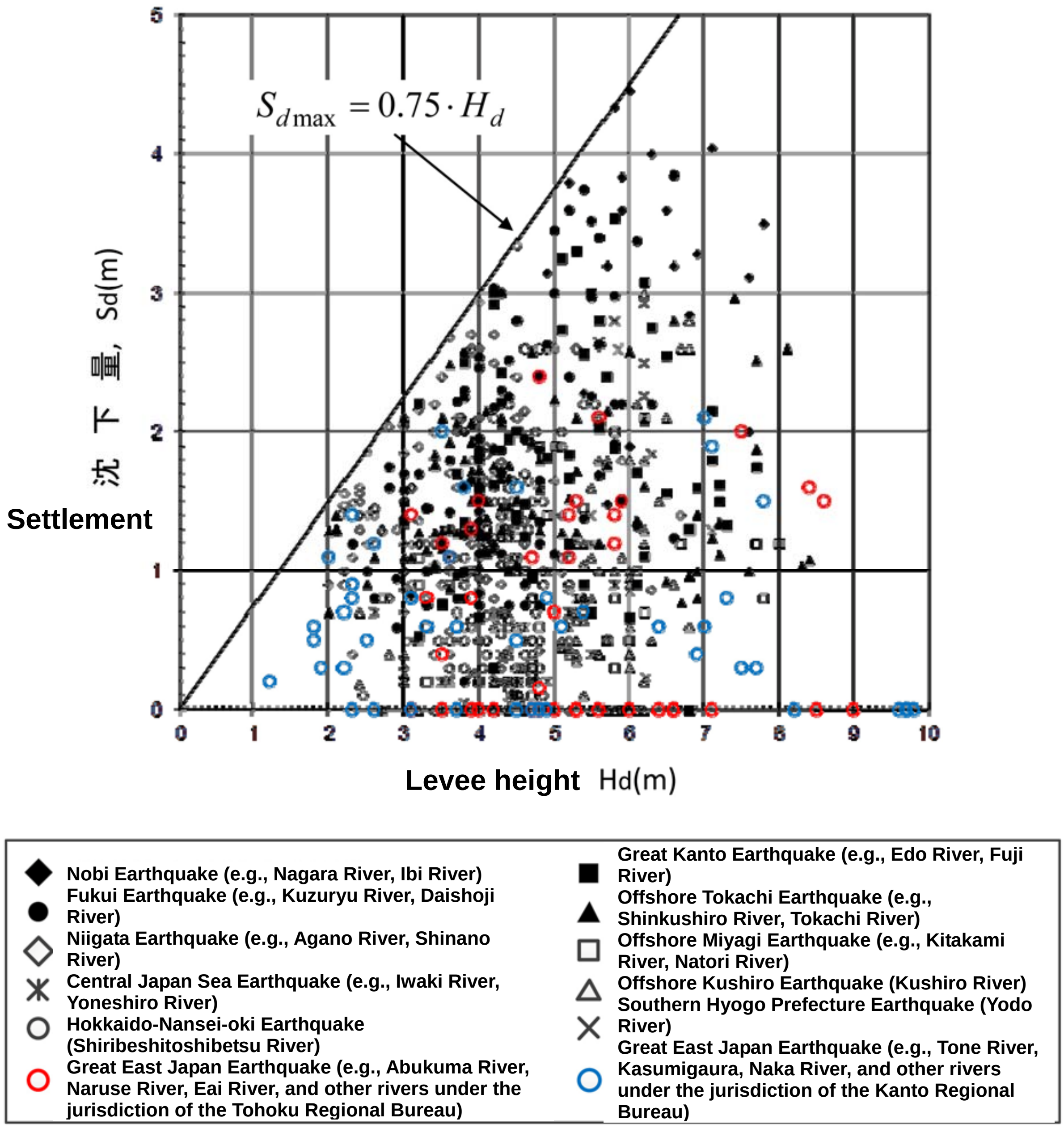

Figure 14 Relationship between river levee height and subsidence after past earthquakes

Source: River Improvement and Management Division, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, *Manual for Inspection of River Levees Resistance to Level 2 Ground Motion*, 2012.

(None of the past earthquakes resulted in a 75% or greater subsidence of the crest height of river levees. It is empirically known that at least 25% of the pre-earthquake height of the levees remained.)

4.3 Output of the results of tsunami inundation simulation

The maximum inundation area and maximum water depth to be specified in the potential tsunami inundation shall be output as the results of the tsunami inundation simulation. This information allows understanding of the status of inundation resulting from the tsunami runup into inland.

<Explanation>

(1) Output of the results of a tsunami inundation simulation

The results of a tsunami inundation simulation, i.e.,

・the maximum area of inundation and

・the maximum water depth of inundation

will be specified in the potential tsunami inundation, and, when necessary,

・the Standard Water Level specified in Article 53, paragraph 2 of the Act[45] (the specific energy at the maximum point[46]) and

・the time from the occurrence of the earthquake to the arrival of a tsunami at the coast

shall be output.

These data will be used for purposes including creating and revising a hazard map, formulating a tsunami evacuation plan, reviewing the local disaster management plan, facilitating the prefectural governors' designation of Security Zones and Special Security Zones, determining the Standard Water Level that is necessary to designate these Security Zones, consideration of required "restrictions on certain construction activities" and "designated evacuation facilities" based on the Standard Water Level, and developing facilitation plan, which is formulated by municipal mayors to comprehensively promote the development of tsunami-resilient communities.

These outputs can be the basis for the development of tsunami-resilient communities. Therefore, the appropriate output formats need to be discussed, with consideration given to usage and understandability.

(2) Maximum inundation area and maximum water depth

Whenever the potential tsunami inundation is determined or revised based on the results of the tsunami inundation simulation, the relevant prefectural governor shall report this to the Minister of Land, Infrastructure, Transport and Tourism, the municipal mayors concerned, and disclose it publicly in compliance with paragraphs 4 and 6 of Article 8 of the Act on the Development of Tsunami-Resilient Communities.

When publicly disclosing the potential tsunami inundation, prefectural publicity, printed materials, the Internet, and other media shall be used to ensure that this estimate is known to all relevant persons.

It should be noted that the maximum inundation area and maximum water depth include uncertainties. To ensure a successful evacuation, measures such as providing a buffer zone outside of

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45 The "standard water level" is determined by adding the necessary value in terms of the increase in the water level of a tsunami when it hits a structure etc., to the water level for the depth of water specified in the tsunami inundation estimate.

46 "Specific energy" is the hydraulic head with the ground level used as a reference. It is expressed by adding the velocity head (corresponding to kinetic energy) to the water depth (the sum of potential energy and pressure energy, using the ground level as a reference).

the maximum inundation area (the area that is expected to be free from inundation based on the simulation results, but could still be subject to inundation due to uncertainties) should preferably be discussed.

With consideration given to such issues as discussing an evacuation plan using the potential tsunami inundation, inundation information, background information, and other necessary data should be organized using the geographical information system (GIS) and be made available upon request.

When disclosing the potential tsunami inundation, possible steps should be considered, such as stating in the relevant document that there are uncertainties in terms of, for example, the tsunami inundation simulation errors described in 1.6.4 of these guide.

<Reference> Example of classifying inundation depths, using colors to represent the different degrees of inundation

Table 5 Example of classification by inundation depths[47]

Classification of depths	Definition
≥10 m	A three-story building (or up to the third floor of a building) is completely submerged
5 m – 10 m	A two-story building (or up to the second floor of a building) is completely submerged
2 m – 5 m	Most wooden houses are completely destroyed
1 m – 2 m	Most people die if caught in the tsunami
0.3 m – 1.0 m	Cannot take evacuation action (or move)

Table 6 Example of classification by colors[48,49]

