The Practice and the Role of Earthquake Engineering Researchers in Constructing a Resilient Society

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Abstract

Earthquake engineering researchers are conducting research with the goal of protecting the public from natural disasters like earthquakes and tsunamis. The following three missions should be accomplished to create a resilient society:①Avoid danger, ②Become more resistant, ③Become more resilient.
In order to implement these recommendations, earthquake engineering researchers need to proceed with the following research:①Create a city plan that builds in areas that are not at high risk from disasters, ②Research on creating buildings and infrastructure that are stronger in the event of disasters, ③Use disaster prevention information, have a business continuity plan, and rebuild and restore damaged structures.
By promoting the first two types of research, pre-disaster preparations can be made and the damage from disasters can be reduced. Conducting the third type of research will make it possible to have precise post-disaster responses and for reconstruction to take place at an early stage. Furthermore, it is essential to train a variety of capable people to take charge of preparations and disaster responses.
Primarily, the local universities should fulfill the role of undertaking the research and education for the safety of a region. It is possible to reduce the damage in a disaster if citizens perform all types of disaster prevention actions. These disaster prevention actions are precisely the social implementations of research results. They also practice the concept of "thinking globally and acting locally" to reduce the damage caused by disasters.
As an example, the actions at the Disaster Mitigation Research Center at Nagoya University will be introduced.

Keywords: Earthquake, Disaster Mitigation, Social Implementation

1. Introduction

In Japan, there are concerns over an imminent occurrence of a Nankai Trough Earthquake. Provisional calculations performed by the Japanese government predict that, at worst, there would be 320,000 victims, almost 3 million homes destroyed, and 2 trillion dollars in economic damage, which equals to 40% of the gross domestic product. The causes of such severe damage could include (1) a large-scale earthquake occurring directly beneath a land area with a population of 60 million (half of Japan's population), (2) the presence of cities with dense housing in low-lying coastal areas, and (3) the existing non-confirming buildings that have not experienced strong vibrations.
The Nankai Trough Earthquake is an interplate earthquake that occurs repeatedly at intervals of 100 years. There is a 70% probability that an earthquake will occur in the next 30 years. The past occurrence of earthquakes in the Nankai Trough has overlapped with turning points in Japan's history. If the worst possible damage occurs, Japanese society would be bankrupt, resulting in a national crisis. This is a disaster we know will happen; therefore, we must work to prevent damage using every means possible.
The author of this paper resides in the city of Nagoya, which is the central city in the area that would be affected by this earthquake. He is involved in earthquake engineering education and research at Nagoya University, which is the core university in this region. As an earthquake engineer living in the region, the author wishes to do everything possible to reduce the damage caused by the earthquake.
Essentially, earthquake engineers conduct research in order to suppress damage and maintain social peace in connection with earthquakes and tsunamis.
The following four measures are essential to reduce earthquake damage:
(1) Avoid danger: avoid highly dangerous areas and construct cities that are resistant to disasters.
(2) Provide resistance: build infrastructure to suppress disasters and increase the strength of existing buildings in cities.
(3) Strengthen response capabilities: collect accurate information on damage and utilize response resources effectively to prevent additional damage.
(4) Increase recovery capabilities: cultivate "strength to live" in individuals and society, and quickly restore and reconstruct society after a disaster.
By promoting the first two measures, damage to buildings and injuries to people can be reduced and additional damage can be minimized by utilizing the third and fourth measures. In order to do this, it is necessary to conduct research on hazard prediction, city planning, earthquake engineering, disaster information, disaster prevention education, etc.

2. Vulnerability to Earthquakes in Japan

Since World War II, Japan has achieved a rapid growth, concentrated the population in large cities, and promoted national development that emphasizes convenience and efficiency. As a result, Japan has become one of the world's leading nations in economy. However, because of the excessive concentration of populations and optimization, large cities have expanded into hazardous areas and housing densities have increased: Japan has become vulnerable to disasters.

