No.36 August 2012

STEEL CONSTRUCTION TODAY & TOMORROW

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【 *i n o - r u* 】

祈 (*ino-ru*) in Japanese, or "pray" in English:
Seeking divine intervention

We pray for a speedy return to normalcy for the victims of the Great East Japan Earthquake, and for the earliest possible restoration of tranquility in the disaster-stricken area.

In this issue.....

Special Feature: The 2011 Great East Japan Earthquake

Photo: Port and Airport Research Institute

Published Jointly by

The Japan Iron and Steel Federation

Japanese Society of Steel Construction

How to Interact with and Prepare for Natural Disasters?

by Nobuo Shuto
Emeritus Professor, Tohoku University

Nobuo Shuto: After entering the Ministry of Construction in 1957, he became researcher of the Ministry's Public Works Research Institute in 1960. He became professor of School of Engineering, Tohoku University in 1977, and of the University's Disaster Control Research Center in 1990. His professional field is tsunami engineering.

Steady Social Infrastructure Improvement

In Japan, it was after 1960 that the nation's inventory of social infrastructure, including structures for dealing with natural disasters, began to increase. A major reason for progress in this area was the income doubling plan and the resulting availability of the funding required for infrastructure improvement and development.

Civil engineering construction materials changed. The soil, wood and stone that had served as the major materials in conventional civil engineering were replaced with steel and concrete. Scaffolding logs were replaced with steel pipes. Vibrators came into use for concrete placement. Similarly, the extensive use of construction machinery led to faster construction times and improved structural reliability.

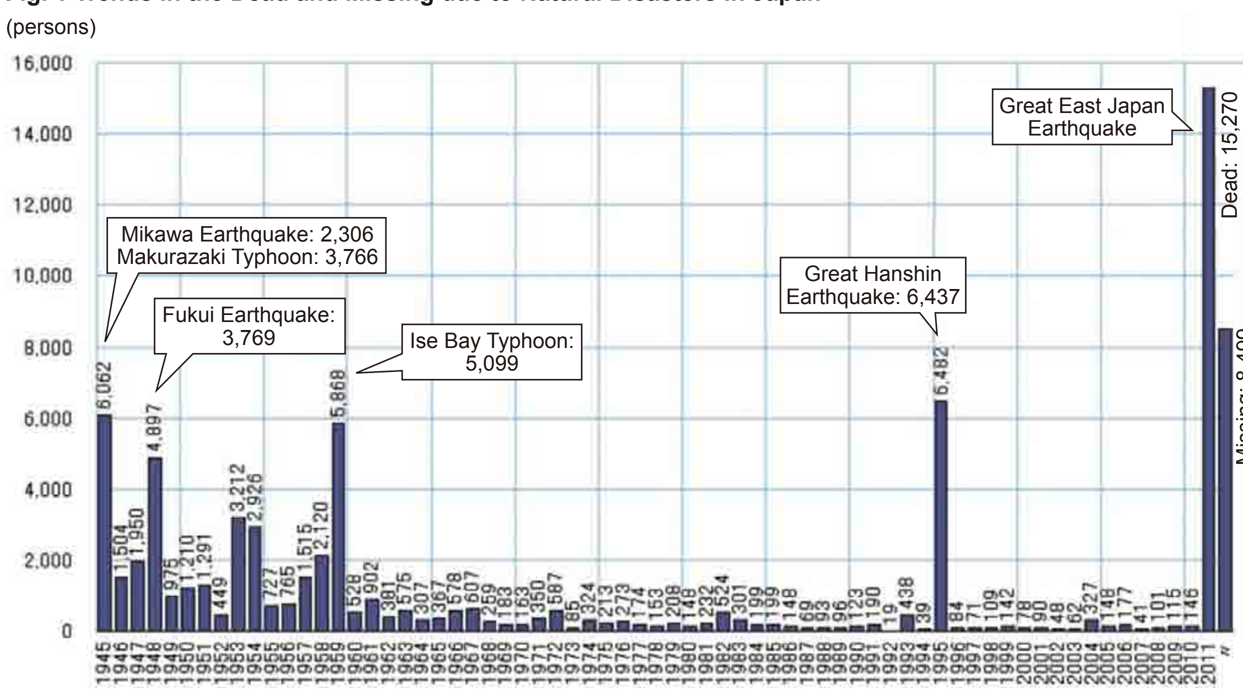
Previously, even major national highways such as Routes 1 through 9 were gravel roads, but nowadays even the farm roads running between fields are finely paved. Embankments have been built and dams have been constructed with the result that flooding is rare. As can be seen in Fig. 1, the number of deaths caused by natural disasters dropped sharply after 1960.

Tsunami Preparation

What countermeasures were taken against tsunamis? Before the Showa Sanriku Tsunami of 1933, the major countermeasures against tsunamis, except for a few examples, were to live on high ground and to seek refuge when a tsunami struck. Even after 1933, the primary countermeasure was to live on high ground. But, in Kamaishi, Taro and three other urban areas in the Tohoku area where spacious land could not be secured, tidal embankments and seawalls were constructed.

At that time, it was recognized that radios could be used to warn of tsunamis and it was then that radio usage began to increase. In 1941 a radio-based tsunami alert system was first aimed at the Sanriku area (eastern-most

Fig. 1 Trends in the Dead and Missing due to Natural Disasters in Japan



Note:
1945: Dead and missing due to major disasters (Chronological Scientific Tables); 1946-1952: Japan Natural Disaster Report; 1953-1962: Data of the National Police Agency; From 1963 onward: Data of the Fire and Natural Disaster Management Agency; Dead in 1995: Including 919 disaster-related deaths in the Great Hanshin Earthquake (data of Hyogo Prefecture); 2010: Preliminary report for dead and missing; Dead and missing persons in 2011: Data for the Great East Japan Earthquake (as of May 30, data of the Headquarters for Emergency Disaster Control)
Source: White Paper on Disaster Prevention for 2011

Pacific coast of Japan). In 1952, the target area was expanded nationwide and the Meteorological Business Act was implemented. Just before 1952, a temporary tsunami alert system worked successfully against a tsunami caused by the 1952 Tokachi-Oki Earthquake.

Are Tsunami-prevention Structures Trustworthy?

It was with the tsunami generated by the1960 Valdivia earthquake in Chile that tsunami-prevention structures became the main countermeasure against a tsunami. This tsunami affected the whole length of Japan from the northern tip Hokkaido to the southern tip Okinawa; it reached 6 m in the area of greatest height and 3~4 m in most other areas. Accordingly, the effects of the tsunami were easily contained by the structures. The Act on Special Measures for the Chile Tsunami clearly indicated that "tsunami-prevention-measures were to be newly installed and tsunami-prevention structures to be improved." As a result of this, the giant tsunami breakwaters in Ofunato and other structures of similar scale were constructed. In addition, the international tsunami warning system was completed.

In those days, however, people were not without doubt regarding tsunami-prevention structures. Symbolic of this mistrust was the caption to some photos in the *Sanriku Tsunami Report* published in commemoration of the 1960 Chile Tsunami (by the Sanriku Area Survey Committee). The caption reads, "Do people control nature? Or, does nature laugh at people?" However, soon after completion of the new tsunami-prevention structures, a tsunami resulting from the 1986 Tokachi-Oki Earthquake struck the Sanriku area. Because the height of this tsunami was no higher than that of the 1960 Chile Tsunami, its effect was almost completely blocked.

In this way, it became clear that natural forces of limited power could be controlled by means of man-made structures, and this, in turn, promoted the concept that the effects of not only tsunamis but even flooding could be controlled by the use of man-made structures. Of course, although structures can control natural forces, there is a limit to their capacity to do so. The generation that built these structures learned the effectiveness of tsunami-prevention structures by seeing them actually protect against external forces; but they then forgot the fact that such structures inevitably reach their limit in terms of preventive capacity. The next generation felt certain from the outset that natural external forces could be controlled by the use of structures. Then, they forgot the necessity of preparing for the worst. Representative of this attitude is a recent review and prioritization of government programs that concluded, "Embankments to protect Tokyo from flooding that may occur only once in 200 years are unnecessary."

The 2011 off the Pacific coast of Tohoku Earthquake

On March 11, 2011, a giant earthquake occurred off the Pacific coast of Tohoku Area. The Japan Meteorological Agency was unable to accurately predict the earthquake. According to the seismo-techtonics, which was based on 30 years of observation, each of three blocks involved would move independently; whereas, in the current earthquake, the three blocks moved simultaneously. If five billion years have passed since the birth of the Earth and if the lifespan of human beings is set at 50 years, 30 years of geological observation is equivalent to a 10-second checkup for humans. The error in the seismo-techtonics seems to be attributable to the assumption that everything could be understood through only 30 years of observation. This error will be corrected through continued observations over three or four hundred years and through in-depth studies of past tsunamis.