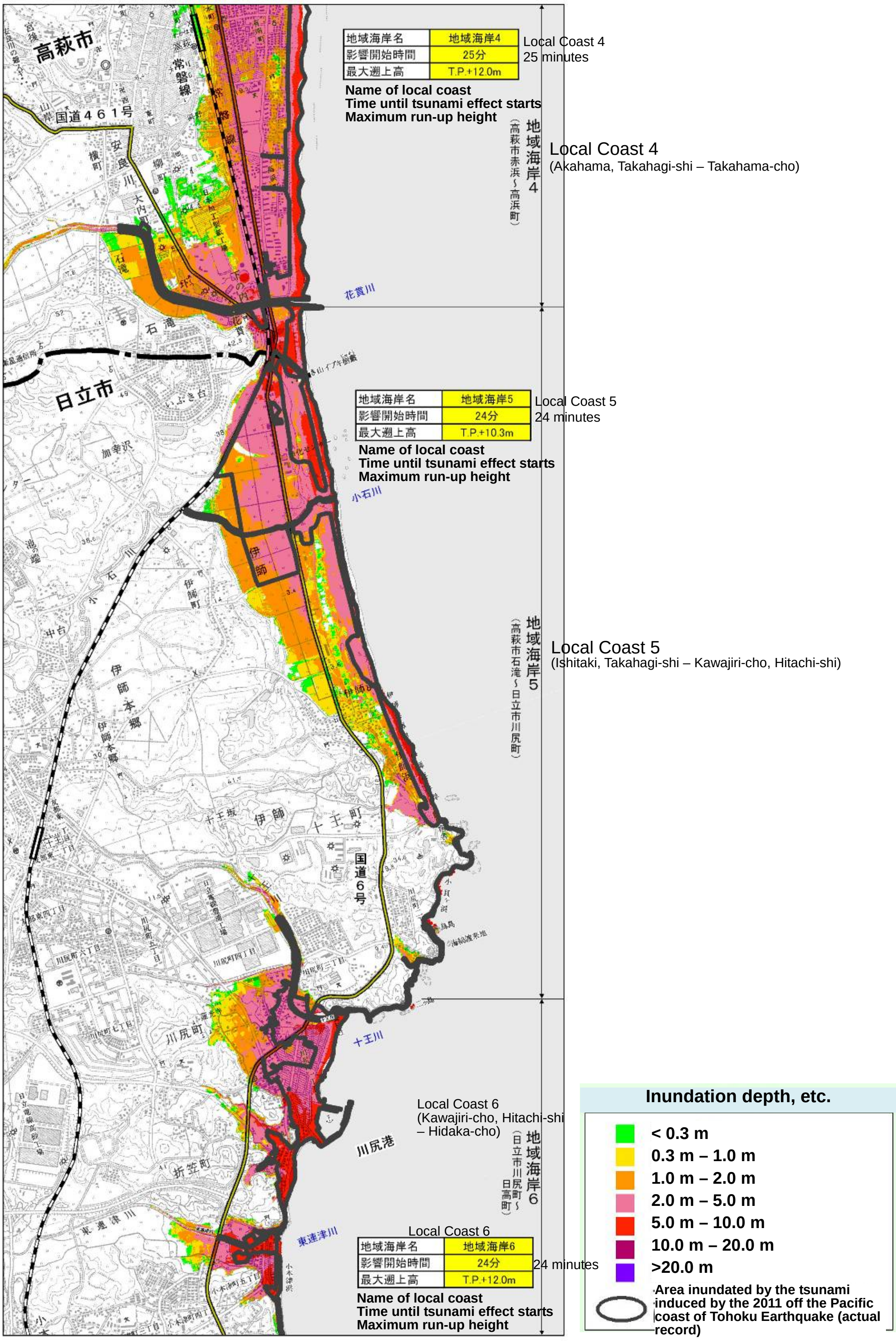
Classification of depths	Color	RGB value	Color sample
≥ 20 m	Purple	128,0,255	
10 m – 20 m	Brown	180,0,104	
5 m – 10 m	Red	255,40,0	
2 m – 5 m	Pink	239,117,152	
1 m – 2 m	Orange	255,153,0	
0.3 m – 1.0 m	Yellow	255,230,0	
0.01 m – 0.3 m	Green	0,255,0	

47 Cabinet Office (Disaster Control), additional material for Panel on the Nankai Trough Massive Earthquake Model (2nd report) (e.g., notes on using tsunami estimates), 2012, http://www.bousai.go.jp/nankaitrough_info.html.

48 Cabinet Office (Disaster Control), Estimation of Tsunami Levels, Inundation Areas (Second Report) and Estimation of Damage (First Report) related to Nankai Trough Massive Earthquake, 2012, http://www.bousai.go.jp/nankaitrough_info.html.

49 Japan Meteorological Agency, “Description Regarding the Use of Standardized Colors for Weather Information,” Japan Meteorological Agency website, 2012, http://www.jma.go.jp/jma/press/1205/24a/120524hpcolor.html.

[Example of output of tsunami inundation simulation results[50]]



This map is a reproduction of the digital map 25000 (map image) published by the Geospatial Information Authority, which has been approved by the Director-General of the Authority. (Approval code: 2012 General Reproduction No. 292)

50 Ibaraki Prefecture, Tsunami Inundation Estimation Graph, 2012, http://www.pref.ibaraki.jp/bukyoku/doboku/01class/class06/kaigan/tsunamisinnsui/l2shinsui.html.

(3) About Standard Water Level

The equation below can be used to calculate the Standard Water Level (when the specific energy is the greatest) specified in Article 53, paragraph 2, of the Act.

The equation below is designed to calculate the specific energy from the results of a tsunami inundation simulation obtained before buildings, etc. are specified. This is because the swell-head, which is caused by obstruction of tsunami flow by buildings, can be attributable to the amount of energy the tsunami at the time.

The inundation depth and the Froude number used for the calculation shall be as of the time the specific energy reaches its peak. It is important to choose an appropriate time point, in the big picture, in terms of the sequence of tsunami behavior, not the time point at which the water is shallow and the velocity becomes instantaneously or locally larger, like the runup wave front.

It should be noted that buildings with a shape or layout that could easily concentrate the energy of tsunami runup mean that it is possible that the standard water level calculated using the equation below may be lower than it would actually be in the event of a tsunami.

$$h_{f\,\max} = \max[\mathrm{E_b}] = \max\left[h_b + \frac{v_b^{\ 2}}{2g}\right] = \max\left[h_b\left(1 + \frac{Fr^2}{2}\right)\right]$$

In the above formula,

$h_{f\max}$: Standard Water Level

$\mathrm{E_b}$: Specific energy

h_b、v_b : Inundation depth and velocity at the specified point in the tsunami inundation simulation

(Relationship to the parameters described in the governing equation in p14: $h_b = h + \eta = D$)

(Relationship to the parameters described in the governing equation in p14: $v_b = \sqrt{u^2 + v^2}$)

Fr : Froude number for the specified point in the tsunami inundation simulation

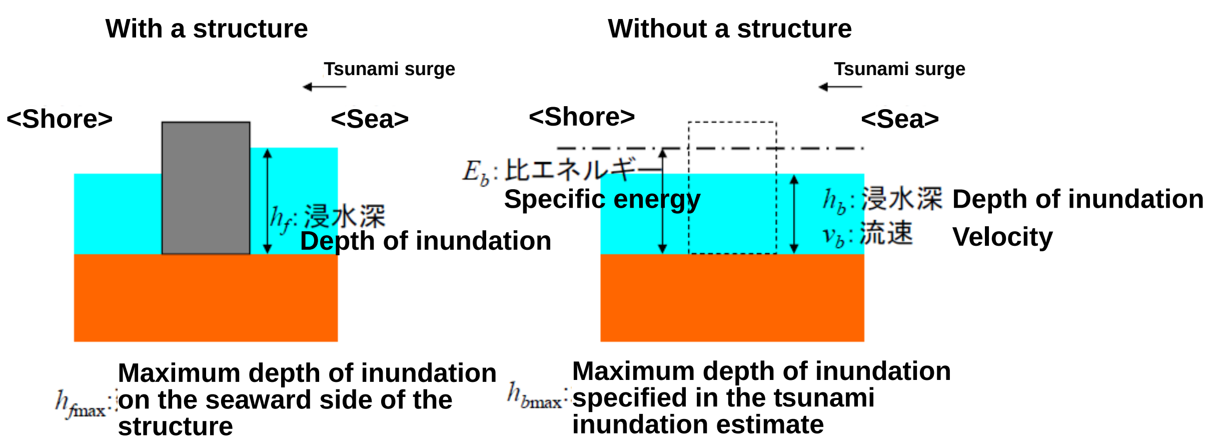


Figure 15 Establishing average water level in consideration of the height of the tsunami afflux

The *Technical Study Report on the Development of Tsunami-Resilient Communities* (January 27, 2012, Technical Panel for the Development of Tsunami-Resilient Communities)[51] serves as a good reference for determining Standard Water Level.

(4) Time until tsunami arrival

The time until the tsunami arrives at the coast may be utilized for development of an evacuation plan, etc for the event of the largest scale tsunami.

However, it should be noted that there are possibilities of tsunami occurrence which require shorter time to reach the coast than the largest scale tsunami.

[51] Technical Panel for the Development of Tsunami-Resilient Communities, *Technical Study Report on the Development of Tsunami-Resilient Communities*, 2012, http://www.mlit.go.jp/river/shinngikai_blog/tsunamibousaitiiki/houkokusyo_120127.pdf.

5. Reference Information and Documents

5.1 Information regarding fault models

5.1.1 Central Disaster Management Council of Japanese Government (Cabinet Office)

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
Tsunami Fault Parameters designated by the Committee for Technical Investigation on Countermeasures for the Tokai Earthquake	○Any of the following kinds of earthquakes can occur: ・Estimated focal zone + Accretionary fault A ・Estimated focal zone + Accretionary fault A + Accretionary faults B and C ・Estimated focal zone + Accretionary fault A + Accretionary fault B + Rectangular fault D	○Go to the website for the CDMC for a detailed explanation of fault models: http://www.bousai.go.jp/jishin/chubou/tokai/11/siryou2-1.pdf
Tsunami Fault Parameters designated by the Committee for Technical Investigation on Countermeasures for the Tonankai and Nankai Earthquakes.	○Any of the following kinds of earthquakes can occur: ・The focal zones for an East Nankai Earthquake and a Nankai Earthquake are simultaneously destroyed ・Only an East Nankai Earthquake occurs ・Only a Nankai Earthquake occurs ・The focal zones for an estimated Tokai Earthquake, East Nankai Earthquake, and Nankai Earthquake are simultaneously destroyed ・The focal zones for an estimated Tokai Earthquake and an East Nankai Earthquake are simultaneously destroyed	○ Go to the website of the CDMC for a detailed n of fault models: http://www.bousai.go.jp/jishin/chubou/nankai/index.html http://www.bousai.go.jp/jishin/chubou/tokai/index.htm
Tsunami Fault Parameters designated by the Committee for Technical Investigation on Countermeasures for the Trench-type Earthquakes in the Vicinity of the Japan and Chishima Trenches	○Earthquakes can take any of the following forms: ・Earthquake off Iturup Island ・Earthquake off Shikotan Island ・Earthquake off Nemuro and Kushiro ・Earthquake off Tokachi and Kushiro ・Earthquake that occurs every 500 years ・Earthquake off northern Sanriku ・Earthquake similar to the Meiji Sanriku Earthquake ・Earthquake off Miyagi	○Go to the website of the CDMC for a detailed explanation of fault models: http://www.bousai.go.jp/jishin/nihonkaikou/index.html http://www.bousai.go.jp/jishin/nihonkaikou/10/index.html

