STRONGER MEGA CITIES FOR THE NEXT MAJOR EARTHQUAKE

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Abstract

In this paper, effective pre-earthquake countermeasures especially for mega cities are proposed, which are: (1) deliberation with wider imagination based on the latest scientific knowledge, (2) appropriate selection of places for living and activity, (3) introduction of seismic design factors for big cities, (4) strategies to retrofit low seismic strength structures, (5) re-distribution of concentrated population and functions, (6) developing buildings and cities where people can stay and take refuge, (7) strengthening and effective use of information communication technology, (8) preparation and action for the post-earthquake stage, (9) development and application of structural seismic technologies, (10) learning from foreign and domestic earthquake disasters, international collaboration, and sharing of knowledge and action, and (11) sharing of knowledge and collaboration between various fields of expertise.

Introduction

Tokyo is one of the largest cities in the world and is the capital of Japan, a heavily earthquake-prone country. The Japanese population and much of its functionality are highly concentrated in Tokyo. The estimated damage caused by future large earthquakes with a magnitude greater than seven is extremely high. The number of casualties could exceed 20 thousand due to the shaking itself as well as post-earthquake fires. The number of stranded workers, students and others unable to return home due to failures in long-distance commuting lines would be up to 8 million. The number of buildings that have collapsed or burned would be 610 thousand. The economic loss, including the effect of the decrease in productivity and services, could be up to 95 trillion yen, which is nearly equivalent to the Japanese annual general account budget [1,2]. Since the Japanese government may be unable to respond properly following such a major disaster, countermeasures should be carefully prepared. These countermeasures shall focus not only on post-earthquake recovery, but also on a long-term seismic-resisting strategy accompanied by drastic structural changes of the city for reducing the risks. This effort shall be carried out cooperatively by various groups, such as individuals, families, companies, municipalities, and the government [3].

Pre-earthquake Countermeasures

We believe that the following countermeasures are important for big cities against large earthquakes and disasters. These countermeasures are to be taken at various levels, including by individuals, local communities, and municipalities or governments.

(1) Deliberation with wider imagination based on the latest scientific knowledge,

(2) Appropriate selection of places for living and activity,

(3) Introduction of seismic design factors for big cities,

(4) Strategies to retrofit low seismic strength structures,

(5) Re-distribution of concentrated population and functions,

(6) Developing buildings and cities where people can stay and take refuge,

(7) Strengthening and effective use of information communication technology,

(8) Preparation and action for the post-earthquake stage,

(9) Development and application of structural seismic technologies,

(10) Learning from foreign and domestic earthquake disasters, international collaboration, and sharing of knowledge and action, and

(11) Sharing of knowledge and collaboration between various fields of expertise.

Figure 1. A gymnasium with full of people evacuated after the Great East Japan earthquake. (The Asahi Shimbun)

Each of these countermeasures is discussed in the following sections.

(1) Deliberation with Wider Imagination Based on the Latest Scientific Knowledge. The United Nations issued "Sustainable Development Goals (SDGs), 17 Goals to transform our world" [4] in 2016. Included among these goals are, "Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation" and "Goal 11: Make cities inclusive, safe, resilient and sustainable". We shall keep doing our best to make big cities resilient against low-occurrence but high-risk seismic disasters by imagining various worst-case scenarios. In the past several decades from the second half of the twentieth century, many earthquake disasters have occurred in Japan and overseas. Each earthquake disaster has revealed the insufficiency of our disaster countermeasures and our lack of imagination in preparing for them. There are many things that we do not know about earthquakes and tsunami disasters and we have to realize that people, as well as cities and society, are inadequately prepared to survive natural disasters. So far, the insights of researchers and engineers have been insufficient, and society has limited disaster-reduction measures according to the technology and funds available at the time. In the future, we shall consider, with a broader vision, immense earthquake damage, including combined disasters with tsunamis, high tides, fire, torrential rain, etc., and start making and implementing countermeasures against the damage expected based on the latest scientific knowledge, irrespective of the presence of current countermeasures. These major earthquake disasters, including combined disasters, have not been fully studied before. Although it is difficult, it is necessary to develop cities that are resilient to major earthquake damage. In addition, since our forecasts are not perfect, we must respect nature without forgetting its great power and be prepared to revise our countermeasures as necessary.