How to Prevent or Mitigate Tsunami Damage

In 1983, "Guidelines for Disaster-prevention Measures in Areas Constantly Threatened by Tsunamis" (draft) was prepared jointly by the River Bureau, the Ministry of Construction, and the Fisheries Agency. In 1998, '"Guidelines to Strengthen Tsunami Countermeasures in Local Disaster-prevention Plans" was prepared with the consent of seven tsunami-related government agencies. Both sets of guidelines clearly state that huge tsunamis cannot be prevented by man-made structures, that human lives should be protected by means of a disaster-prevention system, and that disasters should be controlled by building towns that are highly resistant to tsunamis. Accordingly, it was already anticipated that in a huge tsunami such as the one produced by the once-in-a-millennium great one like the 2011 earthquake, the tsunami would overflow or destroy all tsunami-prevention structures.

In this tsunami, there are many examples in which excessive reliance on disaster-prevention structures and on contemporary information led to suffering. For example, although a part of the Kirikiri area of Ozuchi Town in Iwate Prefecture is located outside the tsunami inundation area assumed by the prefecture and in spite of having been moved to high ground in 1933, the death rate there was the highest in the Kirikiri area. In Toni-Hongo of Kamaishi City in Iwate Prefecture, a grandmother, who had experienced the 1933 Showa Sanriku Tsunami and lived on high ground, sought refuge on an even higher ground just after the earthquake hit. Her daughter, who also lived on high ground, similarly took quick refuge because they had agreed between them to seek safety whenever an earthquake occurred. The older woman's 40-year old grandson, who lived in a low-lying area, was caught off guard by the tsunami because he believed that the high anti-tsunami embankment would protect him. After seeing the tsunami overtop the embankment, he sped off for safety in his car but was still caught by the tsunami wave.

The tsunami-prevention structures currently in use are fully capable of protecting against tsunamis that might occur once several tens of years, or one-hundred and several tens of years. But studies are underway regarding the need for structures that could reliably demonstrate damage control against a tsunami strike of even greater magnitude.

Anyway, human lives cannot be fully protected merely by the use of man-made structures. It is more important for us "to live on high ground, to judge a situation with our own eyes, and to seek safety at our own initiative." Only then can we put ourselves in a position to mitigate the effect of natural disasters. This basic concept will never change.

"Do people control nature? Or, does nature laugh at people?"

A page of Sanriku Tsunami Report published in commemoration of the 1960 Chile tsunami: At Naka-Akasaki in the Sanriku area, new building plans were withheld in anticipation of construction of new tsunami-prevention facility.

Coastal Facilities: Lessons Learned from the Quake and Tsunamis

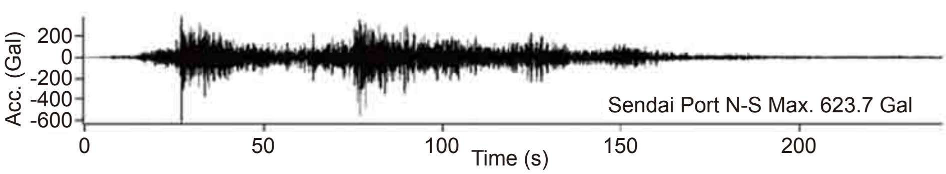
by Takahiro Sugano, Port and Airport Research Institute

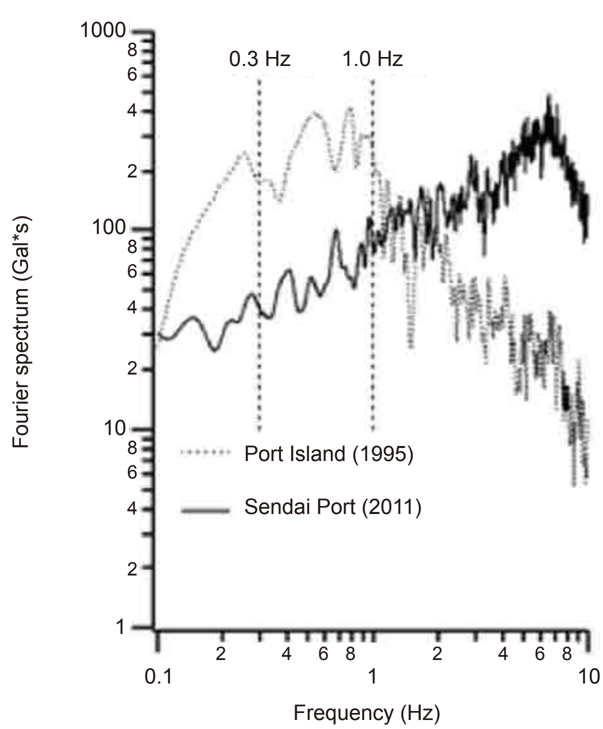
Introduction

On March 11, 2011, the largest earthquake ever recorded in Japan struck the coast of the Tohoku region of Japan, which was named as the "2011 off the Pacific coast of Tohoku earthquake" by the Japan Meteorological Agency. The Mw=9.0 earthquake generated strong motions that affected the Honshu island from Tokyo Bay to the northern extent of the island, and induced a series of tsunamis that devastated coastal communities throughout the region. Significant aftershocks (Mw>7) were experienced that further contributed to damage in the Tohoku coastal region during emergency response and recovery efforts.

This report summarizes the findings of the Port and Airport Research Institute research team as they investigated coastal structures along approximately 600 km of coastline, the follow-up experiments and analyses. A characteristic feature of the ground motion observed is the long duration and high frequency component, as shown in Fig. 1. For the reason, the degree of damage of coastal facilities by the ground motion was rather small. This broad coverage of investigation thus far made facilitated the interpretation of damage patterns across the entire region affected by the earthquake, by distinguishing coastal structure damages due to strong ground shaking and secondary effects (i.e., liquefaction, ground failures, settlement) caused by subsequent, significant tsunami inundation.

Fig. 1 Comparison of Acceleration Time History and Fourier Spectrum between the Port Island (1995 Hyogoken-Nambu Earthquake) and the Sendai Port (2011 Earthquake)





Damage to Coastal Structures

In many cases, the condition of structures examined at the time of our investigation was the combination effect of earthquake and tsunami, and the determination of the sequence of damage and relative influence of seismic and tsunami loading was not possible in the field. These suppositions are based on the collective engineering judgment, tempered by first-hand experience at coastal structures along with earthquakes worldwide and considerable effort for analyses of case studies (like "criminal" investigations) of many of similar events. Many of the interpretations of failure modes provided in this report are opinions that will be refined with time as more data becomes available at the key sites. The findings and recommendations provided in this initial report are intended to imitate discussions within the port engineering community, foster applied research efforts, and ultimately lead to enhanced knowledge and best practices.

In this report, I would like to discuss with a typical damage due to combination effect of earthquake motion and tsunami and express my opinion about the future outlook of design concept by considering both seismic and tsunami effect.

A notable feature of damage caused by ground motion is the issue of quay wall seaward deformation and subsidence of the ground behind the quay wall. The seaward deformation of quay wall, which is small compared with the central part of the amount of displacement of the quay edge, often shows a gradual arc as shown in Photo 1. Amount of ground subsidence just behind the quay wall tends to grow harmoniously with the amount of seaward displacement. Accordingly, a whole berth often becomes unusable.

Now, consideration is made on the damage to the steel sheet pile quay wall in Soma Port during the 2011 off the Pacific coast of Tohoku Earthquake, shown in Photo 2. It is reasonable that the damage of quay wall occurred as a result of the action of ground motion and subsequent tsunami. However, in the post-disaster field investigations, there are many traces of the damage caused by the ground motion that cannot be separated by the action of the tsunami. Accordingly, from the difference between damage caused by ground motion and caused by tsunami, the cause of damage will be pursued. The difference between Photos 1 and 2 is that, while almost the same degree of damage occurred in both quay walls, the entire damage occurred in the quay wall in Photo 1. On the other hand, in Soma port, damage occurred only to the corner and about 30 m part of entire quay wall, but other parts are quite healthy (Photo 3). The detail of the failure process at that moment is not known. I plan to carry out efforts to clear the failure process by experiments and numerical analyses.

Photo 1 Damage to the steel sheet pile quay wall of Hakodate Port during the 1993 Hokkaido-Nansei-Oki Earthquake

Photo 2 Damage to the steel sheet pile quay wall of Soma Port during the 2011 Off the Pacific coast of Tohoku Earthquake

Photo 3 Damage to the steel sheet pile quay wall edge portion in Soma Port during the 2011 Off the Pacific coast of Tohoku Earthquake

Idea of New Design Concept that Considers the Effects of Both Earthquake and Tsunami

The design standard for port facilities in Japan went through a major revision in 2007. The most remarkable feature of the new design standard is that it is completely based on the idea of "performance-based design methodology." At the same time, the new standard is designed to be consistent with recent advances in the field of engineering seismology and earthquake engineering. According to the current design standard, it is better to investigate and evaluate the damages by considering both the earthquake motion and the tsunami wave loading during the 2011 off the Pacific coast of Tohoku Earthquake so as to improve the current design standard.