○Inquiries

Organization	Address	Website
Director General for Disaster Management, Cabinet Office (*CDMC*)	Central Government Building No. 5 3F, 1-2-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8969 Tel: 03-5253-2111 (operator)	http://www.bousai.go.jp/

5.1.2 Cabinet Office

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
Tsunami Fault Model of the 2011 off the Pacific coast of Tohoku Earthquake	2011 Great East Japan Earthquake	○Go to the website of the Cabinet Office for a detailed explanation of fault models: http://www.bousai.go.jp/jishin/chubou/nankai_trough/12/index.html * Reference 1: About the Tsunami Fault Model of the 2011 off the Pacific coast of Tohoku Earthquake (5. Tsunami Fault Model of the 2011 off the Pacific coast of Tohoku Earthquake)
Tsunami Fault Model of the Nankai Trough Massive Earthquake Model	Massive earthquake in the Nankai Trough	○ Go to the website of the Cabinet Office for a detailed explanation of fault models: http://www.bousai.go.jp/jishin/chubou/nankai_trough/nankai_trough_top.html * Second report to the Panel on the Nankai Trough Massive Earthquake Model

○Inquiries

Organization	Address	Website
Director General for Disaster Management, Cabinet Office	Central Government Building No. 5 3F, 1-2-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8969 Tel: 03-5253-2111 (operator)	http://www.bousai.go.jp/

5.1.3 Secretariat of the Headquarters for Earthquake Research Promotion (Earthquake and Disaster-Reduction Research Division, Research and Development Bureau, Ministry of Education, Culture, Sports, Science and Technology)

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
National Ground Motion Hazard Map	The hazard map shows fault model parameters for estimating the strong ground motion of active faults (partial fault models for marine areas are included).	Fault model parameters are disclosed and can be downloaded, in CSV format, from the website of the Headquarters for Earthquake Research Promotion: http://www.jishin.go.jp/main/chousa/09_yosokuchizu/index.htm

○Inquiries

Organization	Address	Website
Secretariat of the Headquarters for Earthquake Research Promotion (Earthquake and Disaster-Reduction Research Division, Research and Development Bureau, Ministry of Education, Culture, Sports, Science and Technology)	3-2-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8959 Tel: 03-5253-4111 (operator)	http://www.jishin.go.jp/main/index.html

5.1.4 Japan Meteorological Agency

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
Method for the Prediction of Tsunamis	A quantitative tsunami prediction system estimating approx. 4,000 seismic sources around the country	○Go to the website of the Japan Meteorological Agency for a detailed explanation of fault models: http://www.seisvol.kishou.go.jp/eq/know/tsunami/ryoteki.html

○Inquiries

Organization	Address	Website
Japan Meteorological Agency	1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122 Tel: 03-3212-8341	http://www.jma.go.jp/jma/

5.1.5 National Research Institute for Earth Science and Disaster Prevention

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
J-SHIS (Japan Seismic Hazard Information Station)	The document shows fault model parameters for estimating the strong ground motion of active faults (partial fault models for marine areas are included).	Fault model parameters are disclosed and can be downloaded, in CSV and SHP formats, from the J-SHIS website: http://www.j-shis.bosai.go.jp/download

○Inquiries

Organization	Address	Website
J-SHIS Team, Social System Research Department, National Research Institute for Earth Science and Disaster Prevention	3-1 Tennodai, Tsukuba-shi, Ibaraki 305-0006 Tel: 029-851-1611 (operator) Email: j-shis@bosai.go.jp	http://www.j-shis.bosai.go.jp/

5.1.6 National Institute of Advanced Industrial Science and Technology (AIST)

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
Active Fault Database	The database includes data on the 10-km or larger active faults around the country that are known so far.	Fault model parameters are disclosed and can be downloaded, in CSV format, from the AIST website: http://riodb02.ibase.aist.go.jp/activefault/index.html

○Inquiries

Organization	Address	Website
Active Fault and Earthquake Research Center, National Institute of Advanced Industrial Science and Technology	1-1-1 Chuo Dainana, Higashi, Tsukuba-shi, Ibaraki 305-8567 Tel: 029-861-3691 (operator)	http://www.aist.go.jp/

5.1.7 Nuclear Civil Engineering Committee, Japan Society of Civil Engineers (JSCE)

○List of data

Document title	Specific earthquakes and information described in the document	Remarks
Tsunami Assessment Method for Nuclear Power Plants in Japan (2002)	○Fault models including comparisons with tsunami trace heights (the marine areas along the Japan Trench and along the southern Chishima Trench) 1611: Keicho Offshore Sanriku 1677: Offshore Boso 1793: Offshore Miyagi 1856: Offshore Tokachi 1896: Meiji Offshore Sanriku 1897: Offshore Sanriku 1931: East off Aomori 1933: Showa Offshore Sanriku 1938: Offshore Shioya II 1938: Offshore Shioya IV 1938: Offshore Shioya V 1952: Offshore Tokachi 1968: Offshore Tokachi 1968: Offshore Iwate 1973: Offshore Nemuro Peninsula 1978: Offshore Miyagi 1994: Offshore Sanriku 1994: East off Hokkaido ○ Fault models including comparisons with tsunami trace heights (marine areas involved in the sinkage of the Philippine Sea Plate) 1498: Meio 1605: Keicho 1633: Kanei Odawara 1703: Genroku 1707: Hoei 1854: Ansei Tokai 1854: Ansei Nankai 1923: Kanto 1944: East Nankai 1946: Nankaido 1968: Hyuganada Sea 1978: Sea around Izu Oshima Island 1995: Sea around Amami Oshima Island ○Fault models to explain trace heights of previous tsunamis (east periphery of Japan Sea) 1833: Tenpo Offshore Yamagata (A) 1833: Tenpo Offshore Yamagata (B) 1940: Offshore Shakotan 1964: Niigata 1983: Central Japan Sea 1993: Southwest off Hokkaido	Fault model parameters are disclosed. The report can be downloaded, in PDF format, from the JSCE website: http://committees.jsce.or.jp/ceofnp/node/5

○Inquiries

Organization	Address	Website
Japan Society of Civil Engineers	Sotobori Park, Yotsuya 1-chome, Shinjuku-ku, Tokyo 160-0004 Tel: 03-3355-3441 (operator)	http://www.jsce.or.jp/

5.2 Information on topographic data (marine areas)

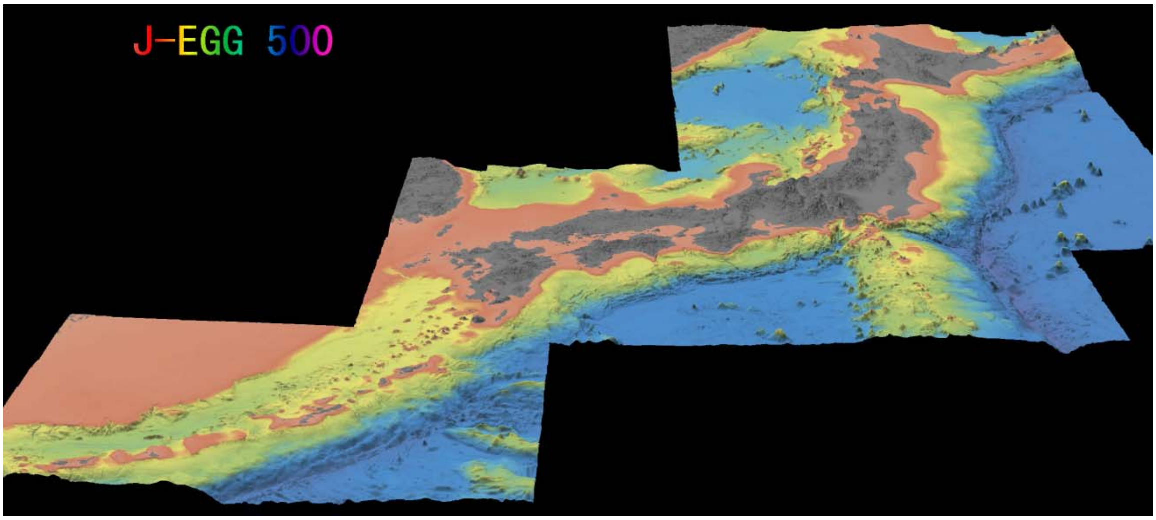
5.2.1 Hydrographic and Oceanographic Department, Japan Coast Guard

○List of data

Document title	Organization	Remarks
500-meter Grid Seabed Topography Data around Japan (J-EGG500)	Oceanographic Department, Oceanographic Data and Information Division, Japan Coast Guard/Japan Oceanographic Data Center (JODC)	The data set integrates an enormous amount of seabed topography survey data, obtained by the Hydrographic and Oceanographic Department and other marine survey agencies, into a grid form at regular intervals to make it more reader-friendly (the data set can be downloaded from the following link).

