A Thought: What have We Learned from Natural Disasters? Five Years after the Great East Japan Earthquake *

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Abstract: After the Great East Japan Earthquake occurred on March 11, 2011, it appeared that Japan was extremely vulnerable to natural disasters and was lacked of adequate social systems for mitigating natural disasters. This paper describes the author's views on what we have learned from recent natural disasters, including the Hanshin – Awaji Earthquake in 1995, the Great East Japan Earthquake in 2011, the Kanto – Tohoku Flooding in 2015 and the Kumamoto Earthquake in 2016. The paper then points out the need for socialization of disaster – related knowledge, followed by a need for the development of safety index systems for natural disasters for policy makers and decision makers to prioritize mitigation measures to be implemented. The paper also adds the author's view on what current civil engineering profession lacks for mitigating natural disasters.

Keywords: natural disaster, earthquake, vulnerability, mitigation, safety index

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1. Lessons Learnt

1.1. The Hanshin – Awaji Earthquake in 1995

The Northridge Earthquake occurred in California, USA, on Jan. 17, 1994. Many Japanese engineers in the fields of civil, geotechnical and earthquake engineering visited the affected areas to examine the damages and possible main causes for the damages. Answering a question raised by a US news reporter at a site of highway bridge collapse, a Japanese bridge engineer was proudly saying that this type of complete collapse of bridge piers will never happen in Japan, because Japanese aseismic design is well advanced. Exactly a year later, however, the Hanshin – Awaji Earthquake occurred on Jan. 17, 1995 and the bridge engineer witnessed the similar complete collapses of highway bridges in the city of Kobe.

What we have learnt from the Hanshin – Awaji Earthquake 1995 may be summarized as follows.

(1) There exists no absolute safety for buildings and infrastructures.

(2) It is practically impossible to allocate an unlimited budget for constructing absolutely safe buildings and infrastructures.

A viable solution under these circumstances is to adopt the concept of performance based design. Using the concept of performance matrix shown in Figure 1, a society will select a combination between the performance of structures and the risk that the society might encounter for a particular type of infrastructures. A few years after the Hanshin – Awaji Earthquake, then the Ministry of Construction, Japan, issued general principles of structural design for civil and building structures, adopting the concept of performance based design.

On more technical sides, the experiences of the collapse of bridge piers triggered the rapid development of various aseismic reinforcement methods or retrofitting methods, which have been widely implemented

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throughout Japan.

During the Hanshin – Awaji Earthquake, several river dikes collapsed mainly due to liquefaction. Since January was not considered to be a typical season of typhoon in Japan, restoration works for the failed river dikes were not considered to be extremely urgent at that time. Recent climate change, however, has led us to change our attitude for a possible combined disaster between earthquake and water – related disasters such as flooding or high tide.

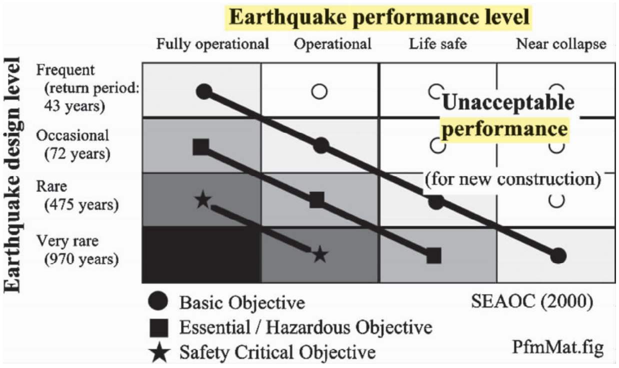


Figure 1. An example of Performance Matrix

1.2. The Great East Japan Earthquake in 2011

The Great East Japan Earthquake in 2011 occurred on March 11 differs from the Hanshin – Awaji Earthquake in many ways. The Hanshin – Awaji Earthquake is an active fault type of earthquake located directly above the focus, while the Great East Japan Earthquake is a trench type earthquake occurred in a subduction zone. Thus the duration of the earthquake motions is much longer and the scale of affected areas is much wider for the Great East Japan Earthquake. More importantly, trench type earthquakes are usually associated with tsunami disaster. Consequently the damages caused by the Great East Japan Earthquake are much more significant and extend a much wider region, requiring a long period of restoration works.