Table 1 shows the changes in Japanese society over a 20-year period. The table shows the decline in the physical strength of Japanese society. National economic growth has stagnated, debt has tripled, the number of young people has reduced by 20%. Regional and home emergency food storages have decreased because of the increase of convenience stores and family restaurants. Society has also become dependent on express home delivery and other distribution methods. Dependence on mobile phones and internet has also increased. In contrast to the convenience to the society, the effect of traffic disruptions and power outages has become serious.

As shown in Figure 1, Japan's population is concentrated in cities and has expanded to alluvial lowlands. Thermal power plants and oil refineries are often located on reclaimed coastal land that has high earthquake hazards. Houses are concentrated on weak lowlands protected by banks, and skyscrapers have been built in close proximity to each other. There is an increased danger of earthquake disasters to cities: potential damage to electrical facilities and oil refineries; interruptions to gas, water, and sewer services from liquefaction; long-term flooding from collapsed banks; fires in high density areas with insufficient firefighting resources; and severe vibrations of skyscrapers with long-period/long-term seismic motions.

Currently, the development of a resilient society is an urgent issue for Japan, which has a declining population and is entering a period of seismic activity. To create an autonomous, distributed, and cooperative society that is resistant to disasters, it is desirable to develop national and community resilience and to emphasize regional creation.

Table 1. Changes in Japanese society over 20 years

Year	1993	2013
Population below 15 years of age	20.84 million	16.59 million
National and regional debt	333 trillion yen	977 trillion yen
Gross national product	467 trillion yen	520 trillion yen
Convenience stores	23,000 stores	47,000 stores
Family Restaurants	3,876 stores	12,429 stores
Distribution of mobile phones	1.70%	106.80%
Distribution of the Internet	-	79.10%
No. of items couriered	1.19 billion	3.4 billion

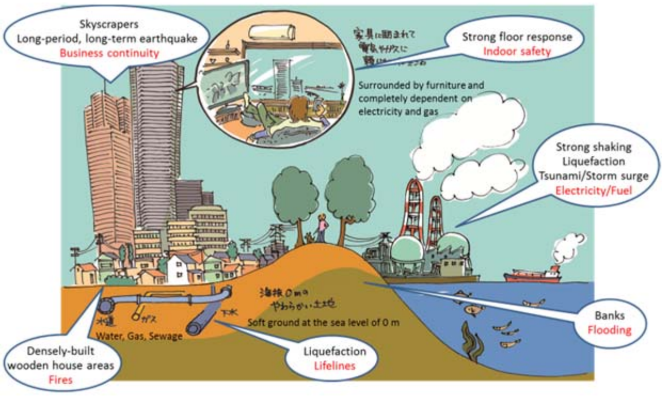

Figure 1. Vulnerability of Japanese cities to disasters

3. Collective efforts

Knowing that an earthquake, which would lead to a serious disaster, is sure to come one day, people involved in earthquake disaster prevention must maximize their efforts to mitigate potential damage from disasters. Because there is a limit to post-disaster response resources, advance efforts must be made to minimize damage.

Research fields related to earthquakes include the following:

1) Scientific research such as seismology, which deals with earthquakes as a natural phenomenon.

2) Research related to earthquake engineering, such as civil engineering and construction of buildings that are safe during earthquakes.

3) Social science research for a society and people that can respond appropriately to earthquakes.

The combination of these research fields in order to effectively mitigate damage is necessary. The mitigation of earthquake damage also requires the following:

1) Predictive research in which the various phenomena that occur during earthquakes are observed and transferred to physical models that calculate behavior of structures during earthquakes.

2) Damage prevention research such as earthquake resistant infrastructure and buildings that can respond to the predicted event.

3) Research on quickly understanding information on damage during disasters, utilizing response resources effectively in order to appropriately respond to disasters, and achieving restoration and reconstruction early for the recovery of society.

Moreover, to connect the results of research with disaster reduction, standards and laws should be created by generalizing these research results and connecting to policies. Furthermore, specific disaster reduction must be tied to actions in industry and at home. In other words, academia, government, industry, and public must cooperate on research, policy, and implementation.