○Inquiries

Organization	Address	Website
Oceanographic Department, Oceanographic Data and Information Division, Japan Coast Guard/Japan Oceanographic Data Center (JODC)	2-5-18 Aomi, Koto-ku, Tokyo 135-0064 Tel: 03-5500-7131	http://www.jodc.go.jp/index_j.html



Data range of J-EGG500

○List of data

Document title	Organization	Remarks
Offshore Tohoku Seabed topography data (Results of a seabed topography survey conducted before the Great East Japan Earthquake)	Hydrographic and Oceanographic Department, Japan Coast Guard/Marine Information Service Office	The seabed topography dataset is more detailed than the 500-meter grid data published by the Japan Oceanographic Data Center. Not available to the public, the dataset can be provided upon request to organizations such as research institutes and local governments involved in disaster control activities. (Fill out the e-mail inquiry form in the following link and submit it)
Sendai Bay and Miyako Bay Airborne Laser Hydrography (results of a survey conducted in June 2011)		
GridGrid Dataset for Tsunami Simulation (data used to create the existing tsunami hazard map)		

○Inquiries

Organization	Address	Website
Hydrographic and Oceanographic Department, Japan Coast Guard Marine Information Service Office	2-5-18 Aomi, Koto-ku, Tokyo 135-0064 Tel: 03-5500-7155	http://www1.kaiho.mlit.go.jp/JODC/SODAN/annai.html

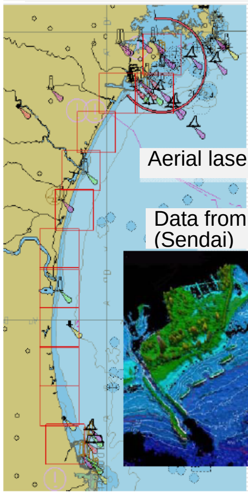
Useful for disaster control activities

Seabed Topography Dataset

Inquiries on using the seabed topography data

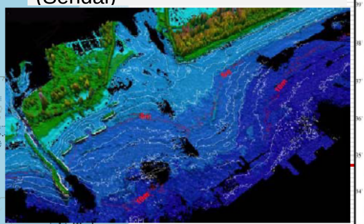
Hydrographic and Oceanographic Section, Hydrographic and Oceanographic Department, Japan Coast Guard
Marine Consulting Center
Click on the link above, fill out the e-mail inquiry form, and submit it.
Your inquiry must be titled "Request for Seabed topography Survey Data."
***The Japan Coast Guard will provide applicants with important notes on the use of the data.**

①Offshore Tohoku Seabed Topography Dataset (results of a seabed topography survey conducted before the Great East Japan Earthquake)
②Sendai Bay and Miyako Bay Aerial Laser Survey Data (results of a survey conducted in June, after the Great East Japan Earthquake)
③Mesh Dataset for Tsunami Simulation (data used to create the existing tsunami hazard map)

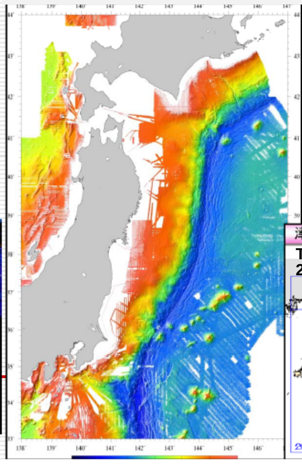


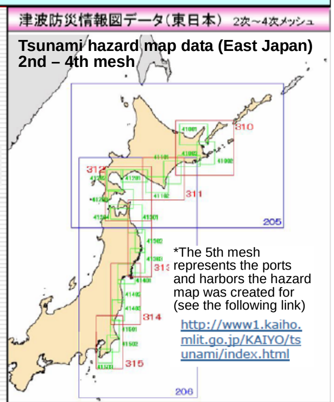
Aerial laser survey area

Data from an aerial laser survey (Sendai)



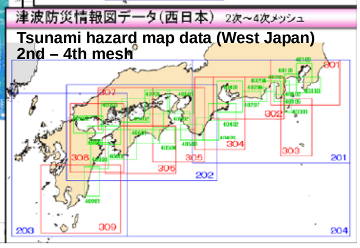
Seabed topography off Tohoku





Tsunami hazard map data (East Japan)
2nd – 4th mesh

*The 5th mesh represents the ports and harbors the hazard map was created for (see the following link)
http://www1.kaiho.mlit.go.jp/KAIYO/tsunami/index.html



Tsunami hazard map data (West Japan)
2nd – 4th mesh

5.2.2 Japan Hydrographic Association

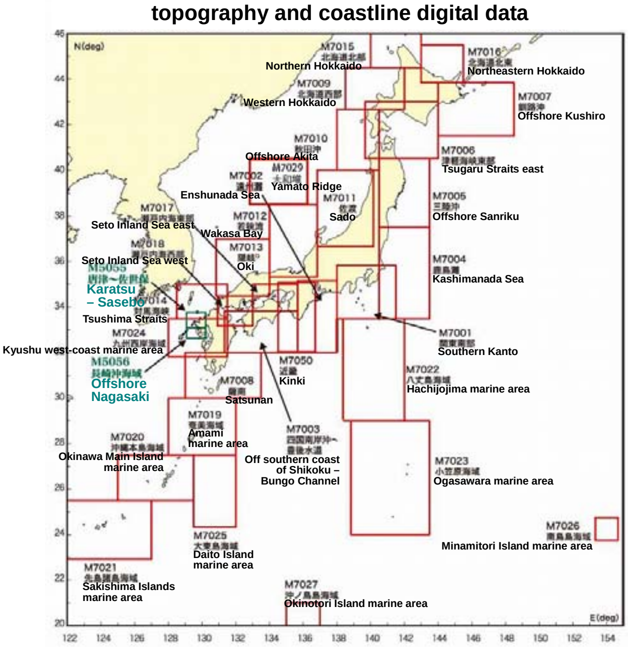
○List of data

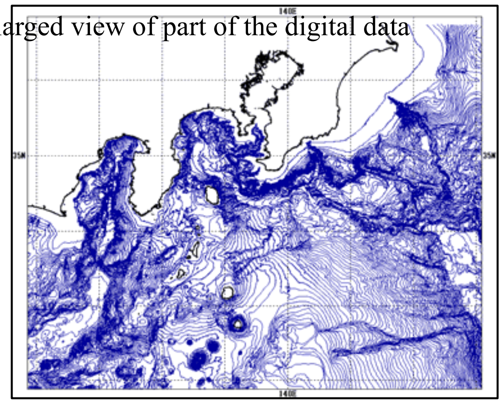
Document title	Organization	Remarks
Seabed Topography and Coastline Digital Data (M7000 and M5000 series)	Japan Hydrographic Association	M7000 series: The seabed topography data cover seashore and coastal areas and 60–70 miles offshore. Isobath intervals differ among marine areas. M5000 series: The series covers some coastal areas that are also covered in the M7000 series. The stored data on isobaths, etc. are equivalent between the two series.

○Inquiries

Organization	Address	Website
Japan Hydrographic Association	Daiichi Sogo Building 6F, 1-6-6 Haneda-kuko, Ota-ku, Tokyo 144-0041 Tel: 03-5708-7070	http://www.jha.or.jp/

Marine areas covered in the M7000 series of seabed topography and coastline digital data





Enlarged view of part of the digital data

5.2.3 Other

Besides the above, it is common practice to use the open-sea topography data that have already been created by public institutes, researchers, etc.

Besides digitized hydrographic maps, etc., the following coastal topography data may be used.

・JTOPO30 (Japanese coastal waters, 30-second grid seabed topography data): Japan Hydrographic Association

・Sounding data: Coastal management body

・Port/fishing port plan view: Port management body, fishing port management body

・GEBCO (General Bathymetric Chart of the Oceans)

5.3 Information about continental topography data

5.3.1 Geospatial Information Authority of Japan

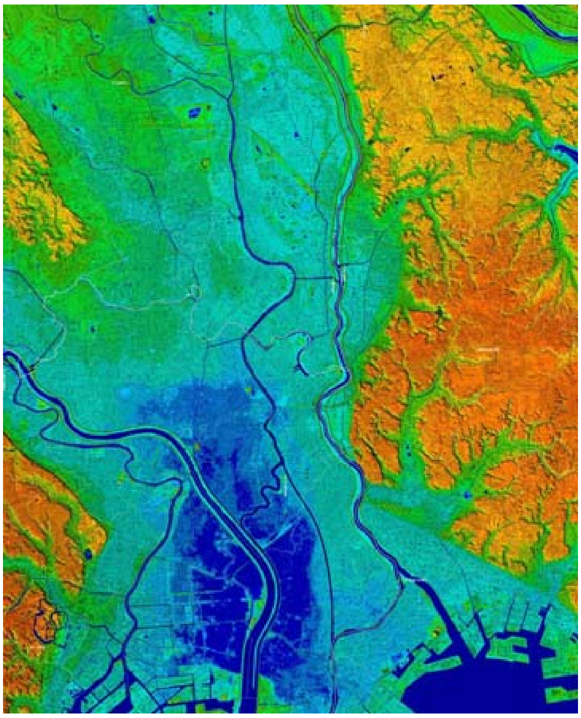
○List of data

Document title	Organization	Remarks
Basic Map Information (Digital Elevation Model) 5-meter and 10-meter grid	Image Survey Section, National Mapping Department, Geospatial Information Authority of Japan	The continental topography (altitude) data cover all areas around Japan. The 5-meter grid data, created through aerial laser surveys, etc., show altitudes with a high degree of accuracy, and mainly cover coastal areas, river basins, and urban areas. The 10-meter grid data are created from the contour line of a 1:25,000 topographic map and cover all areas around the country, though the 5-meter grid data are better in terms of accuracy (the data can be downloaded from the link below).
Elevation data obtained from aerial laser surveys other than the above	Applied Map Section, Geocartographic Department, Geospatial Information Authority of Japan	This consists of 5-meter and 2-meter grid data and other elevation data with a higher degree of accuracy, obtained through aerial laser surveys other than those mentioned above, which are being or will be developed.

*For information regarding the range of continental topography data, see the following pages before making an inquiry.