The idea of "performance-based design methodology" constitutes the backbone of the new design standard. The 'objective of the facility' is at the top of the design process. Then, the 'performance requirements' are specified in the "ministerial ordinance" in a plain language to achieve the objective of the facility so that the objective can be understood by taxpayers. Thirdly, the 'performance criteria' are defined to achieve the performance requirements, using technical terms so that these criteria can be strictly interpreted by engineers. Finally, the performance of the facility is verified by some 'verification method.'

From the geotechnical point of view, if we think a time-series facility damage caused by the earthquake and tsunami, the damages that will occur can be summarized as follows:

a) High response acceleration, large deformation, material degradation such as liquefaction, and growth of cracks that occur
b) Tsunami wave force, hydraulic force of flow such as drag force, buoyancy, impact of floating objects during tsunami attack. Especially, during a seaward tsunami, destabilization of the pore water pressure in the ground may occur, like the quick drawdown phenomenon, as shown in Fig. 2 (lower figure)

At present, the cause of damage and the tsunami-affected actual damage mechanism have not yet been clarified. We are promoting experimental and numerical research in order to clarify the mechanism of damage caused by the combined action of the earthquake and tsunami.

To establish the new design concept for coastal structures with "tenacious design" against the combined action of earthquakes and tsunamis, loading conditions, performance requirements, performance criteria and verification method are specified. The loading conditions are summarized as shown in Table 1, and it is required to set the appropriate combination of loading conditions. In the case of tenacious breakwater, we refer the performance requirements listed in Table 1. In case of the largest tsunami, it is difficult to interpret the performance requirements such as "serviceable" and "repairable" into the performance criteria, and at the present state it is also difficult to verify the design with quantitative accuracy.

At the moment, we can "design" in the case of the tsunami that occurs most frequently. On the other hand, in the largest tsunami case, we propose just "design concept." After learning the lessons from the 1995 Hyogoken-Nambu earthquake, the concept of the Level 1 and Level 2 earthquake motions was introduced, and the settlement of the idea of the seismic design with two-level ground motions took several years. Similarly, it may take few years to settle the new design concept against the combined actions of earthquake and tsunami with consensus among the stakeholders such as designers, construction officials, administrators and so on.

Fig. 2 Assumed Destruction Mechanism of Breakwater

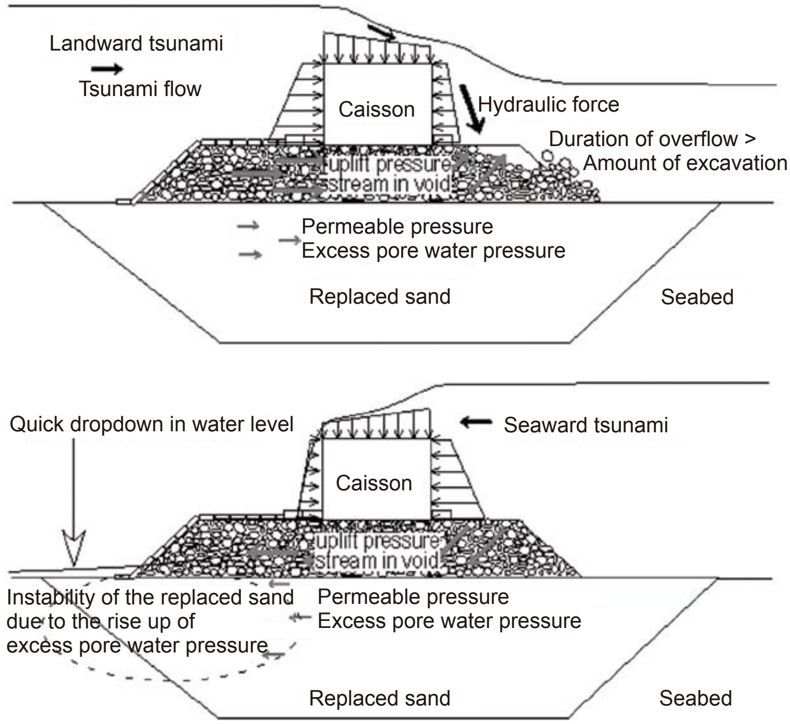


Table 1 Design Concept for Coastal Structures as "Tenacious Design" against Combined Actions of Earthquakes and Tsunamis

Action (load)	Definition	Objective of the facility (performance requirements)	Remarks
Level 1 ground motion (valuable action)	The ground motion with high probability of occurrence at the site during the design working life.	Minor or no damage/little or no loss of serviceability (serviceable)	
Level 2 ground motion (accidental action)	The largest ground motion among ground motions at the site from scenario earthquakes	Damage control/short-term loss of serviceability (repairable)	
Ground motion with the tsunami source (accidental action)	The ground motion sources generate tsunami	To consider in conjunction with the tsunami	
Tsunami that occurs most frequently (accidental action)	To consider the scale of the tsunami from socio-economical point of view of facilities and service period, which occurs once in ten years to a hundred years	a)Protection of human life and property b)To support socio-economic activity (serviceable)	Multi-faceted concept by considering the facilities such as revetment and embankment, and the non-structural measures
Largest tsunami (accidental action)	Scale of tsunami that occurs at the site at a frequency of about once a thousand years to roughly a few hundred years	a)Protection of human life b)Mitigation of eco nomic losses c)Secondary disaster prevention d)Prompt recovery of the facilities	Multi-faceted concept by considering the facilities such as revetment and embankment, and non-structural measures

Damage to River Levees and Measures for Restoration and Reconstruction

by Ikuo Towhata, Professor, Department of Civil Engineering, The University of Tokyo

Introduction

The conventional philosophy of seismic design of river levees in Japan used to be based upon the concept of factor of safety greater than unity, being similar to the design of other structures. However, there have been two important factors to be considered in river levees. The first is the financial issue that the budget available for seismic retrofitting per unit length of levees is limited because the entire length of seismically vulnerable levee is substantial. The second is that the occurrence of the seismic factor of safety less than unity does not mean an immediate disaster or overtopping of water because the probability of the simultaneous occurrence of a strong earthquake and significant flooding has been considered low. Consequently, seismic factor of safety greater than unity has not been compulsory.

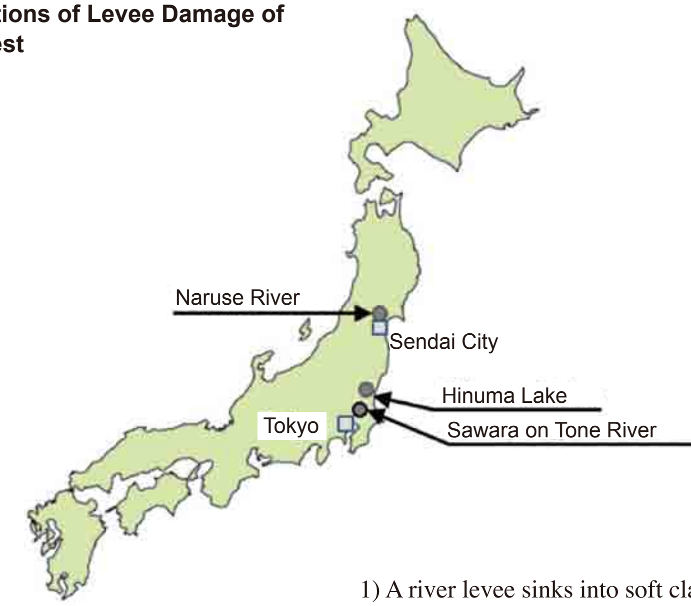
Alternatively, it has been aimed to restore possible damage of river levees within a short period of time that is typically 14 days. To achieve this goal, it is essential to introduce the principle of seismic performance-based design in which the possible distortion of a levee is assessed under a given design earthquake, compare it with the allowable distortion, and, if the assessed one exceeds the allowable limit, examine the effect of any mitigation measure. In this view point, the present short article addresses what river levees experienced during the 2011 Great East Japan Earthquake and successful cases of damage mitigation.

Seismic Damage of River Levees in 2011

Figure 1 shows the location of rivers and levees to be discussed in this article. First, the levee of the Tone River at Sawara (Photo 1) demonstrates a typical damage of levee or embankment resting on liquefied subsoil; subsidence at the top and longitudinal cracks caused by lateral spreading. As is often the case, this site used to be a part of a river channel, and was filled with sandy soil artificially or naturally, forming a liquefaction-prone subsoil condition.

