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Earthquake Engineering Research Framework toward Research Roadmap Based on the Lessons Learnt from the 2011 Tohoku Earthquake

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Abstract ;

The Building Research Institute in Japan (so far referred to as the BRI) has conducted various activities such as research and development on housing, building and urban planning technology, and international training on seismology and earthquake engineering, systematically and continuously from the fair and neutral perspective of a public-sector research institute. In the spring of 2012, the CIB Regional Office of Japan was established in the BRI as requested by CIB. The BRI will play a leadership role of CIB activities in Japan. Meanwhile, the 2011 Tohoku earthquake occurred on March 11, 2011 and caused tremendous damage to buildings and houses and enormous human losses by ground motion and tsunami. Based on lessons learnt from this earthquake disaster, the BRI has decided to develop a roadmap for earthquake engineering research and development for buildings. The roadmap will be utilized in the activities of the current working commission W114 (Earthquake Engineering and Buildings) in CIB. Firstly, this paper introduces the activities of the BRI after the 2011 Tohoku earthquake and summarizes the lessons from this tragedy. Then, the draft of Earthquake Engineering Research Framework toward Research Roadmap for research and development for earthquake engineering is described. At the beginning of the proposed framework, the “Vision” describes the final objective of the roadmap. Then, “Mission” describes the research and development items to realize the vision. The “Goals” and "Objectives” follows describing more specific contents corresponding to each item of the Mission.

Keywords: Earthquake Engineering Research Framework, the 2011 Tohoku Earthquake, Research Roadmap

1. Introduction

This paper presents the earthquake engineering research framework toward research roadmap based on the lessons learnt from the 2011 off the Pacific coast of Tohoku Earthquake (hereinafter referred to as the 2011 Tohoku earthquake). This paper introduces the outline of the 2011 Tohoku earthquake, the strong motion observed mainly by the Building Research Institute (BRI) Strong Motion Network, the motion-induced building damage and the tsunami-induced building damage by the 2011 Tohoku earthquake. Joint activities to establish codes by the National Institute for Land & Infrastructure Management (NILIM) and BRI are also introduced briefly. Based on the lessons learnt from the damage survey of the 2011 Tohoku earthquake and BRI's research activities, the earthquake engineering research framework for research roadmap is described.

2. Lessons Learnt from the 2011 Tohoku earthquake [1]

2.1 Outline of the 2011 Tohoku earthquake and BRI's survey activities

The 2011 Tohoku earthquake of moment magnitude (Mw) 9.0 occurred at 14:46 JST on March 11, 2011 and generated gigantic tsunami in the Tohoku and Kanto Areas of the north-eastern part of Japan. This was a thrust earthquake occurring at the boundary between the North American and Pacific plates. This earthquake is the greatest in Japanese recorded history and the fourth largest in the world since 1900 according to U.S. Geological Survey[2]. An earthquake of Mw 7.5 foreshock preceded the main shock on March 9 and many large aftershocks followed including three Mw 7-class aftershocks on the same day of the main shock. As the epicentral distribution of the aftershocks of the 2011 Tohoku earthquake (hypocentral region) is widely located off the coast of the prefectures of Iwate, Miyagi, Fukushima and Ibaraki with approximately 450km in length in North-South direction and 150km in width in East-West direction. The distance from these prefectures to the fault plane is near, thus the places with JMA (Japan Meteorological Agency) Seismic Intensity of approximate 6 (6+ or 6-) widely spread in these prefectures. The maximum JMA seismic intensity of 7 was recorded by the strong motion recording network (K-NET) [3] of the National Research Institute for Earth Science and Disaster Prevention (NIED) at Kurihara City (K-NET Tsukidate) shown by the purple color in Fig. 1.

Field survey by NILIM and BRI was started from Kurihara City and was followed by the locations shown in Fig. 2. In the coastal area from Aomori Prefecture to Miyagi Prefecture, the tsunami-induced building damage was mainly surveyed. The area facing to the Pacific Ocean in Fukushima Prefecture was excluded from the survey in the cause of the accident in Fukushima Daiichi Nuclear Power Station. In the catchment basin area of Tone River in the border between Ibaraki and Chiba Prefectures and Urayasu City on the Tokyo Bay, damage of residential land associated with liquefaction was surveyed. In the following section, outline of strong motion in buildings recorded by BRI and damage of buildings given by field survey will be discussed and lessons learnt from it.