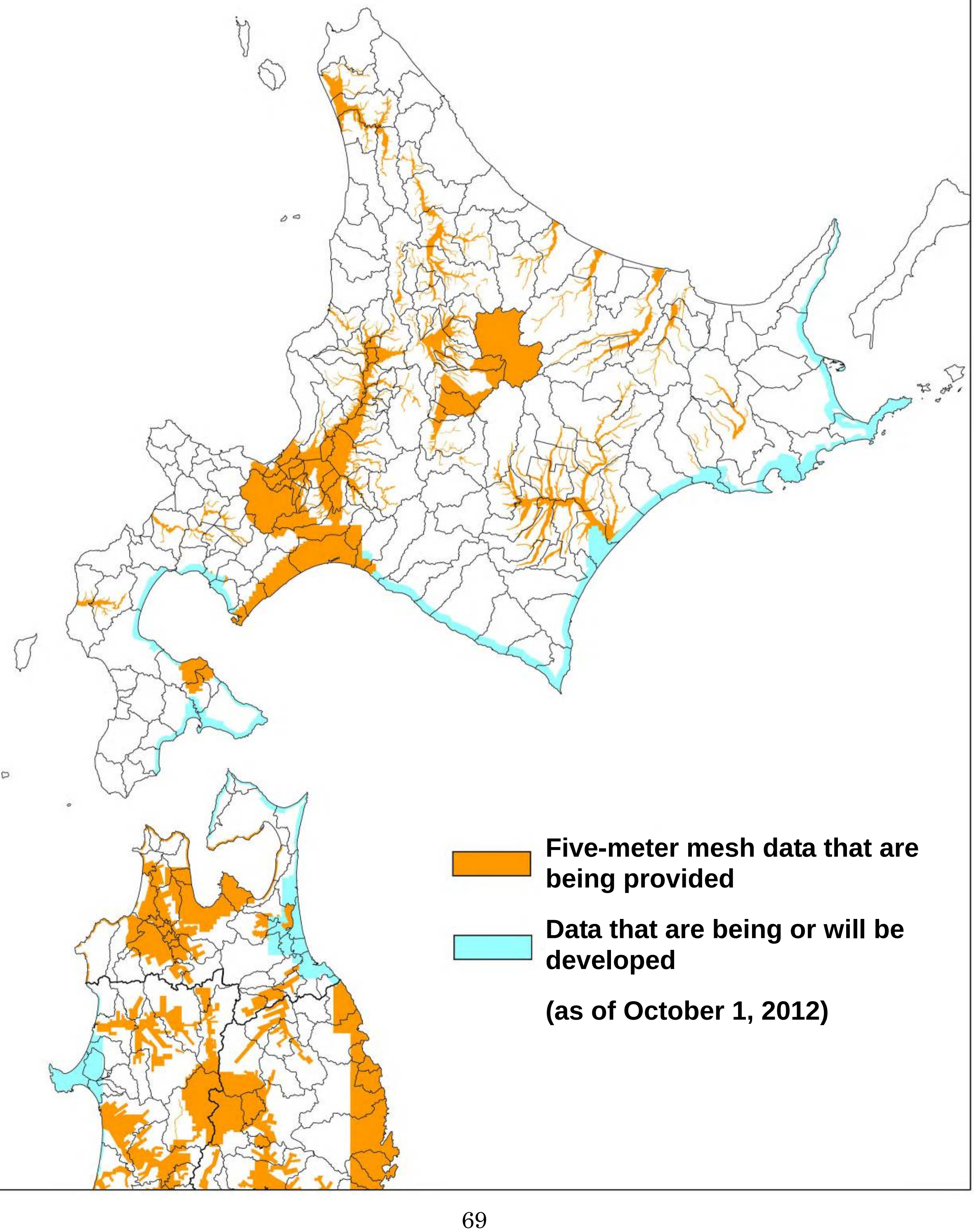
○Inquiries

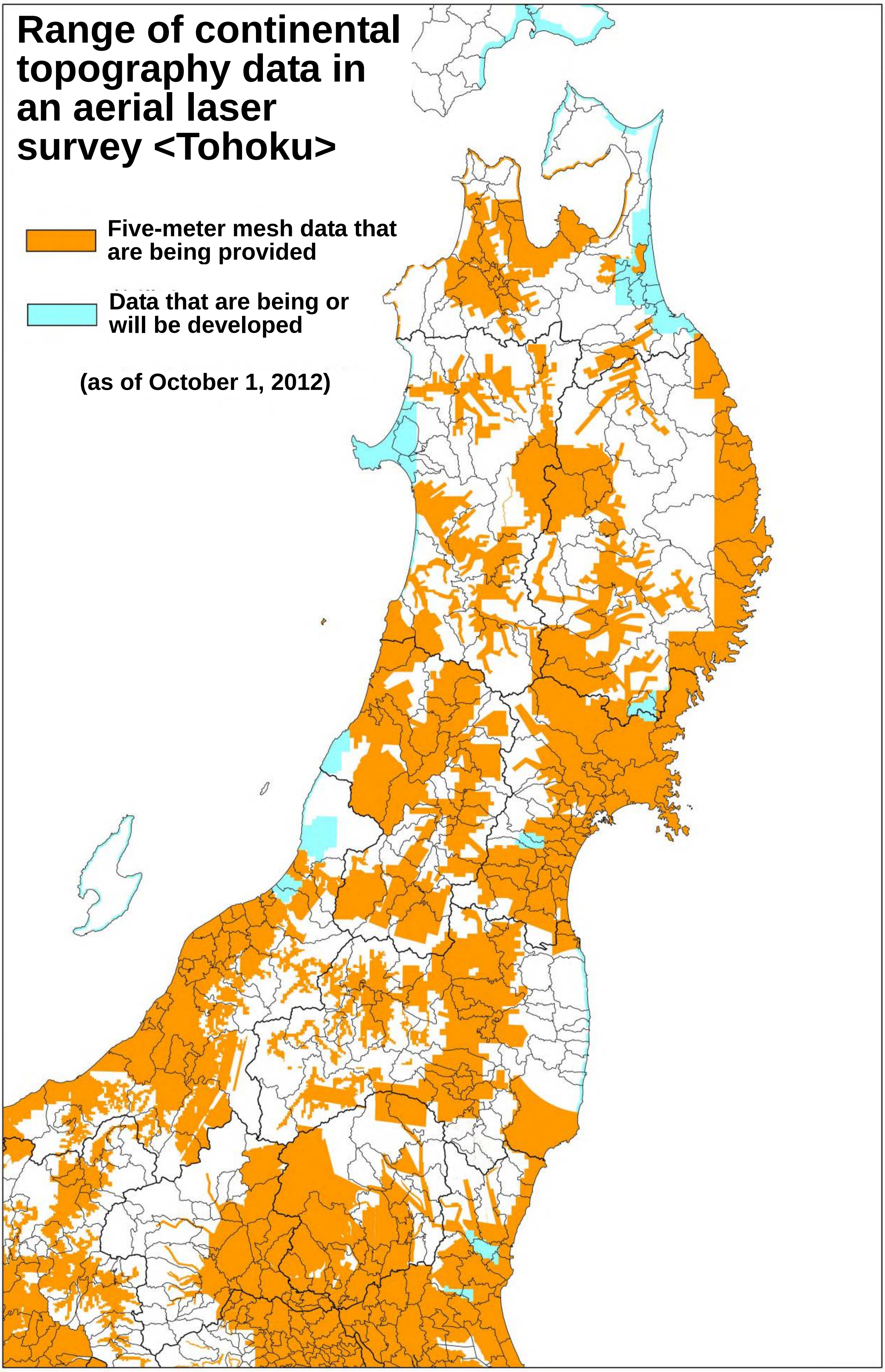
Organization	Address	Website
Geospatial Information Authority of Japan	1 Kitasato, Tsukuba, Ibaraki 305-0811 Tel: 029-864-1111 (operator)	http://fgd.gsi.go.jp/download/