(2) Appropriate Selection of Places for Living and Activity. We shall select safe places to live based on our knowledge of disaster vulnerability using records of past damage, ground motions including regional soil conditions and severe tsunami. We shall also consider moving to areas that are less prone to disasters. Residences and other buildings in Japanese cities are often developed with no direct consideration of disaster risks. As a result, many people live in areas that are vulnerable to natural disasters. The appropriateness of a place for living and working in a city should be judged not only from studying active faults and hypocentral regions but also considering the possibility of large amplification of seismic waves depending on the soil conditions. The soil conditions of construction sites shall also be considered when anti-seismic measures are designed and planned for cities. Since many large cities in Japan are located in sedimentary basins, extra considerations shall be needed for the risk of long-period seismic ground motions, and in particular, the resonance of high-rise buildings, people's fears, and liquefaction or other phenomena in soft soils.

(3) Introduction of Seismic Design Factors for Big Cities. For big cities in Japan where the social impacts of earthquake disasters would be enormous, "seismic design factors for big cities" shall be introduced to enhance the seismic resisting strength of buildings and infrastructure compared to that in other areas. Since damage to big cities in case of large earthquakes brings serious results not only for the cities themselves but also for the nation or even the world, structures in big cities shall be designed with greater strength. In order to prevent loss of life and serious injury as well as the termination or stagnation of social activities after a severe earthquake, it is extremely important to design buildings with high strength to resist earthquakes. Also, the infrastructure must be strengthened to maintain city functions. The earthquake resistance level of buildings and infrastructure should be determined not only in terms of earthquake ground motions, which are scientifically calculated on the basis of data on active faults, seismology, and ground conditions but also from consideration of the scale of the likely total damage and the impact on surrounding areas. In big cities in Japan where degradation of city functions and the difficulty of recovery are expected when a major earthquake occurs, a system of designing cities by using higher seismic design factors, e.g., about 1.25 or 1.5 times greater, depending on the city size, should be developed in order to enhance the earthquake resistance of buildings and infrastructure above that of other areas. A similar seismic design policy has already been adopted in China. The seismic intensity levels of Beijing and Shanghai, which are determined based on seismological investigation, are 7 and 6, respectively; however, these levels are increased to 8 and 7 to take into consideration the importance and scale of these cities [5].

(4) Strategies to Retrofit Low Seismic Strength Structures. Existing civil engineering structures, lifelines, building structures and old wooden houses, whose seismic strength is relatively low, shall be strengthened. In particular, for new construction of wooden houses, a system for applying the latest knowledge to each design and construction needs to be established. For all kinds of structures, including roads, bridges, railway structures, lifelines such as water supplies and sewage facilities, electricity, and gas, factories, plants, buildings, wooden houses, seismic investigations and strength evaluations need to be conducted on the basis of current knowledge. In addition, for effective damage reduction against major earthquakes, we shall promote seismically retrofitting buildings, although this will take time and cost. There is public support and there are tax benefits for retrofitting private houses and buildings. A policy to increase the earthquake resistance of structures, including private houses and buildings, must be enhanced and backed up by social movements.

(5) Re-distribution of Concentrated Population and Functions. In order to enhance the sustainability of Japan by reducing disaster risks and take action for external diseconomy due to the population concentration in Tokyo and regional economic stimulation, national land planning to reduce excessive population concentration and function concentration to cities shall be implemented. An extremely large portion of the population, social economy activities, and government functions of Japan is concentrated in areas where the probability of a severe earthquake occurring within 30 years is high. In order to enhance the sustainability of Japan by reducing disaster risks, it is necessary to appropriately reduce the excessive population concentration and function concentration to cities and distribute residential places and various functions over the country in good balance. The transfer of population and economic activities to rural areas cannot be promoted by private efforts but requires sharing of roles by national and local governments and a fundamental revision of the relation between the administration and the assembly. In particular, realization of decentralized organizations, including change of the situation where local governments and private organizations and companies have to rely on the national government, would largely contribute to reducing the seismic risks.