A noteworthy case was such as in Photo 2 in which a heavy distortion occurred in spite of the clayey and hence unliquefiable subsoil. Because the induced deformation of such levees consists of subsidence at the crest and lateral spreading, which is a typical nature of liquefaction-induced deformation of an embankment, those damage shown in Photo 2 is inferred to have been caused by liquefaction inside levee bodies. The mechanism of this new idea is considered to be as what follows as studied by Sasaki et al. (1994)[1] and Kaneko et al. (1996)[2] on previous cases of Tokachi and Kushiro Rivers in 1993 (Fig. 2):

Fig. 1 Locations of Levee Damage of Interest



1) A river levee sinks into soft clayey subsoil because of consolidation,
2) The sunken part has poor drainage of infiltrated rain water and seeping ground water because the elevation is lower than the ground surface, and the surrounding soil is less pervious clay, and
3) The procedure of subsidence and consequent lateral expansion is possibly accompanied by loosening of soil and reduced liquefaction resistance.

The problems related with the internal liquefaction are such as difficulties in detecting a liquefaction-prone levee and drainage of water from this type of a levee.

Fig. 2 Schematic Illustration of Mechanism of Liquefaction inside a Levee

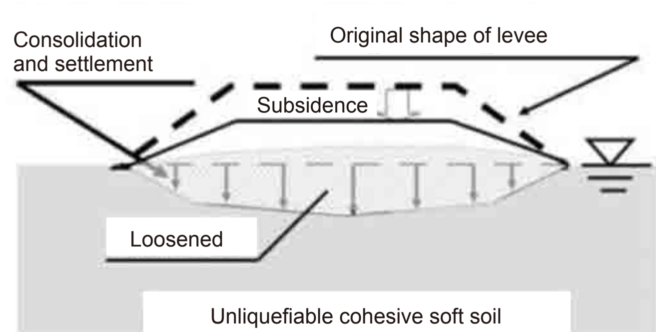


Photo 1 Significant distortion of levee of Tone River in Sawara

Photo 2 Significant distortion of the Hinuma levee

Successful Mitigation of Liquefaction-induced Damage of Levees

Because of the high concerns for seismic safety of levees in the past decade, mitigation measures have been executed. The Great East Japan Earthquake in 2011 offered a good opportunity to validate their effects. Note that the mitigation measures were designed against Level-1 design earthquakes for which the recurrence period is about 50 to 70 years. Although installation of gravel drains was successful at Omigawa of Tone River, while sand compaction pile was effective at the Shimo-Nakanome of Naruse River (Fig. 1), the page limitation does not allow detailed remarks here; refer to Towhata (2012)[3].

At Sakae of Ibaraki, the Tone River levee had been reinforced by underground sheet pile walls (for reducing seepage of water) accompanied by a wide berm on the river side. During the earthquake, no distortion occurred on the river side (Photo 3). In contrast, the land side of the levee distorted due to liquefaction in the foundation soil in which the ground water level is within 50 cm from the surface (the author's observation in April, 2012). The damaged section was restored by installing 8-m sheet piles along the slope toe (Photo 4). The holes in the sheet pile allow seepage of ground water so that the water level in the levee would be lowered during high water level in the river.

Numerical Analyses

The author proposed a viscous modeling of liquefied sand for performance (deformation) assessment of structures subject to strong shaking (Towhata et al., 1999 and 2010)[4),5)] and developed a numerical program. Fig. 3 is a levee model for an example analysis, of which the performance (settlement at crest) is mitigated by embedded sheet pile walls, counter-weight berms, or both (Fig. 4). Results of a flow analysis as shown in Fig. 5 demonstrate that a combination of a sheet pile wall and a counter-weight berm can reduce the crest subsidence to less than 50% after strong shaking and soil flow of 20 seconds.

Photo 3 River side of Tone River levee at Sakae without damage (entire restoration of the levee going on in April, 2012)

Photo 4 Reconstruction of land side of Tone River levee at Sakae by installing sheet pile walls with holes

Fig. 3 Levee Model subject to Liquefaction in Foundation for Performance Analysis

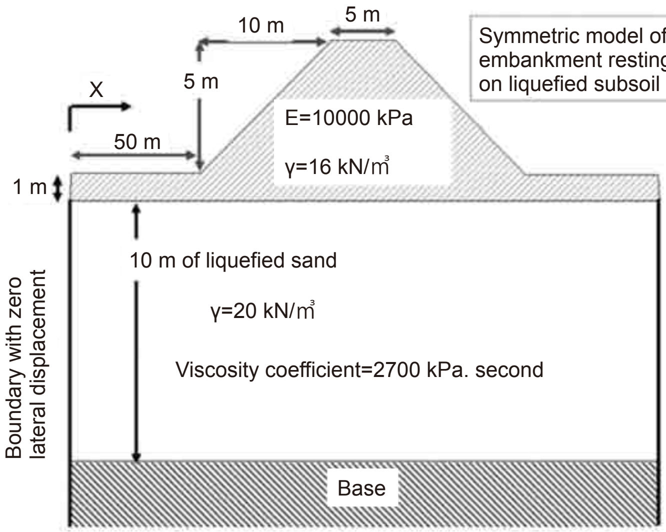


Fig. 4 Sheet-pile Walls and Counter-weight Berm as Mitigation Measures

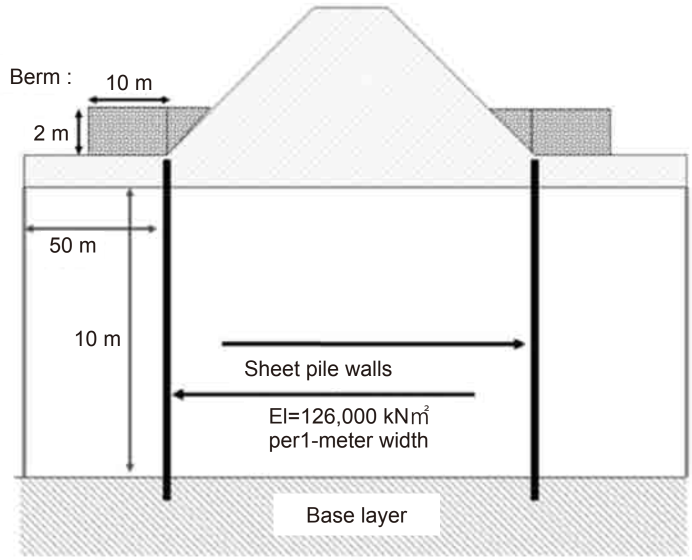
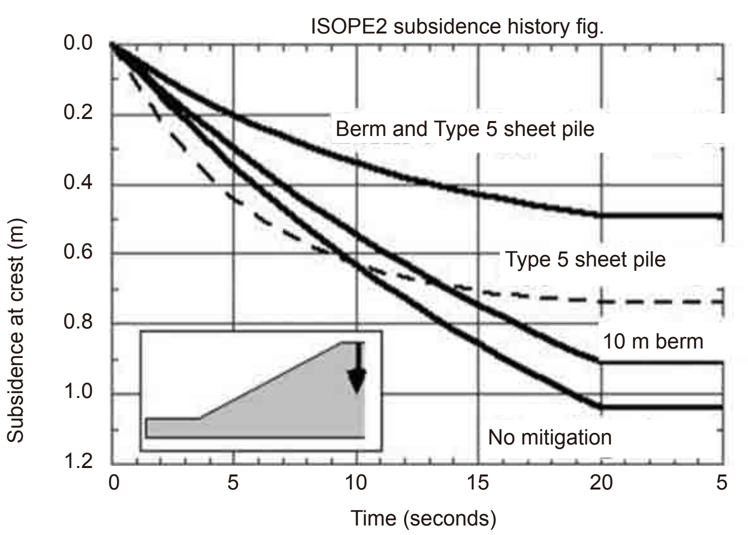


Fig. 5 Mitigation of Subsidence of Levee Undergoing Liquefaction in Foundation



Conclusions

This article concerns the seismic damage of levees during the 2011 Great East Japan Earthquake. Among many damages, the possibility of liquefaction inside a levee is a new important issue. In contrast, several mitigation measures worked successfully and embedded sheet pile wall is among them. Finally, the performance assessment of levees subject to liquefaction is very possible by using a viscous liquid model.

