Ensuring safety and reliability of building structure

1. Outline of Studies and Activities

Year		NILIM's Research Agenda	Major Natural Disasters*	Major Legislative Enactments and Amendments
2001	13			
2002	14			・Revision of the Building Standards Law (Sick house regulations, etc.)
2003	15	🟩 Research on building technology systems for the realization of smart architecture and housing	● Northern Miyagi Earthquake ● Tokachi Offshore Earthquake ● Algeria earthquake	・Start of the Performance Indication System for Existing Houses
2004	16	🟩 Research on technical basis for quantitative evaluation of the security of buildings	● Niigata Chuetsu Earthquake ▲ Tornado in Saga and other areas	
2005	17	🟨 Development of performance evaluation methods for new structural buildings using innovative structural materials such as high-strength steel	● Off the West Coast of Fukuoka Prefecture Earthquake ● Miyagi Earthquake ● Pakistan Earthquake	
2006	18			・Revision of the Building Standards Law (Introduction of structural calculation conformity assessment, stricter verification examinations, etc.)
2007	19	🟩 Research on rationalization of operational standards for structural safety performance verification methods for buildings	● Noto Peninsula Earthquake ● Niigata Chuetsu Offshore Earthquake	・Enactment of the Housing Defects Warranty Performance Law
2008	20	Building Standards Development Promotion Project	● Iwate-Miyagi Nairiku Earthquake ● Iwate Prefecture Northern Coast Earthquake ● Sichuan Earthquake	
2009	21		▲ Tatsumaki, Mimasaka City, Okayama Prefecture ▲ Tatebayashi City, Gunma Prefecture ▲ Tsuchiura City, Ibaraki Prefecture	
2010	22	🟩 Research on technical standards for structural calculation programs to facilitate building practice 🟨 Development of technology for evaluating seismic performance of buildings in response to sophisticated information on earthquake motions		
2011	23		● Great East Japan Earthquake	・Enactment of the Tsunami Disaster Prevention Community Development Act (Structural standards for tsunami evacuation buildings, etc.)
2012	24	🟩 Research on evaluation methods and criteria for seismic safety of exterior materials	▲ Tsukuba City, Ibaraki Prefecture Tornado	
2013	25	🟨 Development of technology for functional continuity of disaster base buildings	▲ Koshigaya City, Saitama Prefecture Tornado	・Establishment of standards to prevent ceiling fallout ・Revision of the Law for the Promotion of Seismic Retrofitting
2014	26	🟩 Research on earthquake damage mitigation technology for low- and medium-rise buildings against huge earthquakes	● Earthquake with epicenter in northern Nagano Prefecture ▲ Landslide disaster in Hiroshima Prefecture ▲ Heavy snowfall in the Kanto Koshin region	Revision of the Building Standards Law (Revision of fire prevention standards for schools, etc., tightening of the periodic survey and inspection reporting system, etc.)
2015	27		▲ Kinugawa River Flooding in Joso City, Ibaraki Prefecture	
2016	28	🟩 Development of a simple performance evaluation method for wooden houses	● Kumamoto Earthquake ● Earthquake in Central Tottori	・Start of Long-Term Quality Housing certification for additions and renovations ・Revision of standards for prevention of ceiling fallout
2017	29	🟨 Development of design and construction techniques for mixed-structure buildings utilizing new wood materials		・Start of examination of measures against long-period seismic motion for ministerial approval ・Addition of criteria considering the effects of rainfall after snow accumulation
2018	30	🟨 Development of suburban residential area revitalization technology for a mature society (Housing Department)	● Northern Osaka Earthquake ● Hokkaido Bold Eastern Earthquake ▲ Tornado in Maibara City, Shiga ▲ Typhoon No. 21	・Revision of the Building Standards Law (Utilization of existing building stock, rationalization of fire prevention standards for wooden buildings, etc.)
2019	1	🟩 Research and studies contributing to the improvement of the wind resistance performance of building exterior materials and roofs 🟩 Development of technology for Rapid determination of soundness of base buildings subjected to earthquakes	▲ Tornado in Ichihara City, Chiba Prefecture ▲ Typhoon No. 15 (Boso Peninsula Typhoon) ▲ Typhoon No. 19 (East Japan Typhoon)	
2020	2	🟨 Development of technology that contributes to urban revitalization and resilience through rationalization of structural provisions for buildings and the ground	● Earthquake off the Coast of Fukushima Prefecture	Revision of wind resistance standards for tile roofs
2021	3			