Figure 2. Stranded people unable to return home after the Great East Japan earthquake (2011). [6] (The Asahi Shimbun)

Figure 3. High-rise buildings in a sea front in Tokyo. (Kazuo Tamura)

(6) Developing Buildings and Cities where People Can Stay and Take Refuge. By promoting seismic-resisting measures for the ground and buildings, we shall create cities where people can continue to stay in buildings and move around at the time of a disaster. Such cities cannot be created immediately but it is necessary to secure emergency roads and evacuation places and maintain lifelines at all times for the protection of people's lives from disaster. It is necessary to create a specific plan for developing future disaster-prevention cities. For example, we shall create a map of the predicted magnitude of future earthquake ground motions that take into account amplification from local soil conditions. We shall also establish a hazard map of current situations of houses, sloping land, and roads. On the basis of this map, a "disaster-prevention city development plan" needs to be created.

(7) Strengthening and Effective Use of Information Communication Technology. For effective functioning of communication and information systems upon the occurrence of a disaster, we shall not only enhance the ability of emergency responses by requiring larger communication capacity, longer battery life, and continuity as compared to normal times but also advance data-processing technology and prepare for an immediate response after the occurrence of a disaster. Following the Great East Japan Earthquake (2011), information was communicated in particular through social media by using mobile data terminals. Only 10% of cellular or fixed-line phones functioned. From the experience and lessons learned from that earthquake, strengthening of the information communication environment has progressed rapidly. The first measure for this purpose is to enhance the communication capacity of the internet and telephones during normal times for the prevention of communication restrictions at the time of a disaster. The second measure is to make more base stations, use longer life batteries at the stations, and introduce mobile base stations in the case of an emergency. It is also necessary to immediately realize the use of satellite communication lines at the time of a disaster. The third measure is to improve mobile information terminals by using longer life batteries and realizing energy-saving modes for emergencies.

Figure 4. People rushed to telephones, which are tentatively placed after the Great Hanshin earthquake (1995), to talk with their families. (The Asahi Shimbun)

(8) Preparation and Action for the Post-earthquake Stage. For effective measures by self-help, mutual assistance, and public assistance to reduce social economic loss due to an earthquake disaster, disaster-prevention education taking into account regional characteristics shall be incorporated into schools and societies and public entities, private companies, and local citizens shall establish appropriate cooperative relations in normal times. It is also necessary to make preparations and measures for foreigners who do not know about earthquake disasters and have little Japanese language ability. Measures shall be taken before and after a major earthquake. To prepare for a major earthquake, the earthquake resistance of social infrastructure and buildings shall be secured so that they survive and maintain their functions after the earthquake, and people should be protected from harm. After a major earthquake evacuation, fire prevention, and lifeline preservation measures shall be taken to ensure people have a means of contact and a safe place to stay, in order to reduce damage and social disorder to the extent possible. Assuming that a certain level of earthquake disaster is inevitable, we shall divide tasks of evacuation and recovery at the occurrence of a disaster with self-help by victims, mutual assistance by local citizen groups, and public assistance by national and local governments. We shall combine these roles in good balance and make them work to reduce socioeconomic loss.

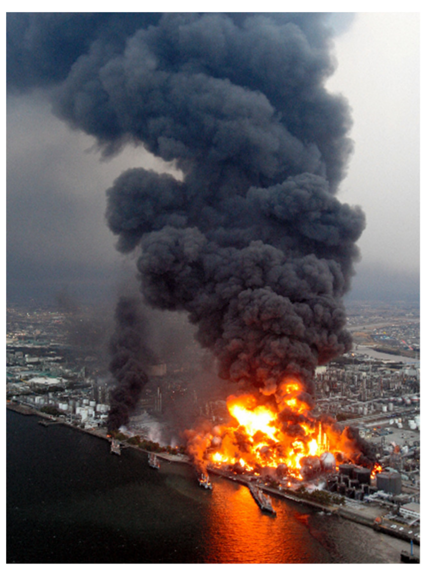

Figure 5. Petroleum refinery fire after the Great East Japan earthquake. (The Asahi Shimbun)