What we have learnt from the Great East Japan Earthquake are summarized in a document published by the Japan Geotechnical Society (2011)[①] entitled "Gehazards during earthquakes and mitigation measures – Lesson and recommendation for the 2011 Great East Japan Earthquake".

Some of the important points which the author pointed out in the above publication are as follows, together with a few additional points.

(1) Significance of subduction zone earthquake. Unlike earthquake caused by inland active faults, such as the 1995 Hanshin – Awaji Earthquake, the Great East Japan Earthquake is an earthquake along the subduction zone of a large moment magnitude of $M_W 9.0$, whose seismic motions continued for a long time. Damage from this earthquake and its many aftershocks occurred in many locations over a very wide area, causing restoration and recovery to be delayed. The unprecedented scale of the problem was overwhelming with the immediate damage compounded by the tsunami, ground contamination, salinity of farmland and the need for dispose of the waste generated.

(2) The difference in structural safety of public and private assets. Damages of many public assets such as social infrastructures that had been designed in accordance with the latest technical standards were little or none, which had proven effectiveness of the current seismic technologies, but on the other hand there was an evident lack of safety in private assets including reclaimed residential land and private houses.

(3) The need for the development of technologies against gigantic tsunami. The unprecedented power of tsunami caused significant damages in port and harbor structures as well as river dikes by in and out dynamic water pressure and erosion processes. Design and construction methods should be developed for resilient water – related structures against the tsunami attack.

(4) The need for improving social sys-

① Japan Geotechnical Society. 2011. Ge – hazards during earthquakes and mitigation measures – Lesson and recommendation for the 2011 Great East Japan Earthquake.

tems. Experiences of the Great East Japan Earthquake have proved that technologies alone are not adequate enough for protecting society and people from natural disasters. Society itself needs to be resilient by awareness and preparedness of natural disasters. Thus positive disclosure for potential vulnerability of land and socialization of disaster – related technology are absolutely necessary. Experiences with natural disasters in the past have driven rapid development of disaster – related laws. Together with reviewing the laws relating to buildings, restrictions on land use, laws guaranteeing a steady and continuous upgrade process for safer social environment should be established. In order to achieve this goal, social systems have to be established for making social consensus and decision making processes to allocate enough budget for mitigating disasters, together with the development of a safety index of the areas to be of use for decision makers. Qualified engineers in disaster – related fields play a vital role in this context. The Japanese Geotechnical Society took an initiative to create a new qualification system by forming the Japanese Association for Geotechnical Evaluation after the earthquake.

1.3. The Kanto – Tohoku Flooding in 2015

It has been a global trend that climate change progresses in a rapid rate and the frequent occurrence of water – related disasters, such as typhoon and flooding, are associated with heavy rainfall becomes common phenomena worldwide. The Kanto – Tohoku Flooding occurred in September 2015 with a record – breaking 500 mm to 600 mm intensive rainfall in a few days caused overtopping, erosion and failures of river dikes in the areas of Kanto and Tohoku region.

What we have learnt from Kanto – Tohoku Flooding are as follows.

(1) Because of the recent dramatic climate change, in particular, in the pattern of rainfall, current preparedness of flooding disaster is very poor both in authorities responsible for the safety of river embankment systems and in residents living in potential risk areas. In addition, most of the current river control systems cannot cope adequately with the recent intensity and total amount of rainfall.

(2) The authorities responsible for river safety are immature in disseminating the potential risks and the evacuation information to local residents in the area.

(3) Due to budgetary limitaion, there is an inclination to adopt software measures, rather than hardware measures, such as strengthening river dikes. This tendency results in potential risks remained unchanged.

(4) Attitude of the authorities that are responsible for safety of river embankment is rather old – fashion and tend to stick to traditional design philosophy that soil materials are the best for embankment material, and hesitates in adopting more resilient materials for reinforcement such as steel, probably because of budgetary limitations.

A good example was witnessed in the recovery program of Kanto and Tohoku Flooding. A line of steel sheet piles were installed as a temporary structure protecting the areas of failure zones during the recovery construction until the river embankment was rebuilt using soil materials. Surprisingly, the line of the sheet pile wall was completely removed after the recovery work completed. In contrast, there is an increasing trend to use steel sheet pile wall for recovery works in the coastal levees after the Great East Japan Earthquake.