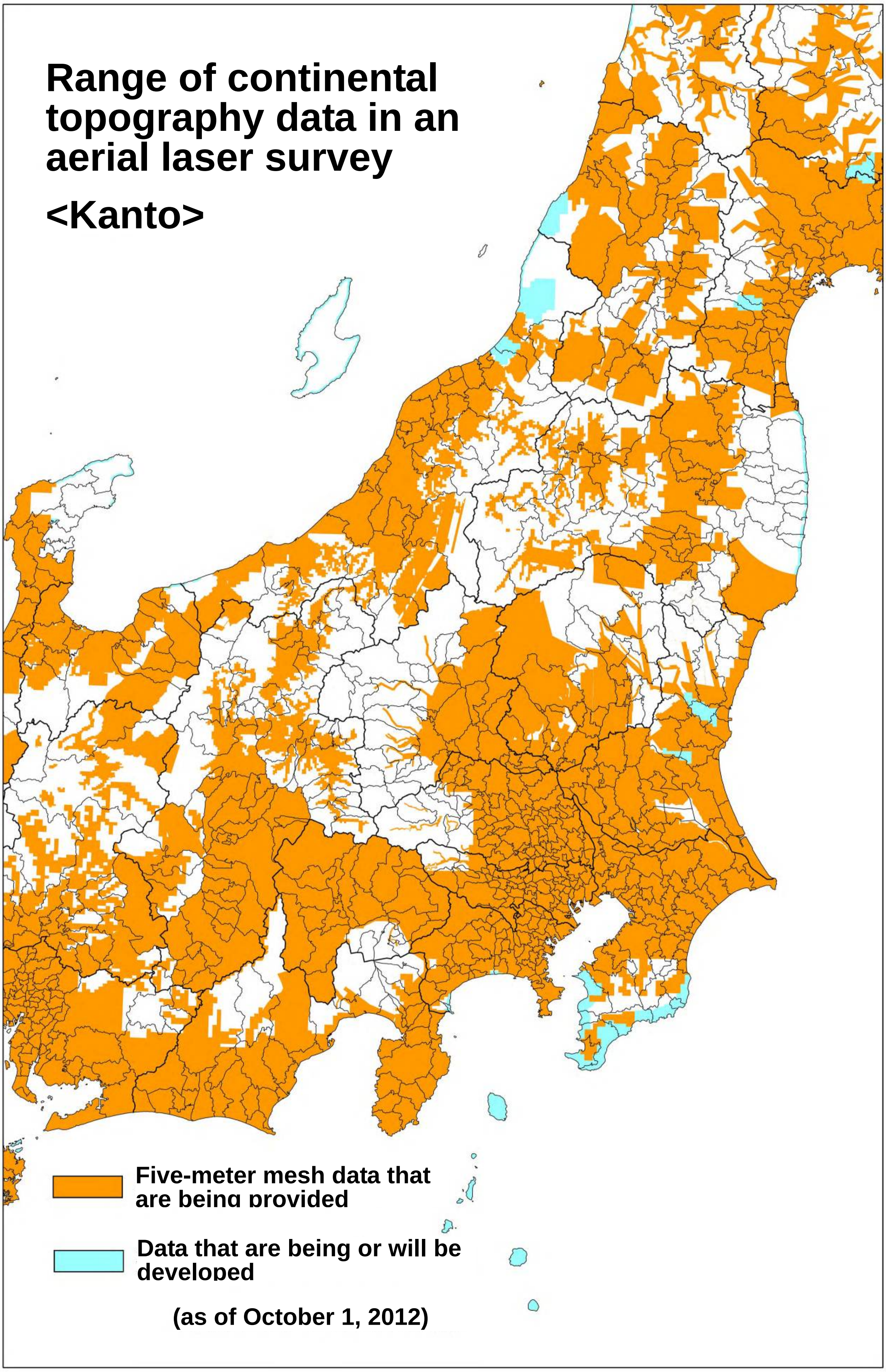


Elevation data obtained through an aerial laser survey

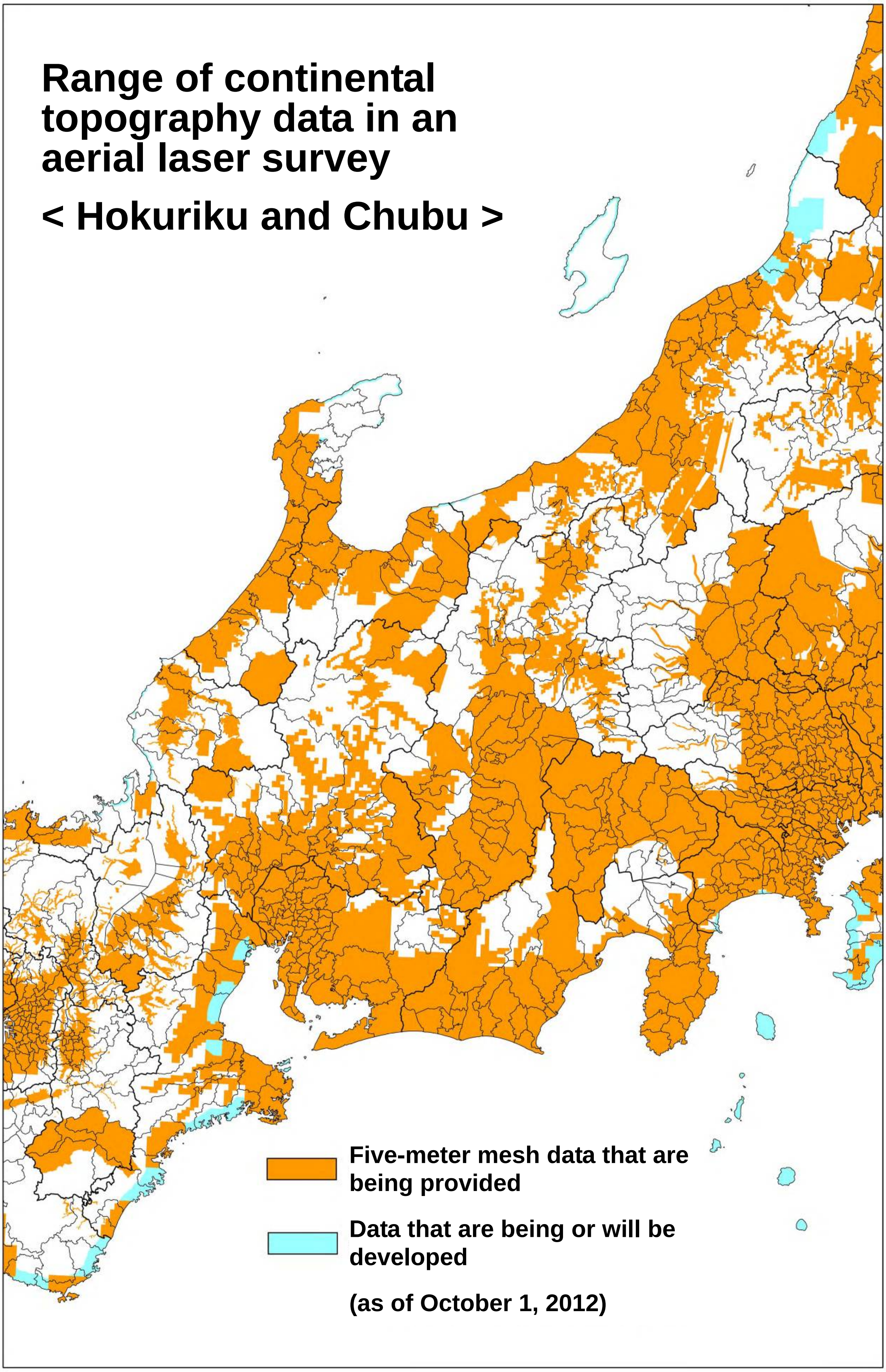
Range of continental topography data in an aerial laser survey <Hokkaido>




Range of continental topography data in an aerial laser survey <Tohoku>
Five-meter mesh data that are being provided
Data that are being or will be developed
(as of October 1, 2012)

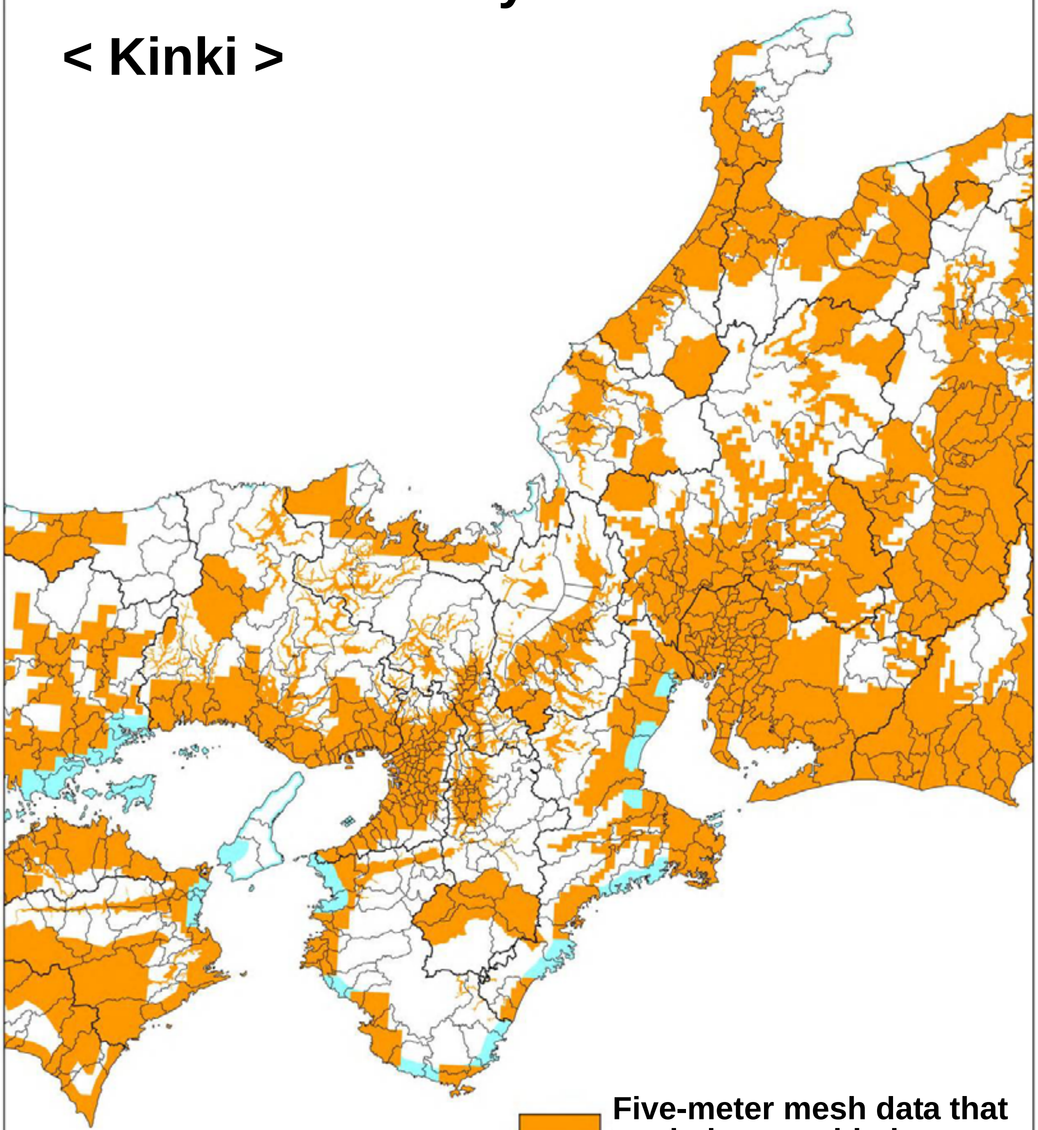

Range of continental topography data in an aerial laser survey
<Kanto>
Five-meter mesh data that are being provided
Data that are being or will be developed
(as of October 1, 2012)