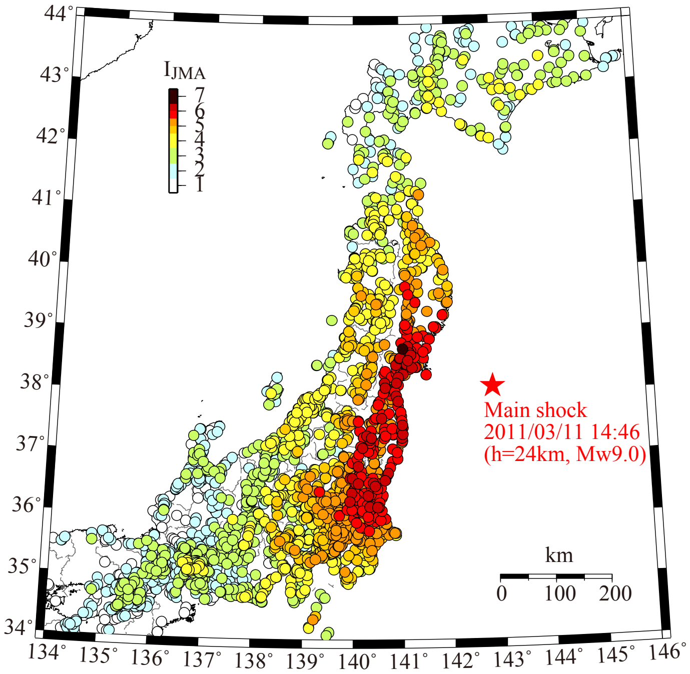


Figure 1: JMA Seismic Intensity Map[1]

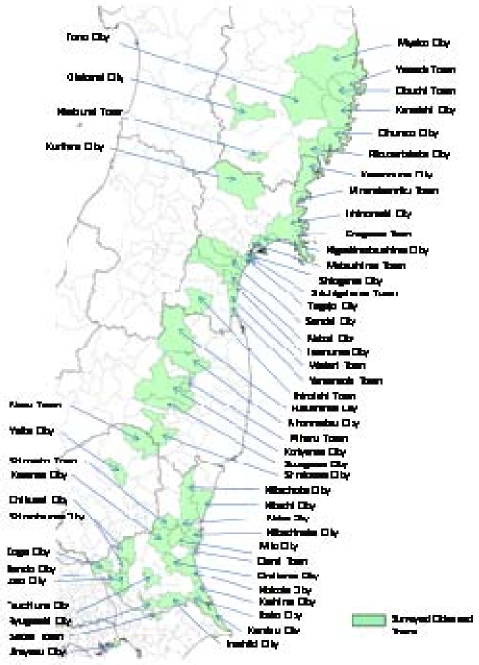


Figure 2: Locations of Surveyed Areas[1]

2.2 Earthquake and Ground Motions

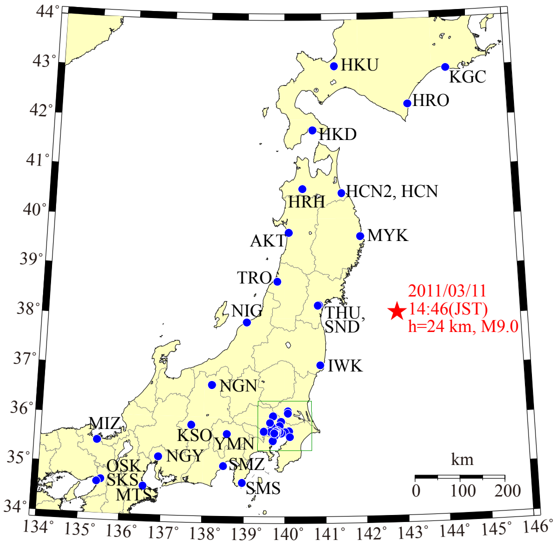
2.2.1 Characteristics of Earthquake Motions

During the 2011 Tohoku earthquake, severe ground motions were observed in wide area, and massive amounts of strong motion records were accumulated by K-NET of NIED [3]. From the acceleration records, a maximum acceleration in the N-S direction is understood to have reached almost 3700 cm/s^2, representing that the main shock caused excessively severe earthquake motions. A response in the N-S direction with a period of about 0.2 seconds becomes particularly large. This indicates that earthquake ground motions are dominated by short periods.

2.2.2 Recorded Data Given by BRI Strong Motion Network

The BRI conducts strong motion observation that covers buildings in major cities across Japan [4]. When the 2011 Tohoku earthquake occurred, 58 strong motion instruments placed in Hokkaido to Kansai Areas started up. Locations of the strong motion stations are plotted in Fig. 3 and Fig. 4. Among them, about 30 buildings suffered a shaking with seismic intensity 5- or more.

Among buildings in the BRI Strong Motion Network, at least 4 buildings suffered severe earthquake motions and then some damage. One example of the damaged buildings is the building of the Tohoku University. This is the 9-story steel reinforced concrete (SRC) school building located in the Aobayama Campus in Sendai city. During the 2011 Tohoku earthquake, multi-story shear walls suffered flexural failure and other damage. Thick and thin lines in Fig. 5 (a) and (b) represent acceleration waveforms on the first and the ninth floors, respectively. Maximum accelerations on the first floor exceeded 330 cm/s^2 in both directions. Due to the seismic damage, the fundamental natural period finally became twice longer than that at the initial stage (Fig. 5 (e)), and was reduced to 1/4 on a stiffness basis.