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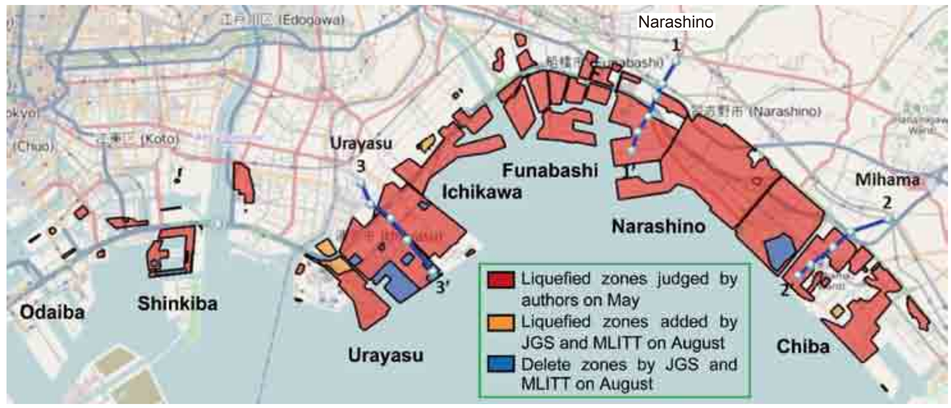
Liquefaction-induced Damage to Houses and Buried Lifelines

by Susumu Yasuda, Professor, and Keisuke Ishikawa, Assistant, Dept. of Civil and Environmental Engineering, Tokyo Denki University

The 2011 Great East Japan Earthquake, with a magnitude of Mw=9.0 occurred in the Pacific Ocean about 130 km off the northeast coast of Japan's main island on March 11, 2011. Liquefaction occurred in a wide area of reclaimed land along Tokyo Bay, though the epicentral distance was very large, about 380 to 400 km. Much land has been reclaimed in the Tokyo Bay area since the seventeenth century. Liquefaction has been induced during past earthquakes, such as 1923 Kanto Earthquake and 1987 Chibaken-toho-oki Earthquake. However, the Great East Japan Earthquake is the first on record to cause liquefaction in such a wide area and to severely damage houses, lifelines and roads.

Fig. 2 Liquefied Area from Odaiba in Tokyo to Chiba City



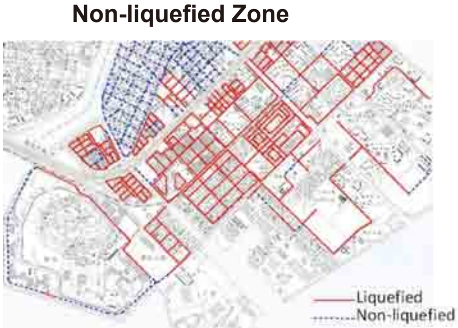
(Joint research by Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism and JGS)

Investigation of Liquefied Sites

The authors started to investigate Tokyo Bay area on the next day from the earthquake because all trains in Tokyo Bay area stopped service immediately after the earthquake until the midnight of the day. In the investigation, the roads where boiled sands were observed and not observed were marked on maps (Fig. 1).The zones surrounded by red lines were judged to be liquefied, but note is necessary that some small districts in the zones did not liquefy because their grounds had been improved by sand compaction method or other methods mentioned later. Thus about ten days were necessary to investigate the whole area from Odaiba in Tokyo to Chiba City through Urayasu, Ichikawa and Narashino Cities. A tentative map of liquefied zones was drawn based on this first stage investigation (Yasuda and Harada, 2011).

As the liquefaction-induced damages to houses, river dikes, roads, lifelines and ports and harbors were serious, Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism intended to make joint research with JGS to identify liquefied sites. Fig. 2 is the map of liquefied zones thus estimated, which is slightly modified from the tentative map.

Fig. 1 Method to Judge Liquefied and Non-liquefied Zone

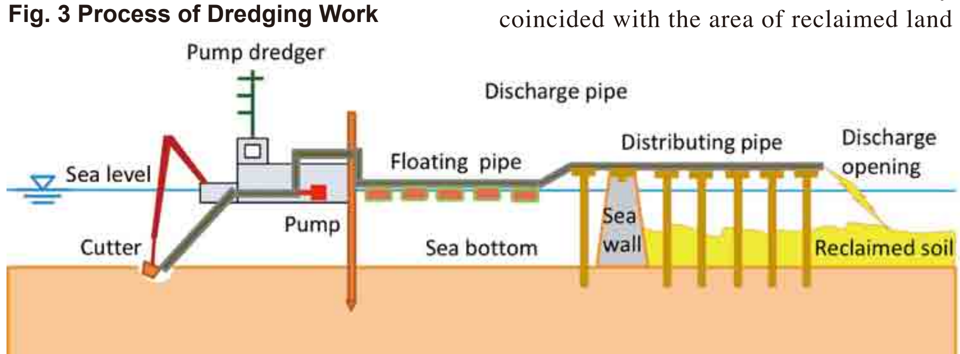


(Yasuda et al., 2011)

Soil Condition in Liquefied Area

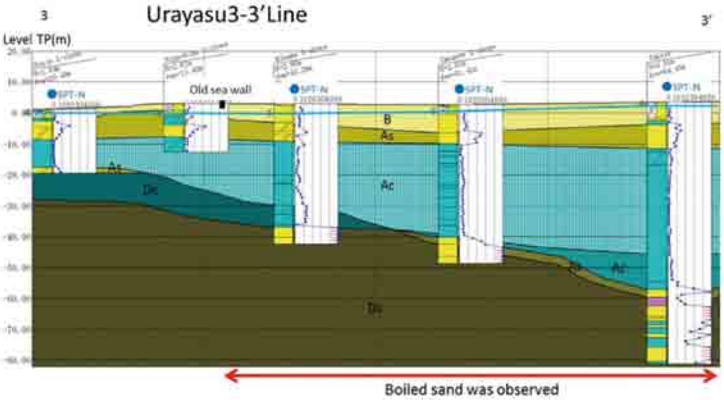
As demonstrated in Fig. 2, severely liquefied area by the earthquake was from Shinkiba in Tokyo to Chiba City through Urayasu, Ichikawa, Funabashi and Narashino Cities in Chiba Prefecture. The reclaimed lands in this area were constructed after 1966. In the reclamation work, dredged soils were filled from the bottom of sea to the height of about sea level. Then the filled surface was covered with hill sands. Fig. 3 draws the process of the dredging work. The soils of sea bottom were excavated by a cutter, exhausted with water by a pump, transported by a convey pipe, then discharged from the exit of the pipe. As the dredged soils contain much water, coarse soil grains and fine soil grains, they are apt to deposit near the exit and far from the exit, respectively. Moreover the position of the exit moves to various positions, resulting in very non-homogeneous strata. After filling with the dredged soils and covered by the hill sands, no soil improvement works were treated except several special areas where sand compaction piles or gravel drain piles and other methods were applied to prevent liquefaction.

Fig. 3 Process of Dredging Work



As three sets of data base had been published by JGS, Chiba Prefecture and Tokyo Metropolitan Government in the liquefied area, the authors estimated brief soil cross sections along 11 lines which are perpendicular to the shore lines based on these data. Fig. 4 illustrates the estimated soil cross sections along a line in Urayasu 3-3' together with the zones where sand boils were observed. The zones where sand boils were observed are exactly coincided with the area of reclaimed land

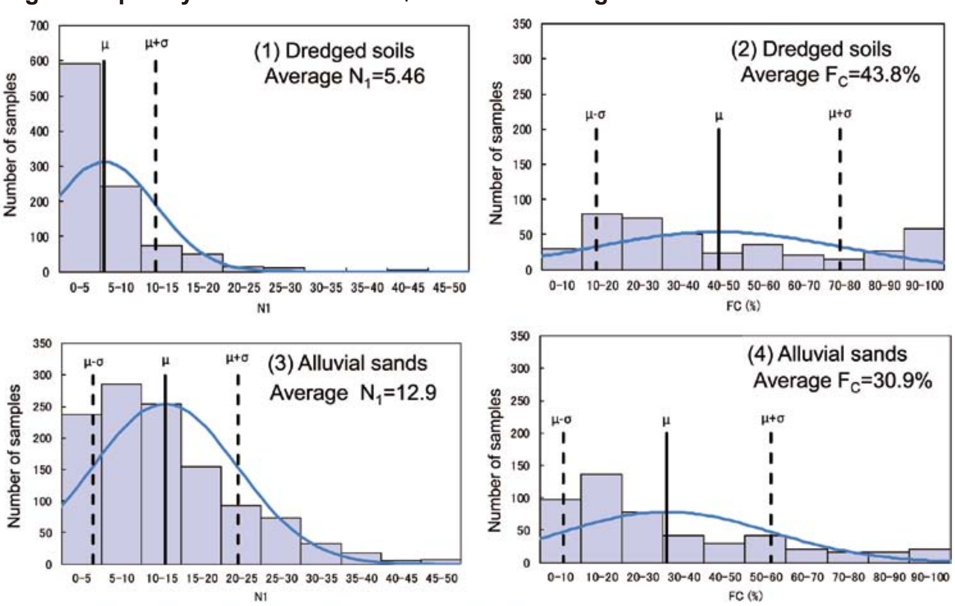
Fig. 4 Estimated Brief Soil Cross Sections



which is the sea side from old sea wall. In the reclaimed zone, a filled layer with mainly hill sand (B) and a filled layer by dredged sandy soil (F) with low SPT *N*-values of 2 to 8 are deposited with a thickness of 6 to 9 m. An alluvial sand layer (A_S) with SPT *N*-values of 10 to 20 underlay with a thickness of 4 to 8 m. A very soft alluvial clay layer (A_C) is deposited under the A_S layer with a thickness of 10 to 40 m, by increasing the thickness towards sea. Diluvial dense sandy layer (D_S) with SPT *N*-value of more than 50 underlay. Water table is shallow as GL −0.5 m to −3 m, by decreasing the depth towards sea. On the contrary, in the zone where sand boil was not observed, A_S layer deposited from ground surface. Therefore it can be estimated that the A_S layer basically did not liquefy by the 2011 Great East Japan Earthquake though some loose part might liquefy in the reclaimed land, and that some part of the dredged sandy soil under water table might liquefy. Composition of soil layers is similar in other 10 soil cross sections, though thickness of each layer is different.