（凡例）
(Explanatory notes)

🟨 総プロ課題
🟩 事項立て課題等

● : Earthquake disaster
▲ : Weather-related disasters (typhoons, tornadoes, heavy snowfall, floods, sediment)
*Underlined disasters: Building damage survey report posted on NILIM HP

(1) Background Events, Social Changes, etc.

In June 1998, the Building Standards Law was revised from specification-based regulations to performance-based regulations (enforced in 2000) in response to diversification and sophistication of social needs, development of new technologies, and internationalization, etc. The structural technical standards in laws and regulations have also been continuously developed and reviewed in accordance with the performance regulations. It can be said that the technological development carried out by NILIM's building structure field over the past 20 years is in line with this trend of performance regulation. On the other hand, over the past 20 years, Japan has experienced large-scale natural disasters such as the Great East Japan Earthquake (2011 off the Pacific Coast of Tohoku Earthquake), the Kumamoto Earthquake (2016), and the Boso Peninsula Typhoon (2019), which caused enormous damage to buildings and had a great impact on society. Through the investigation of the reason for each type of damage, new issues and the need for countermeasures that should be addressed by the building structure field became apparent.

In addition, in today's society, the functions and requirements of buildings have diversified, and the maintenance and early recovery of social and economic activities after large-scale natural disasters such as those mentioned above have become extremely important issues. In other words, there is a need for perspectives such as how to achieve structural performance that exceeds the performance required by laws and regulations, and how to respond to events caused by loads and forces that are not stipulated by laws and regulations. Society is requesting not only the development and review of laws and regulations as minimum standards, but also the research and development to supplement them.

(2) Research and Development Tasks

NILIM's building structure field has been conducting総プロ課題and 事項立て課題等 in order to systematically respond to social needs related to building structures and issues that have emerged as a result of natural disasters. In particular, field surveys have been conducted in cooperation with the Building Research Institute for natural disasters that have caused extensive damage to buildings to identify new technological issues that need to be addressed. All of these R&D projects are steadily producing results over a medium-term span of three to five years, and are being implemented in society.

In addition, the Building Standards Development Promotion Project was established in FY2008 (hereinafter referred to as "Standards Development Promotion"). The Ministry of Land, Infrastructure, Transportation and Tourism (MLIT) presents the survey items necessary to promote the development of building standards, and private businesses and other organizations conduct surveys such as the collection and accumulation of basic data, etc., and prepare basic materials for the draft technical standards based on these surveys. NILIM is also involved in the development and review of laws and regulations within the framework of this project, as well as the setting of issues to be promoted (entrance) and the preparation of draft technical standards based on the results obtained by private organizations.

(3) Outline of Research and Activities

The results of the research and studies are compiled as draft technical standards and guidelines for laws and regulations, etc., keeping in mind that responses based on new technical findings from disaster investigations and research and development may not only contribute to rationalizing the standards, but also to strengthening them.

The draft technical standards also cover areas where structural methods and verification methods have not been sufficiently developed in technical standards (e.g., suspended ceilings, tile roofs) and external forces (e.g., tsunamis, long-period seismic motions, snow loads after rainfall). Technical studies on appropriate structural methods (specifications), setting of design criteria, development of calculation methods, etc., have been conducted as well. For example, the Draft Design Guidelines for Disaster Base Buildings were positioned as a complement to the current technical standards after clarifying the targeted building applications. The former is to tighten regulations, while the latter is to induce a level of performance that exceeds that set forth in the current standards. Therefore, in order to ensure smooth implementation after the compilation of these results, the study was conducted in close cooperation and coordination not only with relevant departments of the Ministry of Land, Infrastructure, Transport and Tourism and academic experts, but also with private organizations. The following is a list of the main research results of these efforts that led to the development of the draft technical standards.