As shown in Figure 2, the collective efforts of society are required to implement disaster reduction. This includes cooperation between the disciplines of sciences, engineering, and social science. The integration of research on prediction, prevention, and response should be included, and the promotion of cooperation among academia, government, industry, and public should be encouraged.

To resolve the general issue of mitigating damage, it is important to adopt the approach of "think globally, act locally" in developing a far-reaching strategy that can be implemented both nationally and locally. The conventional approach, which has been formed to accumulate solutions to problems in subdivided fields of research and organizations, allows only partial optimization, and overall optimization cannot be achieved. In general, the scale of damage from a major disaster exceeds the response resources, requiring response activities to be prioritized. In view of the diversity of society, bottom-up approach must be added to top–down approach, the strengths of the nation and each region must be combined, and the strengths of the individuals must be put together. In other words, the combined strength of self-help, community cooperation and government assistance is required. The basis of a resilient society is an autonomous, distributed, and cooperative society. An effective way of achieving this is to establish cooperative relationships between various regions and organizations in advance, such as mutual support between sister cities.

In the Sendai Framework for Disaster Risk Reduction, which was signed at the UN World Conference on Disaster Risk Reduction held in March 2015, the large-scale reduction of damage from disasters was announced as the goal for the next 15 years. In order to achieve this, vulnerability to disasters is being reduced, preparations are being made, and strength is being increased. Resilience must be strengthened on a national and community level while maintaining consistency with the Millennium Development Goals for sustainable development.

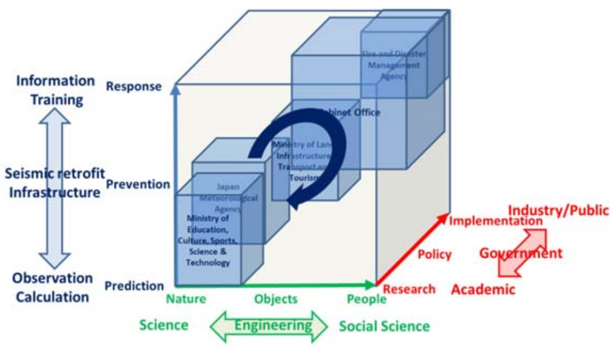

Figure 2. Collective efforts

4. People/things/objects and prediction/prevention/response

The basic factors of any consideration are "people," "things," and "objects." For a society to implement disaster prevention, 'people' to perform the implementation, 'things' such as mechanism and method of this action, and 'objects' such as tools for this action are necessary. 'Locations' in terms of environments for those actions is also necessary.

'People' are required to raise the disaster prevention awareness of citizens and to ensure that the numbers and quality of those who are responsible for disaster prevention are adequate. For raising such awareness, in addition to directly affecting people, an effective method is to raise awareness among those who have points of contact with citizens and could be mediators: the mass media, educators, and local government officials. It is necessary to conduct training for researchers, administrative officials, corporate disaster prevention officials, and disaster prevention NPOs; moreover, this training is necessary to facilitate cooperation between those who are responsible for disaster prevention.

'Things' include mechanisms that various people and organizations can use for disaster prevention initiatives. They also include the creation of policies and standards for the promotion of land use and city planning that avoid hazardous areas and the promotion of earthquake resistant buildings. In addition, databases and disaster information systems to accumulate and supply supportive information of various types are necessary. Furthermore, it is essential to promote research regarding disaster prediction, prevention and response.

'Objects' include development of specific methods for earthquake resistance construction, base isolation and vibration control, tools such as hazard maps, earthquake countermeasure action plans, business continuity plans, and town master plans. Moreover, they may include educational material for disaster prevention education and awareness.

As for researches themselves, there are researches which deal with these people, things, and objects. The research of things includes the observation and prediction of natural phenomena and research that shares and utilizes a variety of disaster information.

The research of objects is related to infrastructure and earthquake resistant buildings.

Research related to people includes researches triggering advance disaster-prevention actions of citizens, ensuring that those responsible for disaster prevention take the correct actions during disasters and managing the disaster mentality and behavior of people and society associated with disasters.