A technical committee organized by Urayasu City Government and chaired by Prof. K. Ishihara carried out detailed soil investigations in Summer by boring, SPT, CPT, PS logging, undisturbed sampling, cyclic triaxial tests and others, and reported valuable data in December 2011. Frequency distributions of normalized SPT *N*-values, N_1 and fines content, F_C of the F layer and the A_S layer are compared in Fig. 5 (1) to (4). Fines content of the F layer are very scattered and greater than the fines content of the A_S layer, though the F layer was essentially taken from the A_S layer. This difference must be attributed to the lack of the alluvial sandy soils for the reclamation work. As the dredged zones were located just the top of a delta formed by Edo River, sandy soils were not enough for the filling, then some alluvial clays had to be excavated and mixed with the alluvial sandy soils. Average value of the fines content of the F layer is extremely high as 43.8 %. However, plasticity indexes, I_P, are not high though their fines content are large. N_1 of the F layer is apparently lower than that of the A_S layer. Undisturbed samples were taken at nine sites to obtain cyclic shear strength and shear modulus. Frequency distributions of shear stress ratio to cause liquefaction in 20 cycles tested by cyclic triaxial tests, R_L (N_L=20, DA=5%) for the F and the A_S layers, are shown in Fig. 6. Dominant R_L values for the F layer and the A_S layer are 0.25 to 0.30 and 0.30 to 0.40 respectively though the data are very scattered in the F layer. Therefore it can be said the soils in the F layer are more liquefiable than those in the A_S layer.

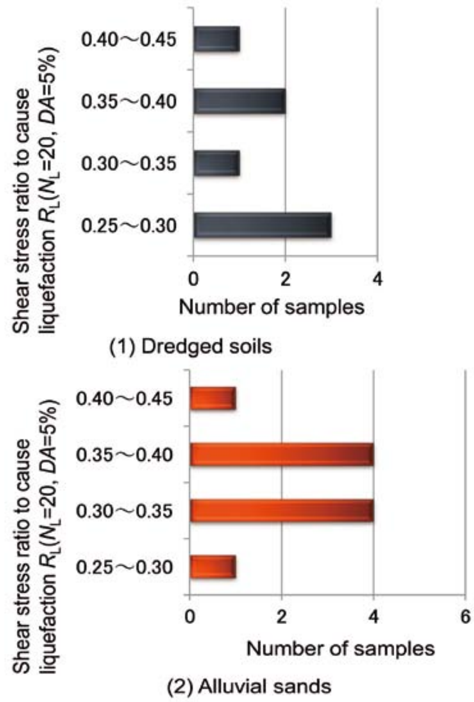
Fig. 5 Frequency Distributions of N_1 and *Fc* for Dredged Soils and Alluvial Sands



N_1=170*N*/(σ_v'+70), σ_v': Effective overburden pressure (kN/m^2)

(Quoted from the research material by the Technical Committee organized by Urayasu City)

Fig. 6 Frequency Distributions of Shear Stress Ratio to Cause Liquefaction



Process of Liquefaction

As the earthquake occurred at 14:46 in the afternoon on Friday, many important photos and movies were taken at many sites along Tokyo Bay to study the process and mechanism of liquefaction. Among them a series of photos taken by Mr. Katsunori Ogawa just after the earthquake at Maihama 3-chome in Urayasu City is introduced in Photos 1 (A~D):

<<< Shake due to main shock started at 14:47 in Urayasu>>>

A <14:56>: Spew out of muddy water started in northeast direction. It took several minutes to start the boiling after the settlement of the main shock.

B <15:01>: Boiled muddy water gradually spread and covered the road.

<<<A strong aftershock hit Urayasu at 15:16>>>

C <15:21>: The southwest road was covered completely with muddy water. Water pipes look like to break.

D <15:22>: Many houses settled and tilted and cars submerged in the boiled muddy water.

The authors sent out questionnaires to about

30 inhabitants in Irifune district which is also located in Urayasu City to ask the timing of boiling and height of boiled muddy water. Answers are summarized in Fig. 7. About 1/3 persons observed the boiling of muddy water immediately after the main shock, however another 1/3 persons recognized the spout of muddy water 5 to 9 minutes after the main shock. Other persons found the muddy water at different timing. Height of the muddy water was not high as mainly less than 9 cm after the main shock. About 2/3 persons mentioned that the boiling of muddy water continued up to the aftershock, and about 3/4 persons watched covered water until aftershock. On the contrary, about 3/4 persons observed spew out of muddy water just after the aftershock and the height of the water was apparently greater than the height after the main shock. This means the boiling accelerated due to the aftershock and more severe liquefaction occurred during aftershock at some sites. Question on the timing of the settlement of houses must be difficult to answer for inhabitants, however, a 1/3 persons and another 1/3 persons answered that the settlement of their houses was zero and 10 to 19 cm respectively after the main shock. And, many inhabitants recognized the settlement on the next day.

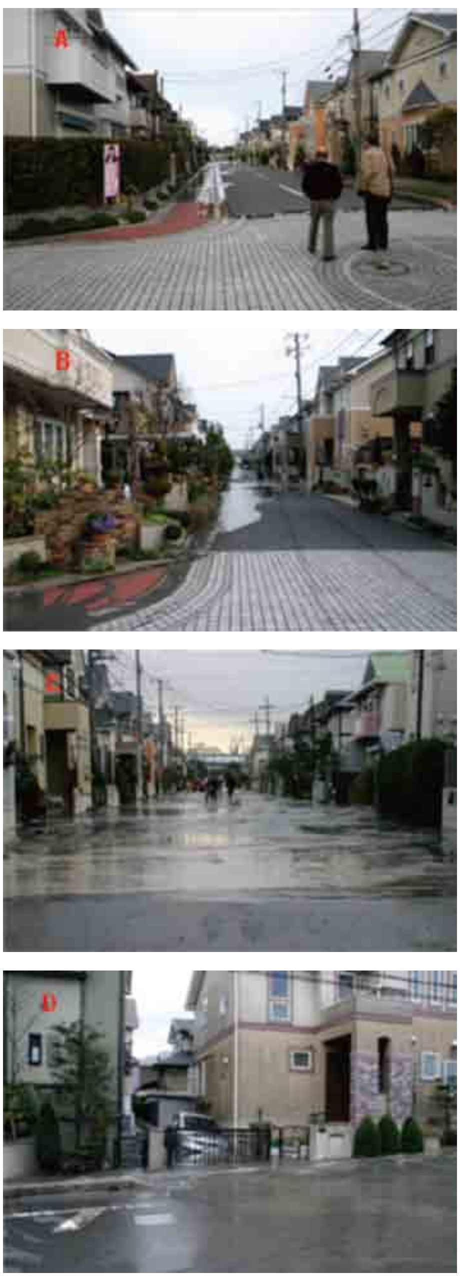
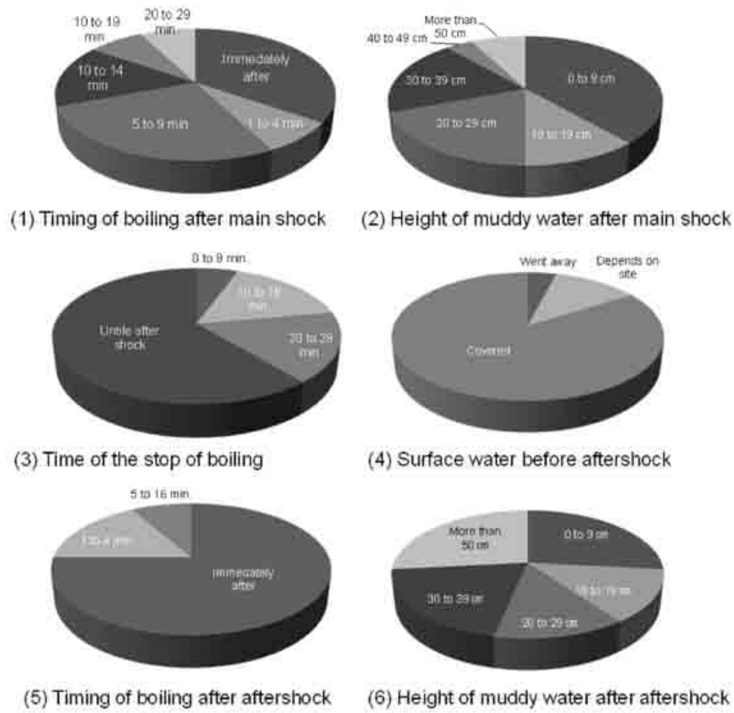