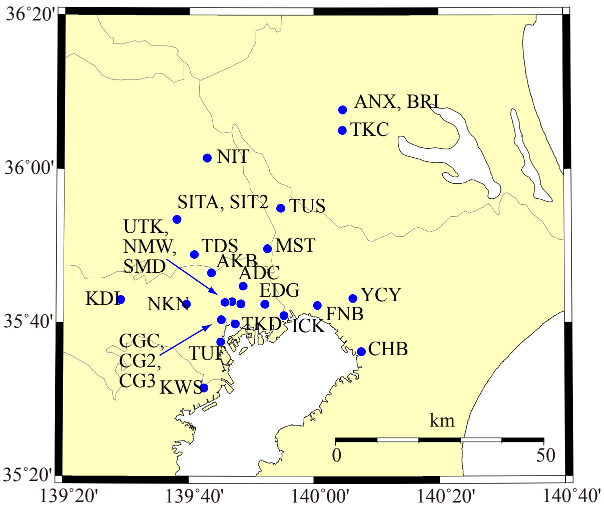
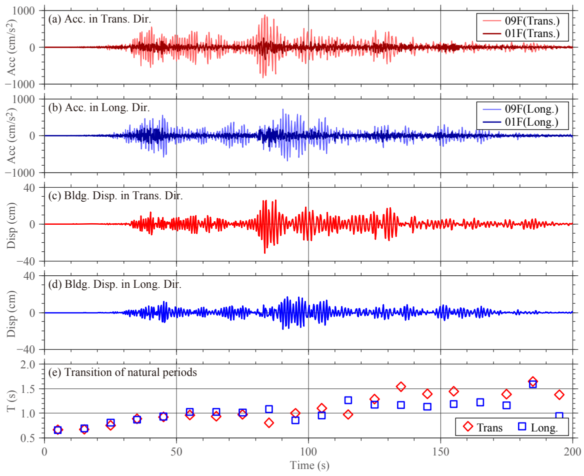


Figure 3: Locations of Epicenter (★) and BRI Strong Motion Network (●)[1]

Figure 4: BRI Strong Motion Network in Kanto Area (corresponds to green rectangle in Fig. 3) [1]



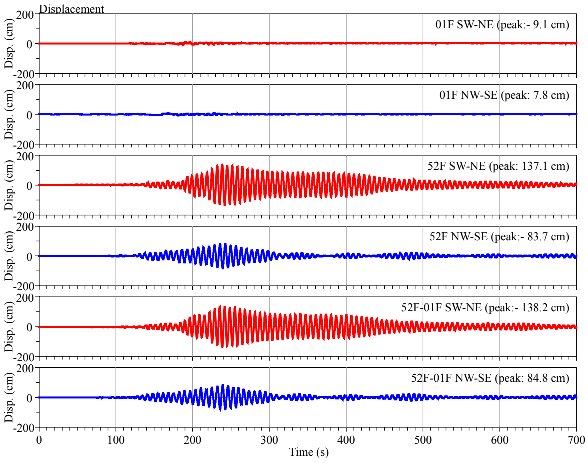


Figure 5: Strong Motion Records of the Tohoku University and Transition of Natural Periods[1]

Figure 6: Displacement observed at a 55-story Office Building in Osaka Bay Area[1]

2.3 Motion-Induced Damage of Buildings

2.3.1 Damage of Wood Houses

As a result of motion-induced damage survey on the wood houses in each city, the followings were provided.

1) The motion-induced damage on many wood houses was confirmed in wide areas. 2) Though the seismic intensity 7 was recorded in Miyagi Prefecture, the damage on wood houses were not so severe. 3) The damage of the roof tile in Fukushima and Ibaraki Prefectures was much larger than Miyagi Prefecture where an earthquake occurred more frequently. 4) The possibility that the ground motion was amplified on the land filled up from meadow or rice field, even if the residential land did not fail, was suggested. 6) The plural rare damage examples that residual story deformation of 2nd floor was larger than that of 1st floor were confirmed.

2.3.2 Damage of Reinforced Concrete Buildings

The types of the damage of RC and SRC buildings that were observed through the site investigation are classified into those for structural components in the following.

The damage of structural elements are; 1) Collapse of the first story, 2) Mid-story collapse, 3) Shear failure of columns, 4) Flexural failure at the bottom of column and base of boundary columns on multi-story shear walls, 5) Pullout of anchor bolts and buckling of longitudinal reinforcements at exposed column base of steel reinforced concrete (SRC) buildings, 6) Shear failure or bond splitting failure of link beams of multi-story coupled shear walls, 7) Building tilting, 8) Destruction, failure or tilting of penthouses, 9) Damage of seismic retrofitted buildings.

2.3.3 Damage of Steel Gymnasiums

The damage of the gymnasiums was classified into the types of 1) to 7). The types of 1) to 6) and the type of 7) refer to structural damage.

1) Buckling and fracture of brace member and fracture of its joint, 2) Buckling of diagonal member of latticed column, 3) Damage of connection (bearing support part) between RC column and steel roof frame, 4) Deflection, buckling and fracture of roof horizontal brace, 5) Cracking of column base concrete, 6) Others (Overturning of floor strut, etc.).