Range of continental topography data in an aerial laser survey
< Hokuriku and Chubu >



Range of continental topography data in an aerial laser survey

< Kinki >



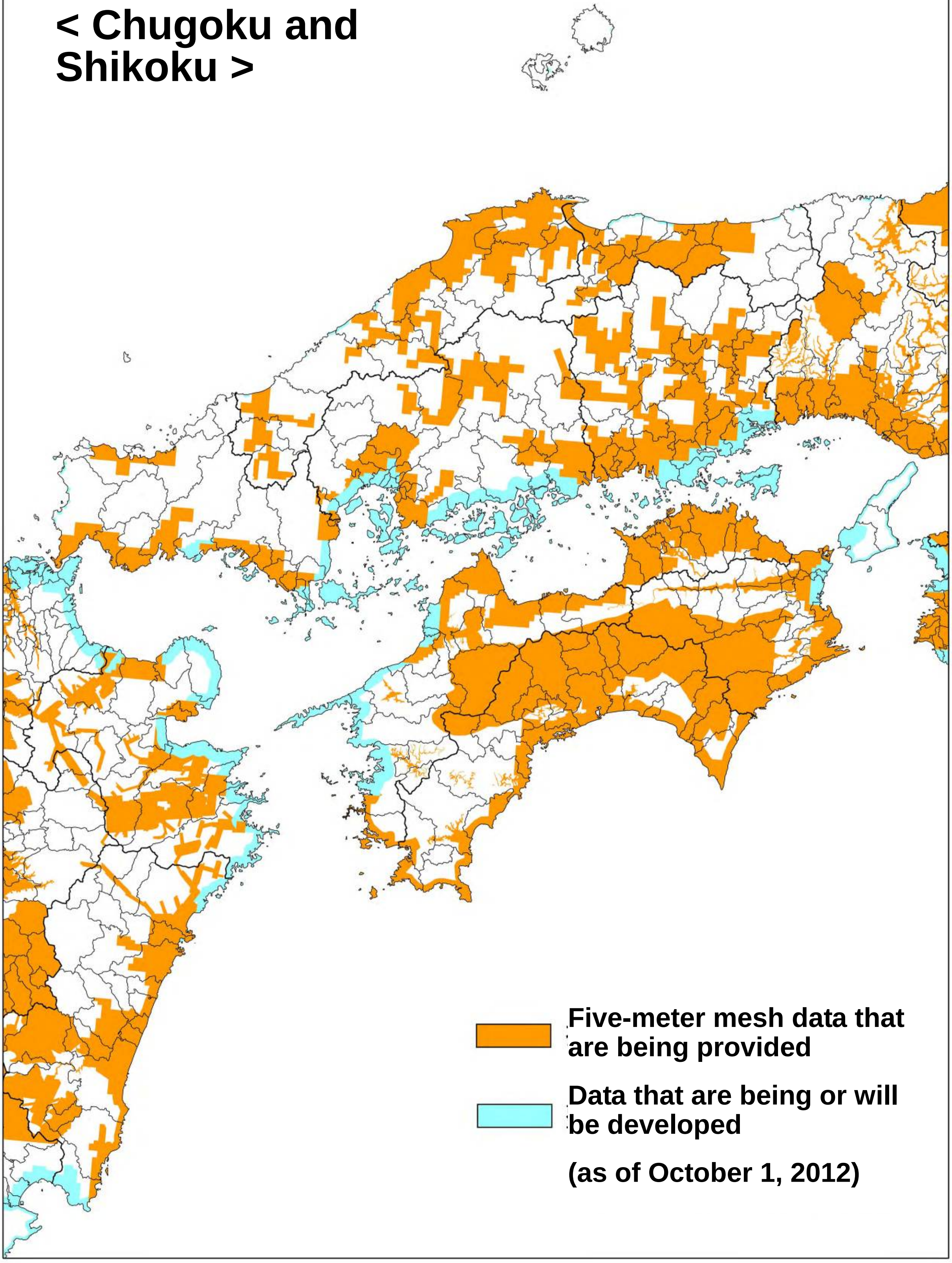
Five-meter mesh data that are being provided

Data that are being or will be developed

(as of October 1, 2012)

Range of continental topography data in an aerial laser survey

< Chugoku and Shikoku >



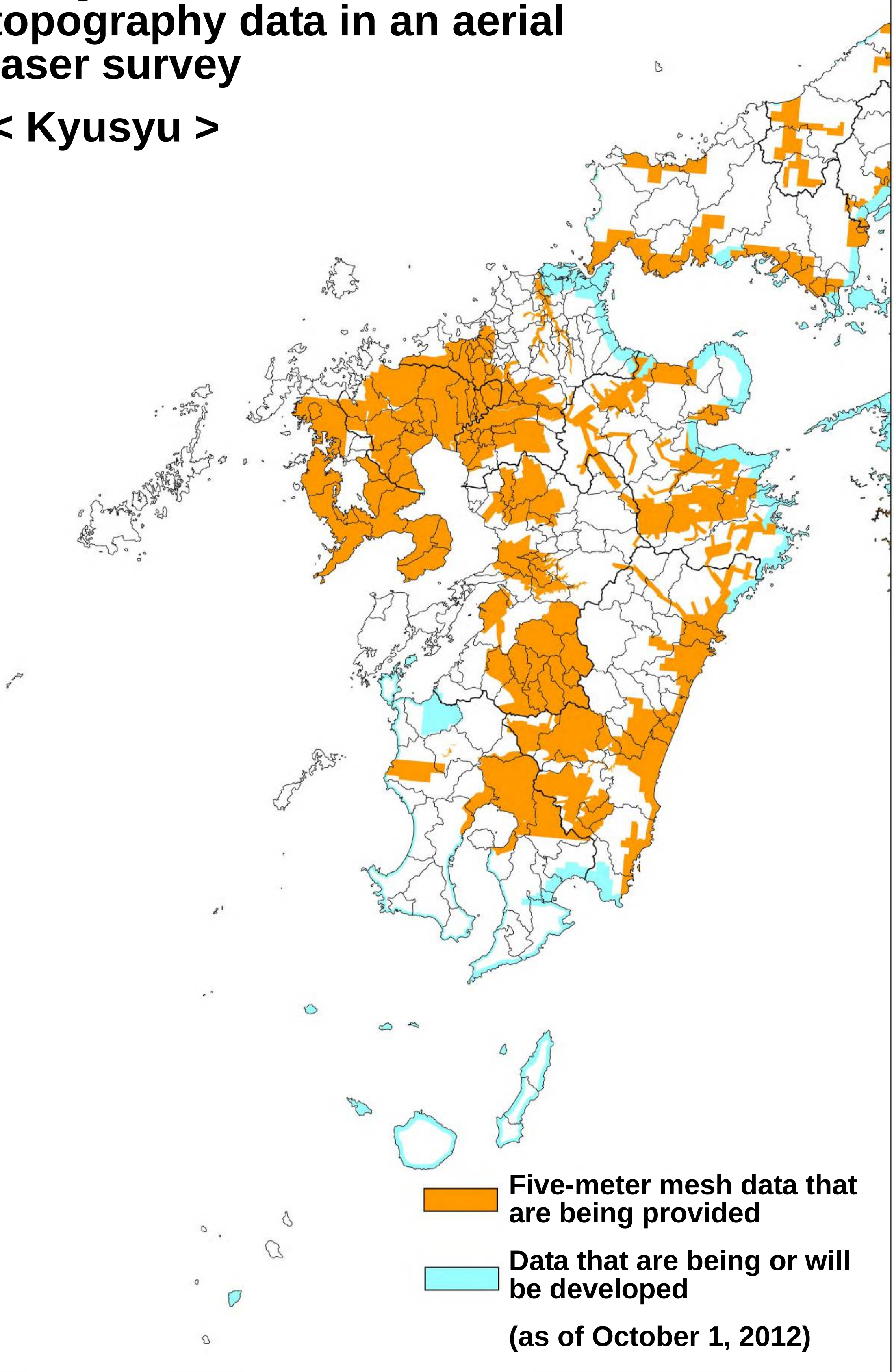
Five-meter mesh data that are being provided

Data that are being or will be developed

(as of October 1, 2012)

Range of continental topography data in an aerial laser survey

< Kyusyu >



5.3.2 Other

Besides the above, the following data may be used:

・Contour lines and height values from the 1:2,500 topographic maps (urban planning base maps) developed by local public organizations

・Contour lines in the 1:25,000 topographic map published by the Geospatial Information Authority of Japan

However, note that the 1:25,000 topographic map may make it hard to accurately replicate the altitude of low-lying areas near a waterfront line, where inundation damage can easily occur. This is because this type of topographic map expresses altitude with contour lines at 10-meter intervals.

5.4 Tsunami Trace Database

○List of data

Document title	Organization	Remarks
Tsunami Trace Database	International Research Institute of Disaster Science at Tohoku University and the Japan Nuclear Energy Safety Organization	The Tsunami Trace Database was developed in cooperation with tsunami specialists with the aim of ensuring that tsunami trace data (information that indicates that a tsunami occurred in a specific location) are properly used in assessing the safety of nuclear power plants, etc. Consisting of three different trees, including tsunami data, document data, and trace data, the database allows information to be browsed and searched in all the trees. Approximately 25,000 pieces of data on tsunami traces have been registered and, to ensure their reliability, undergo detailed examinations by tsunami specialists. Further, the database management system is based on Web-GIS and allows users to search and extract reliable trace data according to their purposes. The database is available to the general public via the Internet, so it can be used by coastal inhabitants and municipal governments engaged in discussions regarding anti-tsunami measures for coastal regions, as well as nuclear power safety and tsunami research.