Photo 1 Sequential photos taken by Mr. K. Ogawa

Fig. 7 Questionnaires to Inhabitants in Irifune



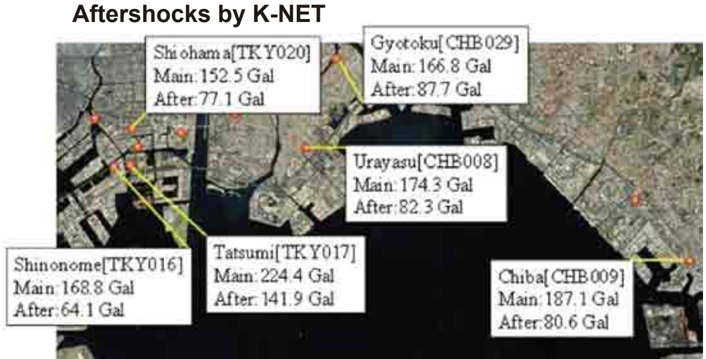
According to the hearing in Imagawa district, some inhabitants testified boiling did not occur during main shock but occurred during aftershock.

Effect of Long Duration of Shaking on Liquefaction

Fig. 8 shows ground surface accelerations during the main shock and the aftershock. Surface accelerations were not high as around 160 cm/s^2 to 230 cm/s^2 though severe liquefaction occurred. The accelerograph, recorded at K-NET Inage in Chiba where actually boiled sand was observed, is very important because liquefied time can be judged from the recorded waves. Fig. 9 shows the accelerograph at Inage together with that at K-NET Urayasu which was recorded on the ground where liquefaction did not occur. Both records started almost same time; 14:46:16 at Inage and 14:46:15 at Urayasu. In Urayasu's wave, frequency did not change drastically after the peak acceleration which induced at about 118 sec. (14:48:13). On the contrary frequency changed to low value after two peaks at 120 sec. (14:48:16) and 126 sec. (14:48:22). Therefore it can be judged liquefaction occurred at around 14:48:16 to 14:48:22 at K-NET Inage. This means many cycles of shear stress, say around 20 cycles from 110 sec., might cause liquefaction at K-NET Inage site. And it must be noted shaking still continued for long time after the occurrence of liquefaction. By referring to the accelerograph at K-NET Urayasu, shake of the ground at Inage continued for about 3 minutes after liquefied.

One more impact to the ground must be the shaking during the aftershock. Peak accelerations during the aftershock were almost a half of those during the main shock in Tokyo Bay area as shown in Fig. 8. Even though, as mentioned above, boiling occurred after the aftershock at some site. Therefore, major reason of the severe liquefaction must be the effect of long duration of shaking during main shock and an aftershock. The authors tried to conduct cyclic torsional shear tests

Fig. 8 Comparison of Accelerations during Main and Aftershocks by K-NET



and some simple analyses to evaluate the effect of the long shaking on the occurrence of liquefaction. Two types of shear wave were applied to specimen, sine wave of 20 cycles and the seismic wave recorded during main shock and aftershock at Urayasu K-NET. In case of seismic wave, excess pore water pressure increased gradually with shear stress as illustrated in Fig. 10. Then, relationships between stress ratio R (τ_d/σ') for sine wave or R_{max} (τ_{max}/σ') for seismic wave and residual excess pore water pressure $u/\sigma c'$ are plotted in Fig. 11. As R=0.27 for u/σ_c'=1.0 and R_{max}=0.31 for u/σ_c'=1.0, the correction factor C_w by JRA standard (2002) becomes 0.82. Then safety factor against liquefaction F_L and liquefaction potential P_L were evaluated for every boring data used for the estimation of 11 brief soil cross section, under the conditions of C_w=0.82 and 1.0. In the estimation, R_L was estimated from SPT N-values and F_C, by using the proposed formula by the technical committee of Urayasu City. Fig. 12 shows evaluated F_L values for a boring data in Urayasu where liquefaction occurred. If the C_w is assumed as 1.0, all F_L are estimated greater than 1.0 whereas F_L are less than if C_w is assumed as 0.82. Fig. 13 compares P_L for all boring data under the assumption of C_w=0.82 and C_w=1.0. If C_w=0.82, P_L for liquefied sites are calculated as greater than about 10 and severity of liquefaction can be demonstrated.

Fig. 9 Comparison of Accelerographs Recorded at K-NET Inage and Urayasu

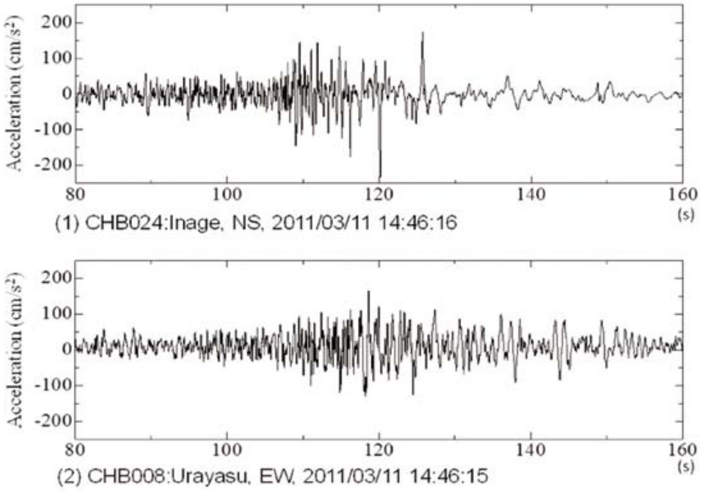


Fig. 10 Time Histories of Shear Stress, Shear Strain and Excess Pore Water Pressure

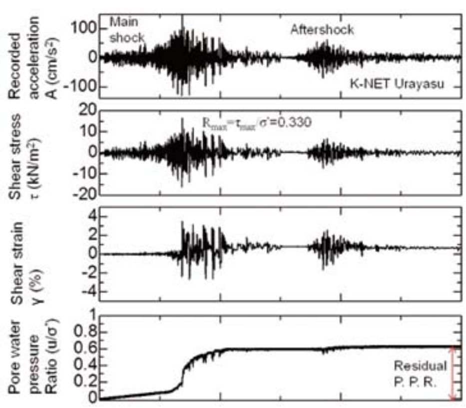


Fig. 11 Relationship between Shear Stress Ratio and Excess Pore Water Pressure

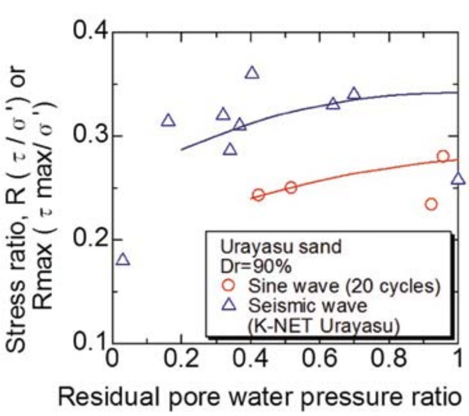


Fig. 12 Analyzed F_L at Imagawa in Urayasu City

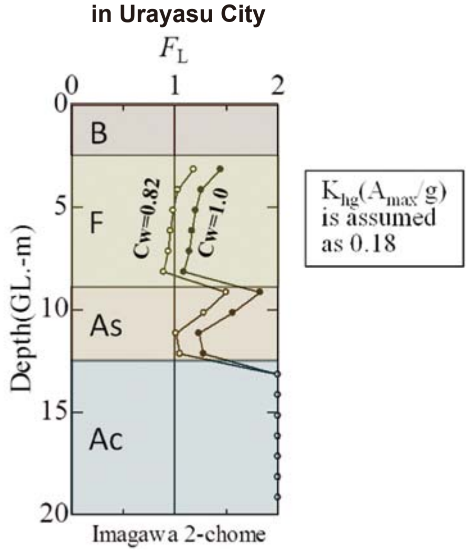
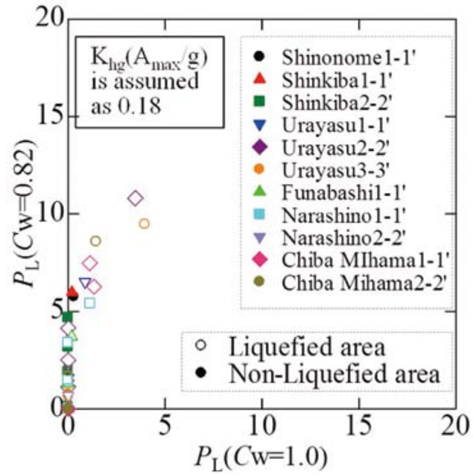


Fig. 13 Effect of C_W on P_L



Settlement and Tilting of Houses

According to the result of totaling by the Ministry of Land, Infrastructure, Transport and Tourism, about 27,000 houses were damaged due to liquefaction (Table 1). Photos 2 (1~2) show a damaged house taken from outside and inside respectively. The house settled and tilted about 40/1,000. In the heavily tilted houses, inhabitants feel giddy and nausea and difficult to live in their houses after the earthquake. However damaged houses due to liquefaction had been judged as partial collapse or injured only during past earthquakes because of no damage to walls and windows, though it has been desired both settlement and inclination must be considered in the judge.