2.3.4 Damage of Non-Structural components

Post-earthquake functionality of government buildings and evacuation facilities such as gymnasiums couldn't be assured due to damage of non-structural components. The examples of damage on non-structural elements in RC buildings are; 1) Flexural failure at the bottom of column with wing wall, 2) Damage of non-structural wall in local government buildings and residential buildings, 3) Damage and falling of external finishing, 4) Tilting or dropout of components projecting above the roof, 5) Collapse of concrete block wall and stone masonry wall. The examples of damage on non-structural elements in steel gymnasiums are; 1) dropping of ceilings and exterior walls, 2) breakage of windows and so on.

2.3.5 Damage due to Failures of Residential Land

The outline of the damage situations in the investigated area is as follows.

Regarding damage caused by liquefaction, extensive damage such as sand boiling or ground transformation associated with liquefaction was confirmed in the catchment area of Tone River and the coastal zone of Tokyo Bay. Highly tilted buildings were seen, but visual cracks or fissures on the foundations investigated were not observed. Regarding damage to housing area, large damage with transformations such as ground sliding was observed mainly in the elevated and developed housing area (particularly marginal part). In some areas, transformations occurred again in the developed lots that had been affected by the past earthquakes. The damage on the wood houses caused by the failures of residential land was confirmed in Miyagi Prefecture, and Tochigi Prefecture.

2.3.6 Response of Seismically Isolated Buildings

Investigation results of Seismically Isolated (SI) buildings in Miyagi Prefecture and one SI building in Yamagata

Prefecture are summarized as follows;

1) Super-structures of SI buildings suffered almost no damage even under strong shaking with JMA intensity 6 upper. Seismic performance of SI buildings BRI surveyed was good. 2) There are 8 buildings with scratch boards to measure displacement of the SI building floor. In most cases, the maximum displacement has been expected as around 20 cm. There is one case with the maximum displacement estimated over 40 cm. 3) In some buildings, damage was observed at the expansion joints. It seems that parts of expansion joints were not well operated due to the large displacement of SI building floor during earthquake. 4) Subsidence of ground around the building was observed in some buildings. 5) Many cracks were found in lead dampers. These cracks might be increased by the aftershocks. 6) Peeling off of paint was observed widely for U-shape steel dampers. In some cases, residual deformation of steel was remained.

2.3.7 Response of Super High-Rise Buildings

Long-period earthquake motions and responses of super high-rise buildings shaken under the motions have been socially concerned in recent years. When the 2011 Tohoku earthquake occurred, long-period earthquake motions were observed in Tokyo, Osaka and other large cities where are away from its hypocenter. There are two cases of Tokyo and Osaka in the BRI strong motion network. Fig. 6 shows the strong motion records that were obtained from the 55-story steel office building on the coast of Osaka Bay which is 770 km away from the hypocenter. This figure shows absolute displacements in the SW-NE and in the NW-SE directions on the 1st floor, absolute displacements in both of the directions on the 52nd floor, and building displacements (relative displacements of 52th floor to 1st floor) in both of the directions, from the top to the bottom. A ground motion displacement was not large, or less than 10 cm, but the 52nd floor in the building suffered a large motion with a zero-to-peak amplitude of more than 130 cm. The coincidence of the fundamental natural period (6.5 to 7 seconds) in the steel office building with a predominant period of the earthquake motion is considered to have caused a resonance phenomenon and then large responses were observed at the top.

2.4 Tsunami-Induced Damage to Buildings in Inundation Areas

The purpose of the field survey by BRI is to clarify an overview of buildings damaged by tsunami, to obtain basic data and information required to evaluate mechanisms for causing damage to the buildings and to establish tsunami-resistant designs for buildings such as tsunami evacuation buildings, by means of collecting building damage cases by tsunami, classifying the damage patterns for different structural categories, and making a comparison between the calculated tsunami force acting on buildings and the calculated strength of structural members in the buildings. The NILIM and BRI jointly created a tsunami damage investigation team that consists of 27 members. The joint team collected national and international standards and codes concerning tsunami evacuation buildings and tsunami loads and surveyed about 100 buildings and structures in three site investigations.

The damage types of RC buildings observed through the site investigation are classified as followings; 1) Collapse of the first floor, 2) Overturning, 3) Movement and washing away, 4) Tilting by scouring, 5) Fracture of wall (fracture of opening), 6) Debris impact. The damage types of steel buildings observed through the site investigation are classified as followings; 1) Movement and washed away by fracture of exposed column base, 2)

Movement and washed away by fracture of capital connection, 3) Overturning, 4) Collapse, 5) Large residual deformation, 6) Full fracture and washed away of cladding and internal finishing materials. As for wood houses, in the case of a maximum inundation depth of about 1 m, most of houses could be remained. Some wood houses were damaged considerably due to debris impact. In the case of a maximum inundation depth of about 1 to 6 m, some wood houses where located behind the relatively substantial building for tsunami load such as a reinforced concrete building remained. In addition to that case, a tsunami load was reduced possibly due to many openings in the direction affected by tsunami, or a wooden house remained despite washed away of columns and external walls at the corner of the building. Several houses which have a reinforced concrete story on the first floor, or a mixture of wooden and reinforced concrete structures, remained.