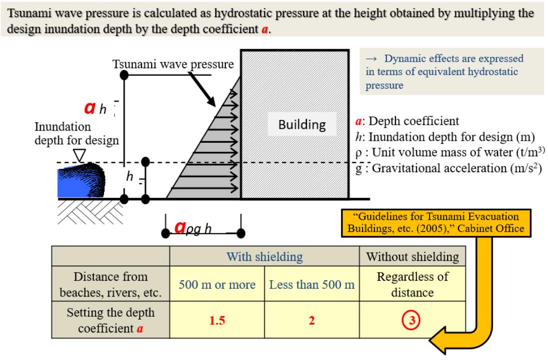
During the past 20 years, we have also conducted research on new structural systems and structural design methods using new materials to contribute to the expansion of design options, structural calculation programs, and advanced earthquake information to contribute to the sophistication, rationalization, and facilitation of structural design, based on the government's basic policy and trends in private sector technological development. The results have been accumulated as fundamental knowledge directly related to the development of future technical standards.

2. Main Research Results

(1) Structural Design Methods for Tsunami Evacuation Buildings

- The Great East Japan Earthquake that occurred in March 2011 caused extensive damage to buildings that were overturned and washed away by the tsunami (Photo-1). In addition to assessing the damage through on-site surveys, structural design methods for tsunami evacuation buildings were studied using the FY2011 Issues of the Standards Development Promotion. In July of the same year, a report focusing on building damage surveys was compiled. Based on the results, we produced the "Practical Guidelines for Structural Requirements for Tsunami Evacuation Buildings, etc., Based on the Building Damage Caused by the Tsunami in the Great East Japan Earthquake" and published NILIM Technical Note No. 673. This document explains the technical standards for buildings to be constructed in hazardous areas designated under Article 39 of the Building Standards Law and the Law Concerning the Creation of Tsunami Disaster Prevention Areas enacted in December 2011. Design examples are also provided.

Photo-1 Damage to four-story RC building caused by tsunami



Tsunami wave pressure is calculated as hydrostatic pressure at the height obtained by multiplying the design inundation depth by the depth coefficient *a*.

	With shielding		Without shielding
Distance from beaches, rivers, etc.	500 m or more	Less than 500 m	Regardless of distance
Setting the depth coefficient *a*	1.5	2	③

Figure-1 Calculation method for tsunami wave pressure

- In compiling the draft technical standards, we worked with relevant departments of the Ministry of Land, Infrastructure, Transport and Tourism to support the legislative and administrative response from a technical standpoint, and we also sought the opinions of experts in the fields of civil and coastal engineering who are familiar with tsunamis and the damage caused by tsunamis. The policy was to add to the existing guidelines the findings based on actual damage, taking into account the extremely limited timeframe. In addition, specific design examples were prepared with the intention of complementing the technical standards and promoting accurate application by practitioners of building structures.
- The structural design of a tsunami evacuation building verifies that the building will not collapse, overturn, or slide under the anticipated tsunami wave pressure (Figure-1). Although the consideration of horizontal forces is similar to that of seismic

design, the following characteristics must be considered: energy absorption by repeated deformation cannot be expected, overturning and sliding are likely to occur due to buoyancy forces, and scouring and drifting debris must be considered.