○Inquiries

Organization	Address	Website
Tsunami Engineering, Hazard and Risk Evaluation Research Division, International Research Institute of Disaster Science, Tohoku University	6-6-11 Aramakiaza-Aoba, Aoba-ku, Sendai 980-8579 Fax: 022-795-7514 E-mail: konseki-info@tsunami2.civil.tohoku.ac.jp	http://tsunami3.civil.tohoku.ac.jp/tsunami/mainframe.php

*To make an inquiry, indicate your name and affiliation before sending via fax or email.

○Data registered

Information	Description
1. Tsunami data	As the first step in developing the database, this database tree contains data on the approximately 60 tsunamis that have hit Japan since 1596. (The database will be made to date back to earlier ages.)
2. Document data	This database tree contains about 500 documents pertaining to the tsunami information mentioned in 1. above. These documents include academic papers, research reports, ancient documents, and historical materials, among others.
3. Trace data	This database tree categorizes about 25,000 pieces of tsunami trace data (information that indicates that a tsunami occurred in a specific location), which have been extracted from the document information mentioned in 2. above. Information on nearly 50 different attributes, such as location name, latitude/longitude, tsunami height, and object of measurement is registered per trace.
4. Map data	Based on Web-GIS, this database tree provides visual information through a dynamic map. The scale of the background map can be switched among 13 different levels, from 1/25,000,000 to 1/4,000. The image data from an old map can also be superimposed onto the background map to compare today's coastal topography with that of earlier periods dating back

	to the Meiji and Showa periods.

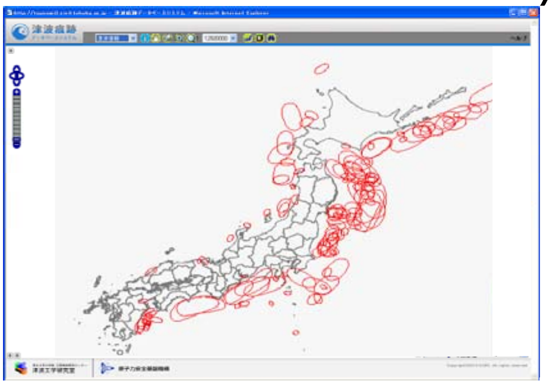
* The registered data are updated as necessary. Before using the data, be sure to clearly record the date you referred to the database.

■Registered data

①Previous tsunamis: approx. 60 (since 1596)
②Documents: approx. 500
③Trace data: approx. 25,000 pieces (verified by tsunami specialists)

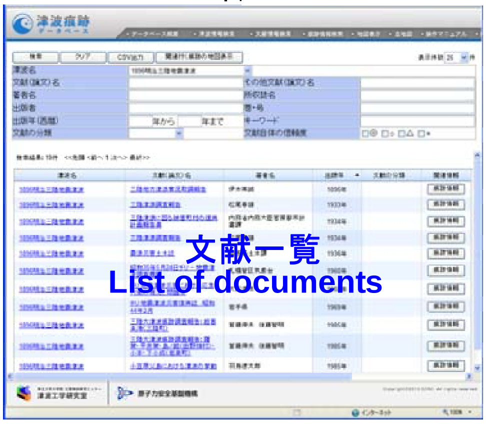
①Tsunami information

(Web – GIS + Source area of tsunami)

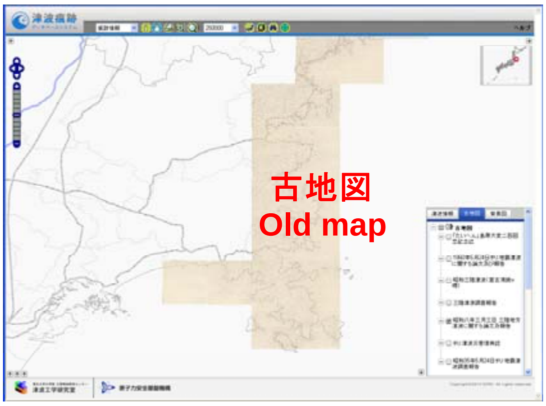


②Document information

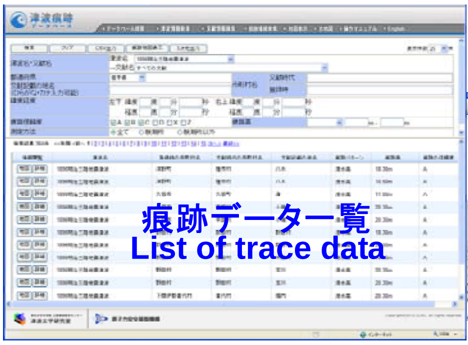
- Academic papers
- Research reports
- Ancient documents and historical materials



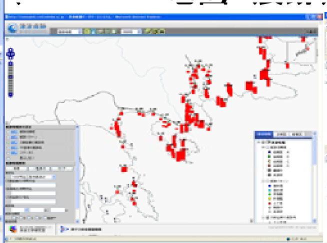
(Web – GIS map + Old map)



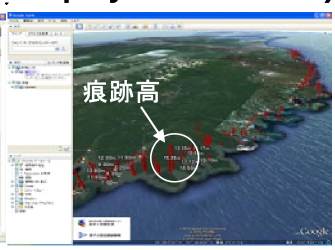
③Trace information



(Web – GIS map + Trace)



(Three-dimensional display of trace data)



Created by the International Research Institute of Disaster Science at Tohoku University and the Japan Nuclear Energy Safety Organization

Guidelines Revision History

Ver. 1.00 : Released on February 29, 2012

Ver. 1.10 : Released on March 28, 2012

The following contents were revised from Ver. 1.00:

- 5.1.2 Summary of data published by the Cabinet Office

  The tsunami fault model for the 2011 off the Pacific Coast of Tohoku Earthquake, which the Panel on the Nankai Trough Massive Earthquake Model published on March 1, 2012, was included.

- 5.1.6 The National Institute of Advanced Industrial Science and Technology, an independent administrative agency, was included.
- 5.3.1 Information related to topographic data (for land areas), published by the Geospatial Information Authority of Japan (including the information scheduled for publication in March 2012), was updated.
- 5.4 The tsunami trace database was included.

Ver. 1.20 : Released on April 12, 2012

The following contents were revised from Ver. 1.10:

- 5.1.2 Summary of data published by the Cabinet Office

  The seismogenic fault model that the Panel on the Nankai Trough Massive Earthquake Model published on March 31, 2012, was added.

- 5.3.1 Information related to topographic data (for land areas) that the Geospatial Information Authority of Japan published on March 28, 2012, was updated.
- 5.4 Expressions for the key data included in the tsunami trace database were validated.

Ver. 2.00 : Released on October 26, 2012

The following contents were revised from Ver. 1.20:

1.1 About these Guidelines

Notes for the practical use of the Guidelines were added.

1.6.3 Method of tsunami inundation simulation

(2) Dominant equation for far-field tsunamis was added.

2.1 About determining the largest scale of tsunami

Descriptions and notes related to determining the largest scale of tsunami were revised.

2.2 Procedures for determining the largest scale of tsunami

Studies on tsunami-caused sediment were added to the classification of records of the actual heights of previous tsunamis.

3.1 Initial tsunami water level (based on a fault model)

A method for determining the initial tsunami water level based on the fault model was added.

3.7 Ground transformation caused by earthquakes

How to account for ground uplift and subsidence in land and sea areas was included, and conceptual diagrams of ground uplift and subsidence were added.

4.2 Establishment of conditions for various facilities

Important considerations in the establishment of conditions for various facilities were added.

(1) Establishment of conditions for various facilities in preparation for earthquakes: How to approach Level 2 seismic motion inspections of levees made from embankments was added.

(2) Establishment of conditions for various facilities in preparation for tsunamis: How to handle artificial embankments and forest zones was added.

(3) Addition of XX regarding the opening and closing of floodgates and land locks

Reference XX was added as an example of ways to approach the establishment of conditions for various facilities in preparation for earthquakes and tsunamis.

4.3 Output of tsunami inundation simulation results

Reference XX was added as an example of inundation depth classifications and the color used to indicate this classification.

Output image XX for tsunami inundation simulation results was revised.

5.1.2 Cabinet Office

Remarks were revised.

5.2.1 Hydrographic and Oceanographic Department of the Japan Coast Guard

Reference titles were revised.

5.3.1 Geospatial Information Authority of Japan

Reference titles and remarks were revised.

The scope of topographic data to be established for land areas through aerial laser surveys was updated.

5.3.2 Other points

The 1:2,500 topographic map (the national land map) was changed to a 1:2,500 topographic map (the basic map for urban planning). The elevation value for 50-meter grids was deleted from numerical maps.

5.4 Tsunami trace database

Notes for the practical use of the database were added.

Help Desks

(For general matters)

Seacoast Office, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism (Planning Officer, Chief Official for Coastal Area Planning and Chief Official for Ocean Development)

2-1-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8918 Tel: 03-5253-8472

(For matters related to tsunami inundation simulations)

Coast Division, River Department, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism (Division Director and Research Fellow)

1 Asahi, Tsukuba City, Ibaraki Prefecture 305-0804 Tel: 029-864-3163

Website URL for the Guidelines: http://www.mlit.go.jp/river/shishin_guideline/

Ver. 2.00