2.5 Lessons Learnt from the 2011 Tohoku earthquake

Some significant lessons learnt from the 2011 Tohoku earthquake are as followings;

1. The strong motion data on those buildings recorded by BRI was effective to understand the behavior of buildings. The enhancement of strong motion network to understand behavior of buildings under earthquake is needed.
2. The damage of non-structural components, especially ceiling, were remarkably observed. Post-earthquake functionality of government buildings and evacuation facilities such as gymnasiums couldn’t be assured due to damage of non-structural components. The measures to mitigate the damage of non-structural components must be implemented as soon as possible.
3. The response of super high-rise buildings and seismically isolated buildings under long-period earthquake was more significant than expected before. The development of advanced response evaluation method and techniques, measures to mitigate the damage against long-period earthquakes is needed.
4. Large-scale liquefaction and settled or tilted structures were observed. The current prediction method of liquefaction should be reviewed and the development on effective indication method of expected performance for residential land for dissemination is needed.
5. Many buildings at coastal area in especially Tohoku area had severe damage by Tsunami. The advanced understanding on occurrence of tsunami and the development for tsunami-resistant design for buildings at coastal area including evaluation method of tsunami load is needed.

2.6 Research Activities by BRI and NILIM Based on the Lessons

For policy response based on the lessons described in 2.5, the following studies should be especially conducted by means of technical investigations. 1) Study on the design of tsunami evacuation buildings, i.e. estimation of tsunami load, 2) Study on advanced seismic resistant design of suspension ceiling system, 3) Study on verification of seismic safety performance for super high-rise buildings and seismically isolated buildings under long-period earthquakes, 4) Study on information indication of liquefaction for residential houses

NILIM has been developing the draft of technical standards for each study item. The research organizations designated by the Building Standard Development Promotion Program of Ministry of Land, Infrastructure, Transport Tourism (MLIT) and BRI have been implementing research activities jointly to provide necessary technical inputs for these standard development. Thus, BRI, together with NILIM, has been playing very important parts for improvement of technical contents of the Japanese building code reflecting the lessons from the 2011 Tohoku earthquake.

3. Earthquake Engineering Research Framework toward Research Roadmap

The structure for CIB roadmap is shown in Fig.7. “Conceptual Framework” in Fig.7 could be common interest among each institute and organization and the other items in Fig.7 depends a great deal on the specific interests and situations of each institute and organization. Because it is expected that the situation on other items of earthquake engineering research in each country is quite different. Once “Conceptual Framework” will be determined, the other items could be discussed among each institute and organization. Thus, first of all, the comprehensive and strategic research framework should be shown. Based on the lessons learnt from the 2011 Tohoku earthquake, this paper presents the earthquake engineering research framework corresponding to “Conceptual Framework” in Fig.7 toward research roadmap with reference to other materials [6,7] to decide the framework. For examples, urgent research issues based on the lessons is considered in research agenda.

The structure of research framework is shown in Fig.8. The framework is triangle shape and consists of the following items; 1) Vision, 2) Missions, 3) Goals, 4) Objectives. Based on the proposed framework, research theme in BRI’s research agenda is finally shown as an example in the paper to show the relationships between the framework and specific research themes in research agenda.

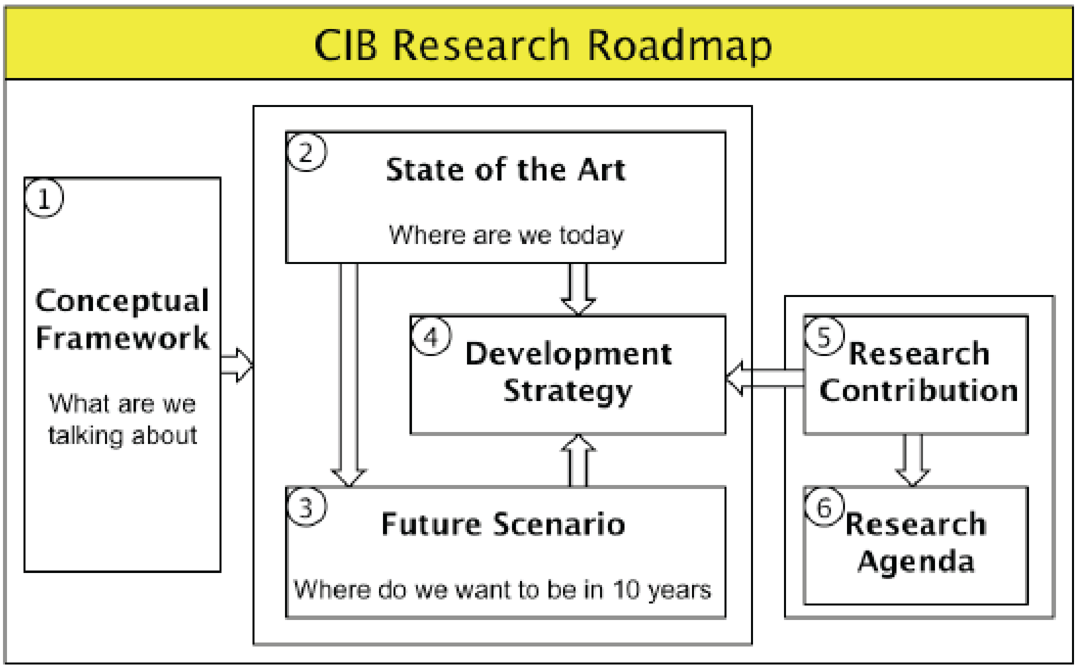


Figure 7: Structure for CIB Research Roadmap [8]