(2) Countermeasures Against Long-Period Seismic Motion

- In Tomakomai City, about 250 km from the epicenter of the 2003 Tokachi-oki Earthquake, oil tank sloshing occurred due to long-period seismic motion (long-period long-duration (LPLD) seismic motion) and a fire broke out. In the 2011 off the Pacific Coast of Tohoku Earthquake, not only high-rise buildings in Tokyo, but also a high-rise government office building on the Osaka Bay coast, 770 km from the epicenter, were severely shaken by long-period seismic motions, causing damage such as elevators being trapped and ceiling panels falling off.
- Based on our experience with this type of earthquake damage, we focused on developing a countermeasure against the long-term repeated deformation caused by the resonance phenomenon of buildings due to long-period ground motion, which is expected to occur in a huge earthquake along the Nankai Trough. Under the Multiple Issues of Basic Improvement Promotion in FY2008-2012, we studied a method for setting long-period seismic motion for design and a method for evaluating the response of buildings to the seismic motion.
- We identified areas where resonance countermeasures should be applied for skyscrapers and seismic isolation buildings, and proposed a simplified design spectrum in the three major metropolitan areas and Shizuoka Prefecture in cooperation with the Cabinet Office’s examination of the damage estimation (Figure-2). In addition, we conducted a seismic experiment on a 20-layer RC frame (Photo-2), examined the extent to which the damage state can be reproduced by normal response analysis technology when a large response deformation occurs due to resonance, and proposed a response estimation method that incorporates the effect of multiple repetitions.

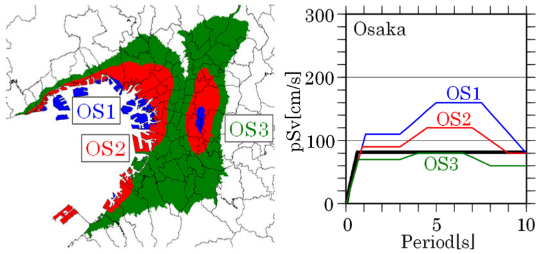
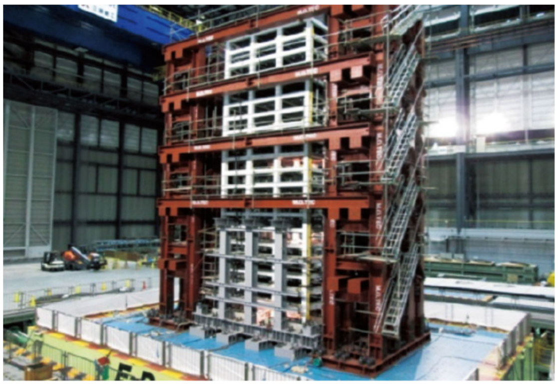


Figure-2 Osaka area (OS) zoning and simplified design spectra (pseudo velocity response spectrum [pSv] with 5% damping) and spectrum in the notification [black bold line].



- These results were reflected in the manual for performance evaluation by time history response analysis as a countermeasure against long-period ground motion caused by a huge earthquake along the Nankai Trough.

(3) Earthquake Resistance Measures for Suspended Ceilings

- The Great East Japan Earthquake caused many large-scale ceiling dislocations in large spaces (Photo-3), resulting in 5 fatalities, more than 72 injuries, and approximately 2,000 cases of damage. Particularly problematic were the many cases of large-scale and extensive damage to ceilings, even though the magnitude of seismic motion was such that the structure was hardly damaged. Despite the fact that the MLIT had previously issued several technical advices, the Great East Japan Earthquake once again caused similar and numerous cases of falling ceilings and human casualties, leading to stronger regulations and disaster prevention measures. Utilizing the FY2011 Issues of the Standards Development Promotion, we quickly grasped the damage situation through on-site and questionnaire surveys, narrowed down the scope of regulations and specifications that should be recommended based on the survey results, and compiled a draft technical standard consisting of provisions such as the installation of diagonal members behind the ceiling and gaps between the walls (Figure-3(a)) based on the opinions of experts. Subsequently, in July 2013, Article 39 of the Building Standards Law Enforcement Order was amended to newly establish standards for "specific ceilings," and related notices were promulgated in August 2014 (enforced in April 2014).