1.4. The Kumamoto Earthquake in 2016

The Kumamoto Earthquake occurred on April, 2016 along two active faults. The first shock occurred on April 14 with the moment magnitude of $M_W6.2$, which had been considered to be the main shock. Two days later on April 16, the real main shock occurred with the moment magnitude of $M_W7.0$, which is the similar magnitude experienced in the Hanshin – Awaji Earthquake. Another important feature of the Kumamoto Earthquake was that strong aftershocks continued. Thus the damage had been gradually accumulated caused by the pre – shock and many aftershocks, accelerating the process of the deterioration of structural integrity. The houses and structures were then subjected to the main shock, causing significant damages and total collapse. This particular phenomena posed difficulty in rescue operations as well as restoration process.

On the other hand, local government and people had learnt from the previous earthquakes described above and acquired the preparedness against natural disaster. The local government took immediate actions for some restoration works which were completed in a very short period, in particular, restoration works for highway embankment as well as protection measures against water – related disasters. The failed highway embankment was restored in a few days, since the highway network is vital for maintaining secure transportation routes for rescue operation as well as for restoration works. The recovery works of river embankment was carried out on a 24 hour basis due to great concerns for combined disasters with high tide. The area of Kumamoto prefecture had been repeatedly suffered from severe flooding due to rainfall as well as high tide. The local government was fully aware of danger for the combined disasters.

2. Socialization of Geotechnical Engineering

A significant number of private houses collapsed due to either soil liquefaction or landslide during earthquakes in the past earthquakes. Using soft dredged material was a quite common practice for reclamation works along coastal areas. Cut and fill method is a common method for developing residential land in hilly areas. In some cases, compaction efforts are not adequate for land development and the fill areas are vulnerable for landslide during earthquake.

During the Great East Japan Earthquake, 27,000 houses were damaged due to liquefaction and more than 5,000 houses in Sendai city were collapsed due to landslide. After experiencing such damage at the time of the earthquakes, people become very sensitive about the ground conditions on which their private houses are built. Very limited information on the ground condition, however, is available as public knowledge, when people buy a piece of land for their own properties. Under the current law system of private ownership, individuals need to acquire an adequate knowledge and an ability to access the information and more importantly, have a system of technical professional support.

To ease the situation, the Japanese Geotechnical Society took an initiative to create a system of geotechnical evaluation especially for private properties. The number of the qualified engineers now amounts to about 800. A group of the qualified engineers now provides a technical support for the people whose houses had been damaged mainly due to ground conditions in the Kumamoto area.

Basic rules of mitigating natural disasters may be summarized as below.

(1) Proper use of land according to the Basic Act for Land. Article 3 clearly states that land shall be properly used according to the natural, social, economic and cultural conditions of its area.

(2) Proper disclosure of potential geotechnical risks in commercial transaction should be implement. Local government often complies the data of reclamation and development of residential land which should be open to the public. In commercial transaction of land, ground conditions with potential risks should be clearly and adequately informed.

(3) Proper visibility of qualified professionals and use their expertise to evaluate ground condition.

(4) Sufficient people's literary for sciences, in particular, natural disaster – related sciences is needed. Currently only 20% of high school students learn physic and only 3% of them learn geoscience in Japan. People's awareness against natural disaster is of essence to mitigate natural disasters.

(5) Development and use of safety index for mitigating natural disaster should be noticed.

3. Development of Safety Index

The World Conference on Disaster Reduction in Kobe in 2005 adopted Hyogo framework for action, which clearly states the urgent need for developing vulnerability index. An extensive literature survey indicates that the system of indicators such as World Risk Index (WRI) is widely accepted. By modifying WRI index, an indicator named GNS (Gross National Safety for natural disasters) was developed by a group of geotechnical engineers, including the author of this paper.

Risk in GNS is defined by Hazard x Exposure x Vulnerability. Five natural events are considered in the 2015 version of GNS, including earthquake, tsunami, storm surge, sediment related disaster event, and volcanic activity. An initial calculation was carried out by using various big data available open to the public. The result of disaster risk and vulnerability was presented in the prefectural scale and in the scale of city in Japan. Figure 2 shows an example of the distribution of GNS both in the prefectural scale and in smaller scales.