(9) Development and Application of Structural Seismic Technologies. We shall not only promote and appropriately use the seismic engineering technologies of Japan but also conduct research, development, and implementation of methods and systems to prevent critical failure in structures or entire social systems against more catastrophic events than those anticipated in design. Based on the lessons learned from the Great Hanshin Earthquake disaster in 1995, seismic isolation and passive control technologies have progressed and been widely used. In the Great East Japan Earthquake in 2011, a combined disaster involving an earthquake, tsunami occurred and people realized the importance of taking countermeasures against such catastrophic events. It is important to develop structural technology of sufficiently high performance to prevent critical failure against unexpectedly catastrophic events. We must move from the idea that infrastructure and buildings need only to survive disasters to the idea that infrastructure and buildings must also maintain their functions even after major earthquakes. Under current seismic design criteria, ductile deformations are expected to occur in structural elements that resist major earthquakes. However, this allows damage of the structure and many damaged buildings that had not collapsed were nonetheless demolished after past major earthquakes. A structural design methodology in which damage is limited to replaceable structural elements is needed. In addition, it is important to develop a technology to prevent critical conditions even when a structure experience a greater seismic ground motion than that used in the design. In order to achieve this, seismically isolated and passively controlled structures are highly recommended for structures in all countries. Researchers and designers shall accumulate experience, develop seismic engineering technology with higher structural performance, and return the outcome to societies to make them more resilient.

Figure 6. Damage by the Great East Japan earthquake protected lives but the residential building was later demolished. (Masashi Sanada)

(10) Learning from Foreign and Domestic Earthquake Disasters, International Collaboration, and Sharing of Knowledge and Action. Efforts to prevent domestic and foreign disasters should be continued by taking advantage of the knowledge of city disaster prevention in various countries, which can be commonly used for city configuration studies, construction methods of structures, and the development of traffic and communication networks. Major earthquake disasters have occurred in various locations in Japan in the 21st century. And disasters have occurred in places where no disasters have occurred for long periods of time. This means that nowhere is free from earthquake risk. There have been catastrophes all over the world, such as the Sumatra Earthquake (2004), Wenchuan Earthquake (2008), Haiti Earthquake (2010), Nepal Earthquake (2015), Tainan Earthquake (2016), and Central Italy Earthquake (2016) and Kumamoto Earthquake (2016). There are various common aspects between cities in different countries, such as basic compositions of the cities, buildings and infrastructures, and the development of traffic and communication networks. Disaster prevention efforts shall be made by referring to and learning from previous disasters in other places [7].

Figure 7. Collapsed wooden house in Kumamoto earthquake. (Akira Wada)

(11) Sharing of Knowledge and Collaboration between Various Fields of Expertise. To prevent and reduce the damage by major earthquakes on cities, people in various fields of expertise, not only in science and engineering, but also the humanities, social science, economy, and medicine, shall work on problems comprehensively and continuously beyond their field boundaries. For this purpose, knowledge shall be shared and exchanged among different fields of expertise. The prevention, reduction, and recovery of disasters involves many academic fields. However, since academia is separated into specialized fields, researchers tend to have less interest in activities and detailed discussions in other specialized fields and trust results in other fields without thinking about them deeply. Important matters are discussed only within each field and the responsibility for results and activities is taken only in limited fields. Therefore, people do not have a cross-field perspective or try to unify the fields. They need to not only deepen their own specialized fields but also share and exchange knowledge more actively with people in different fields at all times. Without a total cross-field view, they will not be able to solve the problems. In addition, researchers and engineers must collaborate with persons involved in administrative work and with citizens, in order to reflect their research results in the disaster prevention and reduction policies of national and local governments.

Conclusions

Large earthquakes may significantly damage buildings and infrastructure. Various types of post-earthquake efforts are needed, such as rescue, medical care, preparation of temporary housing, recovery and reconstruction. These efforts shall be carried out using combined aspects of hardware and software. Since human beings cannot completely overcome natural disasters, post-earthquake countermeasures in software are important. On the other hand, pre-earthquake countermeasures are necessary for life saving and are more effective from an economic and manpower point of view. More focus shall lie in pre-earthquake countermeasures in both hardware and software.

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