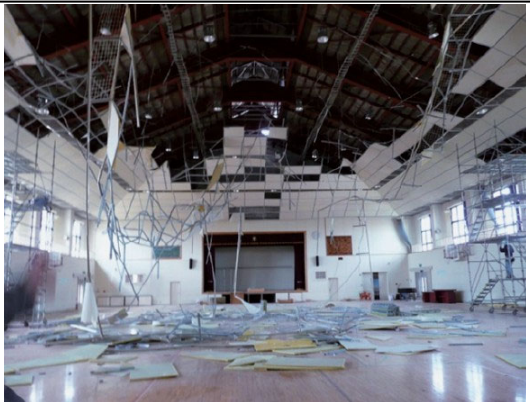
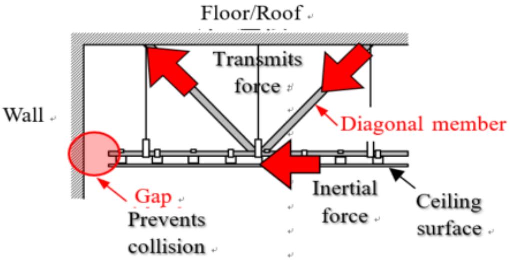
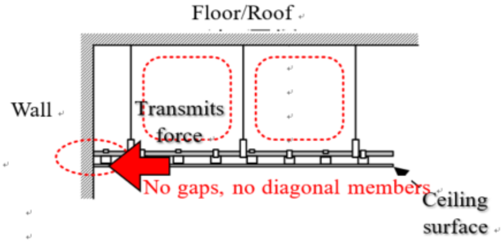


Photo-3 Damage from falling ceiling in gymnasium



(a) Installation of diagonal members and gaps



(b) No gaps or diagonal members

Figure-3 Two types of falling ceiling measures

- In examining the seismic force for ceiling design in the draft technical standards, we newly examined the calculation method that takes into account the increase in seismic force due to resonance with the structural frame, which was not necessarily sufficient even in the previous guidelines for society, etc., and we adopted a larger seismic force so that it would be safe for resonance when simplifying for design purposes.
- In order to promote smooth and accurate operation by manufacturers and building structure practitioners, NILIM Technical Note No. 751, "Practical Guide on the Technical Standards concerning Measures to Prevent the Falling of Ceilings in Buildings," was released in September 2013. In addition to explaining the technical standards, the test method and the method for setting the bearing capacity and rigidity were presented as common operational rules.
- In the initial specifications of specific ceilings (Figure-3(a)), it was difficult to install equipment and piping behind the ceiling, and there was a strong need not to provide gaps from the viewpoint of sound and air conditioning, so it was necessary to consider different specifications. Therefore, utilizing the FY2013 Issues of the Standards Development Promotion, and based on empirical studies conducted by shaking experiments and other methods, we confirmed the earthquake resistance

of the specification (Figure-3(b)) with no diagonal members and no gaps between the walls. Based on this knowledge, specifications were added under a certain scale and conditions by revising the notification in 2016, and standard explanations and design examples were published.

(4) Method for Setting Snow Load Considering the Effect of Rainfall

- In February 2014, a low pressure system that developed with a front moved northeastward along the southern coast of Honshu, causing record-breaking snowfall in the Kanto-Koshin and Tohoku regions. As a result, damage to buildings occurred in various places, and the damage caused by the collapse of the entire roof was concentrated on large-scale buildings with large spans and gently sloping roofs (Photo 4). As a result of damage surveys and analysis of meteorological data at the site, it was thought that one of the causes was the effect of the increased snow load caused by rainfall after snowfall.
- Based on the above situation, under the Issues of the Standards Development Promotion in FY2014-2016, we conducted indoor and outdoor experiments using actual large-scale roof specimens (maximum roof length 50 m) and reproduced the increased snow load due to rainfall after snow accumulation (Photo 5). In this study, Japan's leading experts in snow engineering made a concerted effort to cooperate in compiling the experimental results from the experimental plan and the construction plan of the test object.
- Since the formula for calculating the extra load proposed from the experimental results is set to lead to the tightening of regulations, we carefully assessed the range of the roof scale to be applied in parallel with the construction of the formula. Through the above examination, the calculation formula and scope of application, which had not been developed in the guidelines of the Architectural Institute of Japan, were compiled as a draft of the notification and technical advice. This notification was revised in January 2018 (enforced in January 2019).