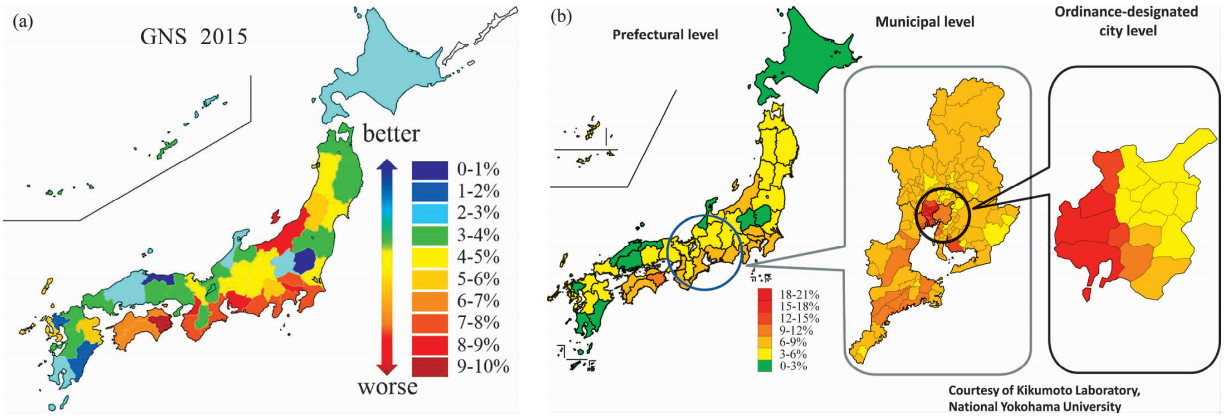


Figure 2. GNS in 2015 in prefectural scale (a) and in smaller scale (b)

The author's intension is not to provide the ranking of GNS but to offer the policy and decision makers a piece of scientific information for selecting highest priority measures for mitigation in a rational manner.

Since GNS is obtained by multiplying values of vulnerability and the value of exposure, the values of GNS is strongly influenced by the exposure indicator, which implies that a gradual change of population structure in areas may form an option for mitigating the natural disasters. It is impossible that occurrence of natural disaster to be null, and measures for reducing the vulnerability may require a considerable expenditure. In this context, transference of population to safer locations may become a possible option to reduce the value of GNS.

Figure 3 shows vulnerability values plotted against corresponding exposure values for various prefectures.

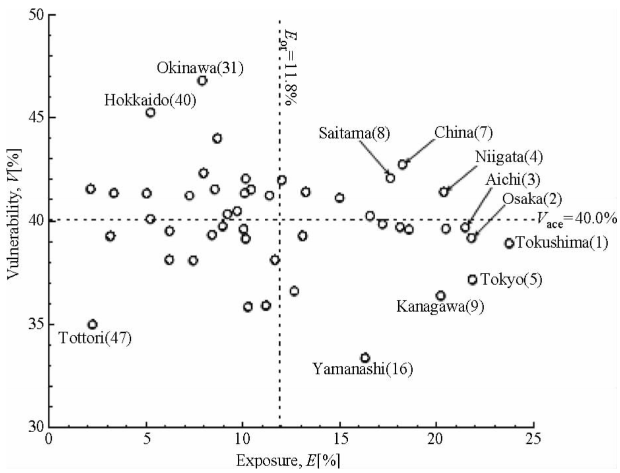
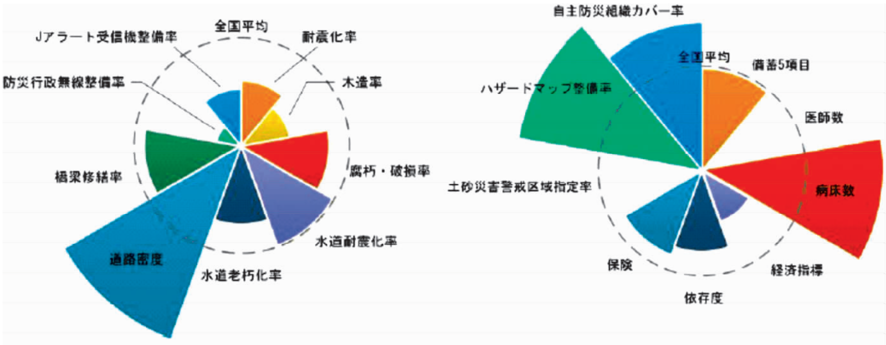