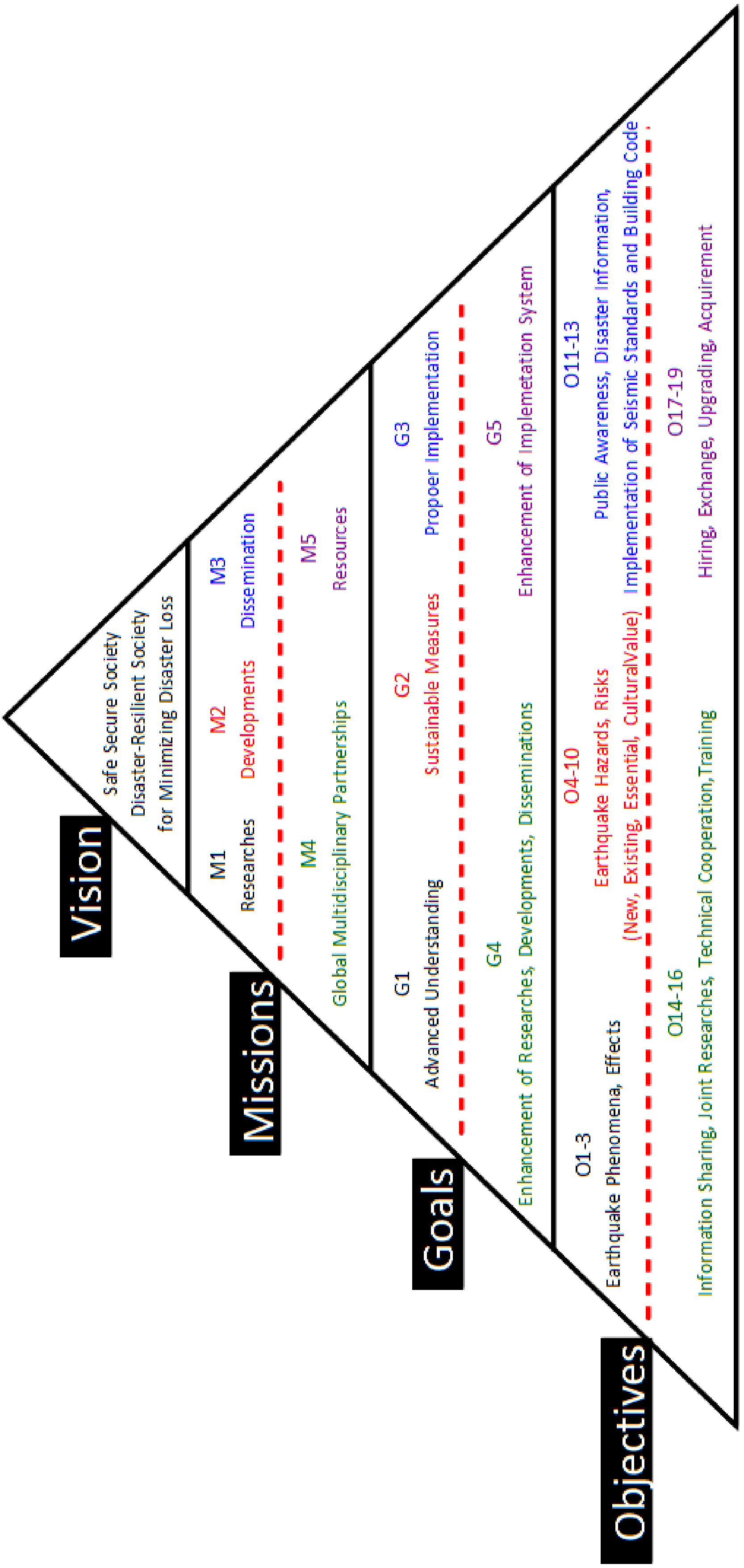


Figure 8: Structure of Earthquake Engineering Research Framework

3.1 Vision

Based on the experiences of The 2011 Tohoku earthquake, we recognized the importance of not only seismic safety performance of buildings but also post-earthquake continuous functionality against severe earthquake. Thus, the Vision which earthquake engineering research can contribute is “Safe and Secure Society” and “Resilient Society for Minimizing Disaster Loss”. Especially countries where frequent earthquakes occur like Japan should prepare the appropriate actions against before and after earthquake for realization of above mentioned society.

3.2 Missions

The Missions to achieve the vision are shown as follows, M1） Research for Earthquake Disaster Loss Mitigation, M2） Development of Technologies and Tools for Earthquake Disaster Loss Mitigation, M3） Dissemination and Promotion for Earthquake Disaster Loss Mitigation Measures, M4） Global Multidisciplinary Partnerships for Earthquake Disaster Loss Mitigation, M5） Upgrading and Utilization of Required Resources for Earthquake Disaster Loss Mitigation.