Prediction research is related to danger avoidance and prevention research contributes to the improvement of the resistance of society; moreover, response research contributes to the improvement of response capabilities at times of disaster and postdisaster recovery capabilities. Prediction is a long-term issue, whereas prevention is medium-term and response is short-term. The power of education is also essential in improving recovery capabilities.

Table 2 Things/objects/people in relation to risk-avoidance/resistance/response/recovery improvement

	Things	Objects	People
Risk avoidance (long-term) Hazard research	Evaluation of the danger of vibrations, liquefaction, flooding, tsunamis, and landslide disasters	Preparation of hazard maps, city planning master plan, and others.	Disaster stories passed on to successive generations (past disasters, origin of place names, and changing topography)
Resistance improvement (mid-term) Risk reduction research	Promotion of earthquake resistance mechanisms, assistance systems, earthquake resistance, and seismic isolation and damping research.	Development of low cost construction methods, earthquake resistant buildings, fixed furniture, and infrastructure supply	Social and individual disaster mitigation action awareness
Response improvement (short-term) Disaster information research	Response resources DB, information sharing, response/evacuation manuals, and business continuity planning	Observation systems, disaster information systems, real-time prediction systems, communications, disaster prevention locations, and emergency use facilities	Training for disaster responses such as evacuation, fire-fighting, life-saving, and first aid/rescue
Recovery improvement (education) Research on human power and community power	Advance preparation, advance reconstruction planning, cooperative structure construction, and autonomous/distributed /cooperative society	Restoration of roads, fuel, goods, and lifelines, and sufficient emergency stores/equipment	Cooperating power, supporting power, mental resilience, and the survival power of societies

Risk avoidance was classified as hazard research, whereas resistance improvement was classified as risk reduction research, response improvement as disaster information research, and recovery improvement as community and human strength research. Then, “things”, “objects”, and “humans” were mapped, and topics to be promoted were summarized (Table 2).

5. Disaster Mitigation Research Center

The author is employed at Nagoya University, which is the core university located at the center of the disaster region of the Nankai Trough earthquake. The Disaster Mitigation Research Center, which advocates disaster mitigation and cooperation, was established in December of 2010 to combine the total strength of the society with the goal of mitigating earthquake damage

The center seeks to function as a think tank for establishing a draft plan for disaster damage reduction. Contributions from lifeline businesses, consultant businesses, as well as external research funds are used to employ teaching staff from private businesses with practical experience in disaster prevention and to assemble many researchers from local government and private business. 20 professors and 30 researchers are working at the Center. In addition, about 30 professors from current research departments in the university also work at the Center, and seven researchers from national research agencies have been invited as visiting professors. Furthermore, a council to promote social cooperation has been established as an advisory board. The council, comprising approximately 20 people, includes stakeholders from local government, industry, the media and volunteers, and university researchers from inside and outside the region.

Five years have passed since the Disaster Mitigation Research Center was established, and we have now prepared systems for disaster damage reduction with concerted efforts by strengthening cooperation among research fields, among industry, government, academia and the public, and among research agencies inside and outside the region.

The Center promotes research for the reduction of damage from disasters, training for those responsible for disaster prevention and raising public awareness, measures to realize a cooperative society for disaster prevention, and practice associated with disaster response and advanced disaster prevention.

A wide range of research is being conducted at the Center: 1) scientific researches associated with crustal movements, underground soil structure, active faults, and historical earthquakes, 2) engineering researches associated with prediction of seismic ground motions, real-time damage prediction, earthquake resistant buildings, the development of seismic isolation and vibration control, 3) and social science researches associated with city planning, urban development, disaster education, economics, and psychology.

A diverse program of education for disaster prevention has been prepared. The program includes summer-intensive seminars for senior high school students, and a college implemented with cooperation between industry, government, academia, and the public. In addition to courses for the general public at the college, there are courses to train disaster prevention leaders in local government, business, and local areas, as well as disaster volunteer coordinators. Each three-day intensive course is held twice a year. There are already more than 5,000 graduates of these courses, who are playing important roles in supporting regional activities. In addition, the graduates gather once a year to share the results of these activities and provide follow-up training.