Figure 3. Vulnerability values plotted against corresponding exposure values for various prefectures from Kusakabe *et al*, 2017)

Dotted lines indicate the mean values. Figure 4 shows the values of various vulnerability indicators relative to the national average (indicated by a dotted circles) with respect to the hardware and software measures, respectively, for the case of Tokyo Metropolitan. Doing such visualization of insufficient indicators leads to prioritization of mitigation measures, which is a beneficial merit of GNS.



(a) **Hardware measures**　(b) **Software Measures Courtesy of Itoh Laboratory, Tokyo City University**

Figure 4. Various vulnerability indicators relative to the national average (Tokyo Metropolitan)

4. What do We Lack in the Infrastructures Development?

Five years after the Great East Japan Earthquake is quite a long period of time with respect to human life – span. The number of evacuee still remains 144, 000 at the end of August, 2016, although major parts of highways, railways, ports and harbors have been restored. The recovery process from the disaster, however, seems very slow from the view of people's living environment. Why is the recovery process so slow, compared to the amazing rate of development in information technology? There must be a number of reasons for that but our profession and technology in civil engineering must change our attitude that development of infrastructures takes time unlike manufactured products. Our profession and technology in civil engineering must work for accelerating the process of infrastructure development, including planning and consensus processes.

In the authors' view, there are two possible reasons for this. One is slow in technology exchange and knowledge transfer among discrete disciplines. Expansion of modern scientific knowledge has been supported and accelerated by the notion of reductionism advocated by Descartes in 17th century. In which a complex phenomenon is divided into several elements and once we understand the element, then we integrate the knowledge of these elements to understand the complex phenomenon. If we cannot understand the divided element, we further subdivide the element into several sub-elements. By doing so, fragmentation process proceeds. Then we start to lack of communication among various disciplines. One of the consequences of the reductionism is fragmentation of scientific disciplines, resulting that new generation is taught not a system but elements. Science for natural disaster is multi-disciplinarily. Our profession needs to communicate with other professions, including professions in social sciences.

The other is slow in adopting new effective technologies to be implemented in practice, and the phenomenon similar to valley of death between research and production. The decision makers for infrastructures have sometimes little knowledge about cutting edge technologies, and have a tendency to use conventional methods simply because there are precedents. In contrast, engineers and researchers engaging in the development of new technology have no experience or limited knowledge about the mechanisms for decision making process and for the ways for implementation of the new technologies into practice. Forum between the decision makers and the research engineers would be of vital use for improving the current situations.

5. Concluding Remarks

The author described his own views on what we have learned from recent natural disasters, including the Hanshin – Awaji Earthquake in 1995, the Great East Japan Earthquake in 2011, the Kanto – Tohoku Flooding in 2015 and the Kumamoto Earthquake in 2016 in this paper. Based on these experiences, the author stressed the need for socialization of natural disaster – related technology, in particular, the geotechnical engineering knowledge and the need for the development of safety index systems for natural disasters for policy makers and decision makers to prioritize mitigation measures to be implemented. To accelerate the recovery process from natural disasters, importance of communication with various disciplines and establishing forum between decision makers and research engineers were suggested.

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一个思考：在东日本大地震 5 年后我们从自然灾害中学到什么？

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摘要：2011 年 3 月 11 日的东日本大地震发生后，表明日本极易受到自然灾害的破坏，但缺乏足够为减轻自然灾害的社会制度。首先，介绍了从近些年的自然灾害中得出的经验，包括 1995 年阪神一淡路地震、2011 年东日本大地震、2015 年关东地区洪水和 2016 年熊本地震等。然后，指出了与灾害相关知识社会化的必要性，以及发展自然灾害安全指标体系的必要性，为政策制定者和决策者提供优先考虑且可执行的缓解措施。最后，对当前土木工程专业所缺乏的减轻自然灾害的考虑提出些许建议。

关键词：自然灾害；地震；易损性；缓解；安全指数