3.3 Goals

The Goals to achieve the Missions are shown as follows, G1) Advanced Understanding of Earthquake Phenomena and Impact, G2) Development of Sustainable Measures to Mitigate Earthquake Disaster Loss and Impact on Individuals, the Built Environment, and Society-at-Large, G3) Proper Implementation of Earthquake Disaster Loss Mitigation Measures for Earthquake Professionals, Owners, Users, G4) Enhancement of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation, G5) Enhancement for Implementation System of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation. Each Mission is corresponding to each Goal as followings;

1) Advanced Understanding of Earthquake Phenomena and Impact (G1) is a goal for Research for Earthquake Disaster Loss Mitigation (M1)
2) Sustainable Measures to Mitigate Earthquake Disaster Loss and Impact on Individuals, the Built Environment, and Society-at-Large (G2) is a goal for Development of Technologies and Tools for Earthquake Disaster Loss Mitigation (M2)
3) Proper Implementation of Earthquake Disaster Loss Mitigation Measures for Earthquake Professionals, Owners, Users (G3) is a goal for Dissemination and Promotion for Earthquake Disaster Loss Mitigation Measures (M3)
4) Enhancement of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation (G4) is a goal for Global Multidisciplinary Partnerships for Earthquake Disaster Loss Mitigation (M4)
5) Enhancement for Implementation System of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation (G5) is Upgrading and Utilization of Required Resources for Earthquake Disaster Loss Mitigation (M5)

Those Goals are long-term targets to support the Missions and associated with the Objectives. The relationship between Goals and Objectives is shown in Fig. 3.3. G1, 2, 3, corresponding to M1, 2, 3 respectively are closely linked and G3 is generally proper implementation with the outcome of G1 and G2. G4 corresponding to M4 is the important item to enhance G1, 2, 3 globally. G5 corresponding to M4 is the basis of activities for other Goals. Each Objective is related to the Goals (see Fig.9) and set to achieve the Goals.

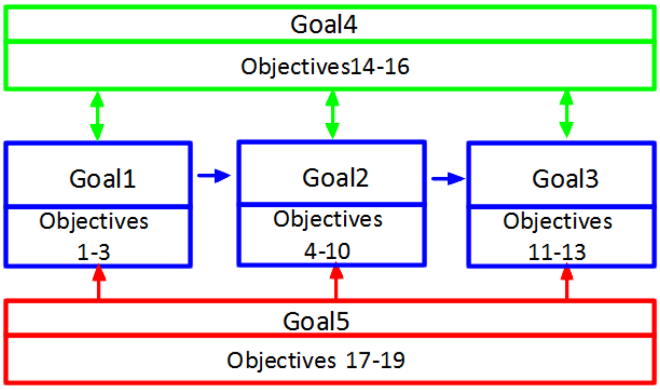


Figure 9: Relationships between Goals and Objectives

3.4 Objectives

3.4.1 Advanced Understanding of Earthquake Phenomena and Impact

The Objectives relevant to G1 are follows, O1) Advanced Understanding of Earthquake Generation, Propagation and Relevant Phenomena, O2) Advanced Understanding of Earthquake Effect on Structures and the Surrounding Built Environment, O3) Advanced Understanding of Earthquake Effect on the Societal Activities. For better understanding, each example on O1 to O3 is mentioned as followings, O1) Fault model evaluation, Earthquake propagation evaluation, Near fault evaluation, Tsunami force evaluation, O2)Effective Input motion evaluation based on strong motion records, sophisticated method on strong motion observation for structures, Response evaluation for structures, Liquefaction evaluation, O3) Post-Earthquake damage information, Post-Earthquake scenarios.

3.4.2 Sustainable Measures to Mitigate Earthquake Disaster Loss and Impact on Individuals, the Built Environment, and Society-at-Large

The Objectives relevant to Goal2 are follows, O4) Development of Technologies and Tools to Assess Earthquake Hazard, O5) Development of Technologies and Tools to Assess Earthquake Risk Scenarios, O6) Development of Technologies and Tools to achieve Seismic Safety Performance of New Structures, O7) Development of Technologies and Tools to Improve Seismic Safety Performance of Existing Structures, O8) Development of Technologies and Tools to Enhance Seismic Resiliency of Essential Structures in Large Urban Areas, O9) Development of Technologies and Tools to continue Post-Earthquake Serviceability of Structures with Cultural Value, O10) Development of Seismic Standards and Building Codes Corresponding to Social Needs. For better understanding, each example on O4 to O10 is mentioned as followings, O4) Updating of existing hazard map, Technical standards of earthquake load, Earthquake evaluation techniques corresponding to construction sites, O5) Earthquake loss and risk evaluation, Performance evaluation and indication tool including excessive load, Risk communication tool, Rapid and detailed assessment techniques for damaged structures, Damage evaluation techniques for structures based on strong motion records, O6) Seismic safety performance evaluation techniques for new structures, New materials, technologies and structural systems, O7) Seismic safety performance evaluation techniques for existing structures, Seismic retrofit technologies, O8) Earthquake damage evaluation techniques and damage mitigation measures, Post-earthquake functionality evaluation techniques for essential structures, O9) Seismic damage evaluation techniques and mitigation measures for structures with cultural value, Serviceability performance evaluation techniques for structures with cultural value, O10) Structural design guidelines for tsunami evacuation buildings, Standards related to long-period component of ground motion and base-isolation/seismic control.