Regular seminars are held for each type of participant. Each month, there is a lecture-style one and science café-style one for the public, a seminar for university teachers and students, a study group known as ESPER for regional engineers, and a study group known as NSL for the mass media. Furthermore, on every public open day, short lectures are presented to the public by professors.

Several research groups are studying potential disaster prevention/mitigation strategies with various regional stakeholders: research group on pre-reconstruction plan, research group on wider and stronger policies, research group that presents the honest opinions of industry and government in order to continue development of regional industry such as Toyota, and research group that considers training of disaster prevention personnel in each region. All of these groups are informal, and create an atmosphere in which regional strengthening and regional creation can be discussed fairly. Through these activities, we are aiming to create a renaissance by constructing an Agora-like setting where people can gather together.

6. The Disaster Mitigation Research Building: a location for research, response, and preparation

In March 2014, the Disaster Mitigation Research Building was constructed. In addition to its role in promoting disaster prevention and mitigation research, this building will serve as the location for regional response in times of disaster. It also plays a role as the base for education and awareness to promote preparation during the nondisaster time.

The building has a base isolation structure made of reinforced concrete with one underground floor and five above-ground floors. As shown in Figure 3, the ground floor displays the base isolation mechanism and also functions as a Base Isolation Gallery where people can learn the history of earthquake resistance, base isolation, and vibration control technologies for buildings. The first floor comprises the Disaster Mitigation Gallery for experiential learning and the Disaster Mitigation Hall where research group meetings and various seminars are held. The second floor comprises the Disaster Mitigation Library for research learning and the Disaster Prevention Head Office for disaster response at the university. Floors three and four comprise research project spaces, and the fifth floor comprises the Disaster Experience Laboratory in which earthquake response are simulated using an actuator for the purpose of vibration experiments and disaster response practices.

(1) The base for disaster mitigation research

The Disaster Mitigation Research Building itself is the focus of earthquake resistance research. To accommodate new base isolation and vibration control technologies, the base isolation system uses elasticated base isolation comprising laminated rubber, cross linear bearings, and oil dampers. The base isolation period is 5.2 s, which averts resonance in the soil for a period of 2.6 s. The building has been designed to withstand the stronger tremor than general base isolation buildings by establishing a base isolation clearance of 90 cm.

A 400 ton laboratory is located on the rooftop. This is also a base isolation structure with a 5.2 second period, and if resonance force is applied with an actuator, it can vibrate at about 70-cm half amplitude. Inside the laboratory, 3D image and sound equipment is installed to actualize a virtual reality system while synchronizing with the vibration. It is used for psychological experiment and disaster response training for earthquakes. Using this force application system, the entire 6,000 ton building can be shaken. In addition, the force application equipment also has feedback-type control functions. On the underground base isolation floor, a jack has been positioned to impart forced displacement of 10 cm, which enables free vibration tests to be conducted. Both main building and rooftop laboratory have identical natural periods of 5.2 s, and both soil and building can be set to recreate the resonance phenomenon. This fact can be used to conduct research and development for vibration control construction and resonance avoidance.

There are also many seismometers, earth pressure gauges, and displacement gauges located in the building. These will be used to clarify building vibration behavior, age degradation of base isolation system, and the distribution of earth pressure during earthquakes. Moreover, by setting up a variety of low-cost sensors, we will be able to ascertain the performance of the sensors and conduct research and development for new vibration monitoring methods in artificial vibration environments and eventually establish lifecycle monitoring technologies.

Figure 4 Overview of the Disaster Mitigation Research Building Display Space

(2) The base for disaster response

The Disaster Mitigation Research Building also functions as the base for disaster response for the region and Nagoya University. On the second floor, the Disaster Response Head Office can protect 24,000 people in the campus. During a large-scale earthquake, earthquake observation information and national/local government disaster information will be gathered. In addition, accurate disaster information will be provided to the public using university-wide broadcasting equipment.

Simultaneously, a space will be provided on the first floor for disaster response for local government and key businesses, as well as the media. In addition, floors three and four will be used by researchers to gather disaster studies. In order to enable these activities, various facilities and emergency storages for disaster response have been prepared.