(5) Wind Resistance of Tile Roofs

- The strong winds of the Reiwa Boso Peninsula Typhoon, which made landfall in the Kanto region in September 2019, damaged


Photo-4: Large-scale roof collapse due to rainfall after snow accumulation


Photo-5 Outdoor experiment using full-scale roof specimen


Photo-6: Example of damage to a tile roof caused by Typhoon Boso Peninsula in 2019


Photo-7 Loading test on clay tiles

the roofs of many detached houses, mainly in Chiba Prefecture, and the vulnerability of tiled roofs to strong winds became apparent (Photo 6).

- NILIM conducted surveys in areas of Chiba Prefecture that were severely damaged, and demonstrated the effectiveness of the design and construction guidelines established by the tile industry in 2001 against strong winds for tiled roofs. Then, a revised draft of the notification was prepared in a way that incorporated the contents of the guidelines into the specification regulations. This notification was revised in December 2020 (enforced in January 2022).
- Additionally, in FY2020, in cooperation and coordination with tile industry players, we proceeded to revise the guidelines to clarify their position as a complement to the above-mentioned revised notification. Through loading tests on tile roofs (Photo-7), we developed specifications for tile roofs that can be adopted in coastal areas to induce higher wind resistance performance. It is expected that the revised notification and revised guidelines will work in tandem to contribute to the spread of disaster-resistant tile roofs.

3. List of Related Reports and Technical Documents

1) "Quick Report of the Field Survey and Research on "The 2011 off the Pacific Coast of Tohoku Earthquake" (the Great East Japan Earthquake)," NILIM Technical Note No. 636, 2011
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0636.htm

2) "Practical Guide on Requirements for Structural Design of Tsunami Evacuation Buildings," NILIM Technical Note No. 673, 2012
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0673.htm

3) "Report on Field Surveys and Subsequent Investigations of Building Damage Following the 2011 off the Pacific Coast of Tohoku Earthquake," NILIM Technical Note No. 674, 2012
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0674.htm

4) "Practical Guide on the Technical Standards concerning Measures to Prevent the Falling of Ceilings in Buildings,"NILIM Technical Note No. 751, 2013
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0751.htm

5) "Snow Damage Countermeasures for Buildings," Subcommittee on Accident and Disaster Countermeasures for Buildings, Building Subcommittee of the Council for Social Infrastructure Development, 2014
https://www.mlit.go.jp/common/001059535.pdf

6) "Countermeasures against Long-Period Ground Motions Caused by a Large Earthquake along the Nankai Trough in High-Rise Buildings, etc. (Technical Advice)," MLIT Notification No. 1111, 2016
https://www.mlit.go.jp/common/001136168.pdf

7) "Design Guidelines for Buildings at Disaster Bases (Draft)," NILIM Technical Note No. 1004, 2018
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn1004.htm

8) "Report on the Investigation of Infrastructure and Building Damage Caused by Typhoons No. 15 and No. 19 in 2019," NILIM Technical Note No. 1111, 2020
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn1111.htm

4. Future Outlook

Research and development that contributes to the development and revision of structure-related technical standards in laws and regulations should continue to be addressed by NILIM over the long term, while taking into account trends in diversifying social needs. At the same time, responses to technical issues that have emerged due to natural disasters, etc., should be addressed in the medium term (or in some cases, in the short term and in a flexible manner), and it is important to formulate R&D items after setting the appropriate issues, and to implement the research results in society.

In addition, approximately 20 years have passed since building codes and ordinances became performance regulations and the Housing Performance Indication System was established. In order to further disseminate and deploy structure-related technical standards, it is necessary to continue to streamline design and verification methods for building structures stipulated in laws and regulations, conduct research and development that contributes to the development of structural performance evaluation technologies for housing, etc., and develop guidelines that complement the laws and regulations.