3.4.3 Proper Implementation of Earthquake Disaster Loss Mitigation Measures for Earthquake Professionals, Owners, Users

The Objectives relevant to Goal3 are follows, O11) Technical Supports for Implementation of Seismic Standards and Building Code Corresponding to Social Needs, O12) Information on serviceability of Structures after Strong Motion, O13) Support for Public Awareness on Comprehensive Earthquake Hazards and Risks. For better understanding, each example on O11 to O13 is mentioned as followings, O11) Educational activities (seminars, lectures) to contribute smooth implementation of current structural relevant codes for structural engineers, O12) Rapid earthquake announcement, Offer of information on continuous use of structures using strong motion record network, O13) Support of activities to enhance the public awareness and preparedness of earthquake hazards and risks mitigation, Support for making guidebooks on earthquake risk mitigation measures, Support of earth-sciences and earthquake-engineering education, Application of earthquake risks evaluation methods in each region, Application of performance indication methods considering serviceability of structures after earthquake.

3.4.4 Enhancement of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation

The Objectives relevant to Goal4 are follows, O14) Implementation of Information Sharing, Joint Researches and Surveys for Earthquake Disaster Loss Mitigation, O15) Technical Cooperation to Enhance Earthquake Disaster Loss Mitigation in Developing Countries, O16) Trainings for Earthquake Engineering Professionals. For better understanding, each example on O14 to O16 is mentioned as followings, O14) Sharing information with CIB and other international institutes, Joint survey with international institutes, Promotion of International joint research, O15) Cooperation to project on technical support for developing countries, O16) Training courses for knowledgeable specialists on earthquake hazards and risks in developing countries.

3.4.5 Enhancement for Implementation System of Researches, Developments, Disseminations for Earthquake Disaster Loss Mitigation

The Objectives relevant to Goal5 are follows, O17) Hiring and Utilization, Exchange of Researchers with High Level of Expertise, O18) Upgrading and Utilization of Advanced Research Facilities, O19) Acquirement and Priority Allocation of Research Budgets. For better understanding, each example on O17 to O19 is mentioned as followings, O17) Establishment of system for human resources required in each institute, Sharing information and joint research with visiting scholars, O18) Upgrading and utilization of facilities for experimental tests using scale-merit of laboratories and hybrid tests using IT technologies, O19) External research funds and the prioritized allocation for earthquake damage mitigation.

3.5 Verification on Validity of the Framework Using BRI's Research Themes

According to the Figure 7, "State of the Art", "Future Scenario", "Development Strategy" and "Research Contribution" are needed to decide "Research Agenda". In this paper, the description of "State of the Art", "Future Scenario", "Development Strategy" and "Research Contribution" are omitted because of the space limitations. In order to verify validity of the framework by showing the relationships between the research framework proposed and specific research themes, BRI's research agendas are introduced in this section. BRI has research agendas in the medium-term plan based on the medium-term goal under the direction of the Minister (MLIT), and has been promoting research and development efficiently. The specific research themes are related to "Objectives" in the framework. BRI has two research agendas, one is priority research agenda which is socially significant and urgent, and the other is basic research agenda which are academically fundamental and leading. Regarding the earthquake engineering, BRI has 2 research themes for priority research agendas and 10 themes for basic research agendas. The research themes for priority research agenda are "Study on explicit criteria for proper engineering judgment required in structural calculation" and "Study on advanced response evaluation technique for super high-rise building structures under long-period earthquake." The former theme is related to Objectives 6, 10. The latter theme is related to Objectives 8, 10 and is also an issue to be addressed as a lesson of the 2011 Tohoku earthquake. On the other hand, the research themes for basic research agenda are "Study on advanced mitigation techniques against earthquake and Tsunami in developing countries and training courses with latest, useful contents" and "Strong motion observation for buildings and the technology for application". The former research is related to Objectives 15, 16. The latter one is related to Objectives 2, 12 and is also an issue to be solved as a lesson of the 2011 Tohoku earthquake. Through above investigation, it is shown that the framework has an appropriate function to relate to specific research themes in BRI's current research agendas.

4. Conclusions

This paper described the earthquake engineering research framework toward research roadmap based on the lessons learnt from the 2011 Tohoku earthquake. This framework consists of Vision, 5 Missions, 5 Goals and 19 Objectives and specific research agendas are related to Objectives and it is shown that the framework has an appropriate function to relate to specific research agenda using BRI's current research agendas. It is expected that this framework will provide the basis of a framework for Research Roadmap on earthquake engineering and be discussed among the related institutes and organizations.

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