In addition to using a base isolation system to reduce earthquake responses, a diesel power generator that can operate continuously for one week and rooftop solar panel power generation guarantees power during power outages. A 3-m^3 potable water tank can serve 100 people for 10 days, and a 17-m^3 tank provides water for other uses. A parabolic antenna connects local governments with satellite communications, and a long-distance wireless LAN is connected to national disaster prevention agencies. This can be used to coordinate with the governments to ascertain the situation and gather information during disaster events. Other equipment includes a wastewater tank, city gas/propane conversion-type gas air conditioner, and a power panel that can be connected to an electric car. There is also a sufficient supply of emergency stores, such as food, bedding, various equipment, and medical supplies. This will allow the building to function as a disaster response center during large scale disasters.

Furthermore, a clearinghouse will provide a location for gathering information on damage and other conditions when disasters occur in other regions.

(3) Disaster Preparation

Normally, the Disaster Mitigation Research Building is used for the study of disaster prevention and mitigation and as a location where those responsible for disaster mitigation activities can coordinate their efforts. Floors one and two are generally open to the public from Tuesday to Saturday.

In the Disaster Mitigation Gallery and Disaster Mitigation Hall on the first floor, there are various displays for learning about disaster prevention and mitigation. Items on display include the basics to the results of advanced science and technology as follows: BiCURI that provides a long-period vibration experience using vibration recreation technology, projection mapping that displays disaster information in 3D on a 3D geographical model, displays that demonstrate how to prepare for disasters, earthquake and seismic wave transmission models, tsunamis and liquefaction models, surface aerial photographs that show the whole Nagoya city area, a hanging screen that lets one experience the height of a tsunami, a climbing rope that allows the visitor to experience long-period vibrations, models of earthquake resistant buildings that vibrate and break, a Kids Corner that allows children to learn about earthquake resistance while doing some crafts, the chronology of historical earthquakes, the map of regional earthquake ruins, a 3D topographic map of the Nankai Trough and active faults, areas of liquefaction during past earthquakes, the latest earthquake activity, active faults, and liquefactions. Projection mapping on surface aerial photographs shows a variety of disaster information. In the Disaster Mitigation Gallery and Disaster Mitigation Hall, a variety of seminars are frequently held.

On the second floor, the Disaster Mitigation Library comprises disaster-related documents for viewing. A variety of materials related to disaster prevention and mitigation has been assembled: newspaper and magazine articles, video archives, publications on past earthquakes, town histories and hazard maps from local governments, regional disaster prevention plans, soil boring data, old maps, and disaster-related laws and medicine. Moreover, a variety of displays are shown on a large "Past and Present Map" display. The map comprises current and historical maps, elevation maps, aerial photographs, and damage projections that show how the region was formed and explain the threat posed by disasters.

The Disaster Mitigation Research Building is a place where visitors gain understanding of natural disasters through various displays and documents and gain a perspective of disaster prevention and mitigation that is close to home: it is a place of 'learning' and 'awareness'. It also provides a venue in which people involved in disaster prevention and disaster mitigation can collaborate.

7. Conclusion

The Nagoya University Disaster Mitigation Research Center is supported by many people of the region. Although it is a small-scale organization, it puts into practice the idea of Youzan Uesugi, who said, "Where there is will, there is a way." By using Disaster Mitigation Research Building, the collective strengths of the region are being gathered. We hope to build a society with the local people, in which many people take the disaster personally, protect their own lives, and help out family and the neighbors. To achieve this, we must learn from the history of the region, understand regional conditions, analyze the appeal and issues of the area, and look to the future while practicing and prompting regional preparedness. By establishing the Disaster Mitigation Research Building as a museum for learning about the region and its social structure, we want to utilize earthquake-engineering research to reduce the threat of regional earthquake disasters.

Please visit the Center's website (http:// www. gensai.nagoya-u.ac.jp/) for the latest information about the Disaster Mitigation Research Center and the Disaster Mitigation Research Building.