Then, in May, Japanese Cabinet announced

Table 1 Number of Damaged Houses due to Liquefaction

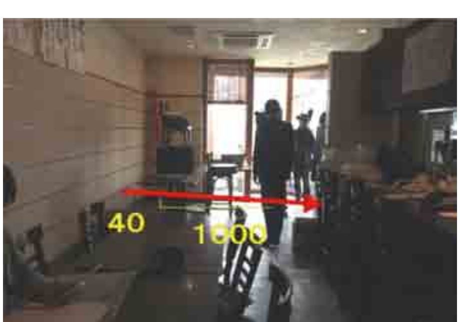
Prefecture	Number of damaged houses
Iwate	3
Miyagi	140
Fukushima	1,043
Ibaraki	6,751
Gunma	1
Saitama	175
Chiba	18,674
Tokyo	56
Kanagawa	71
Total	26,914

Source: Ministry of Land, Infrastructure, Transport and Tourism new evaluation standard for the damage of houses by the two factors, settlement and inclination, as shown in Table 2. Numbers of damaged houses in Urayasu City by the new standard are listed in Table 3 together with the numbers counted by old judging method (Urayasu City, 2011). Numbers of completely and partially destroyed houses increased drastically, and the numbers of damaged houses more severe than partially destroyed enlarged to 3,680.

As mentioned above, occurrence of liquefaction must be affected by the aftershock. Not only the occurrence of liquefaction but also the settlement and inclination must be affected by the aftershock. Ground water table increased after the main shock and boiled muddy water covered the ground surface until the aftershock at many sites. Then, settlement of houses is excitable during the aftershock though shaking amplitude was less than that during the main shock as schematically shown in Fig 14.

Many inhabitants along Tokyo Bay are facing to the serious problem, how to restore the damaged houses. Complicated problem is the re-liquefaction during aftershocks or future earthquakes. Not only the restoration but also some countermeasure against re-liquefaction must be applied, but the problem is the cost and the technique to treat the ground under existing structures. Then early development on effective and economic measures against liquefaction for existing timber houses are facilitating by several organizations. Moreover, applicability of special measures to improve an area by decreasing ground water table is being studied.

(1) Outside of the tilted house



(2) Inside of the tilted house

Photo 2 Severely settled and tilted house in Urayasu City

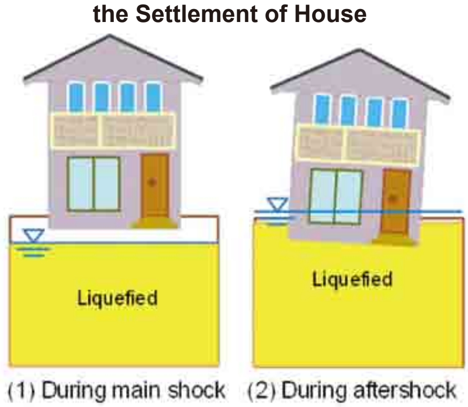
Table 2 New Evaluation Standard for Damage of Houses

Grade of damage	Evaluation method	
	Inclination	Settlement
Completely destroyed	More than 1/20	Floor to 1m upper than floor
Large-scale partially destroyed	1/60 to 1/20	25 cm upper than footing to floor
Partially destroyed	1/100 to 1/60	Up to 25 cm upper than footing

Table 3 Numbers of Damaged Houses in Urayasu City by Old and New Standards (Urayasu City)

Grade of damage	Number of houses	
	Old standard	New standard
Completely destroyed	8	18
Large-scale partially destroyed	0	1,541
Partially destroyed	33	2,121
Partially injured	7,930	5,096
No damage	1,028	1,105
Total	8,999	9,981

Fig. 14 Possible Effect of Aftershock on the Settlement of House



Damage of Sewage and Manholes due to Sloshing of Liquefied Ground

Miracle phenomena, heaving, buckling or thrust, were observed at several footways and alleys as shown in Photo 3 at many sites in Tokyo Bay area. Some thrust might occur at the boundaries due to a kind of sloshing of liquefied ground as schematically shown in Fig. 15 (1), because shaking continued for long time after the occurrence of liquefaction. Fig. 16 shows heaved footways or alleys in Urayasu City together with contour lines of the thickness of the F layer under the ground water table. It may be said that the heaving occurred at the sites where the bottoms of the F layer, in other word liquefied layer, are sloped. This implies that a kind of horizontal buckling of surface layer might occur due to the concentration of horizontal compressive stress as schematically shown in Fig. 15 (2). However, more studies are necessary on the mechanism of the buckling.

In sewage facilities, pipes meandered or were broken, joints were pulled out and pipes were filled with muddy water. Many manholes were sheared in horizontal direction and filled with muddy water whereas few manholes uplifted. Though the mechanism of these unique damages is still being studied, one author's idea is illustrated in Fig. 17. As mentioned above, a kind of sloshing of liquefied ground might occur due to long duration of shaking and caused thrust of roads. By the same movement of the ground, pipes might meander violently in horizontal direction, resulting in pull out or break of joints, and eventually liquefied muddy water invaded into the pipes. Manholes might be sheared due to horizontal force and pressurized liquefied muddy water came into the manholes. Fortunately or unfortunately invaded muddy water into the sewage pipes and manholes might prevent uplift.

Photo 3 Heaving of a footway at Takahama, Ichikawa City

Photo 4 Thick boiled soil observed in Chiba City

Fig. 15 Two Possible Mechanism of Heaving

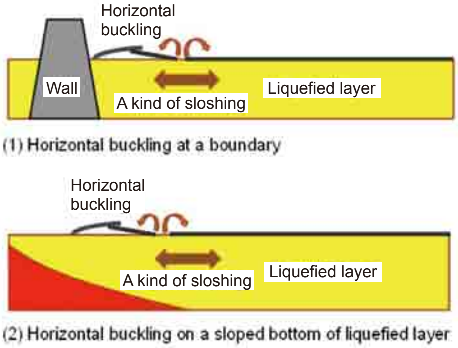
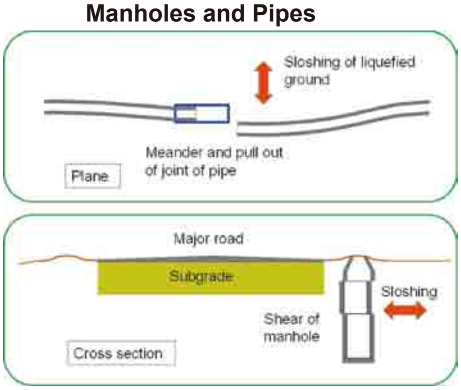


Fig. 17 Unique Damage to Sewage Manholes and Pipes



Traffic Problems due to Boiled Sand and Subsidence

Much eruption of sands and large ground subsidence occurred in the liquefied area. The maximum thickness of the erupted sand and the maximum ground subsidence observed by the authors were about 30 cm and 50 cm respectively. This is the first experience for the authors to see such thick deposited boiled sand in Japan. However, one of the authors had seen similar much eruption and large subsidence in Christchurch during the main shock on September 2010 and aftershock on February 2011. Fig. 18 compares grain size distribution curves of erupted soils in Christchurch during the main shock with those in Tokyo Bay during this earthquake. Fines contents for Christchurch and Tokyo Bay are similar. Then it is estimated that in the very fine sands, ejection of water continues for long time because of low permeability of liquefied soils in both area. Moreover fine soil particles are easy to uplift above the ground surface by the ejecting water. And the removal of the deposited soils by inhabitants accelerated the settlement of the ground surface.

Photo 4 shows an alley covered by boiled sands. It was difficult to run on the thick deposited wet sands by cars and bicycles. Moreover large settlement of the ground around buildings prevented to go out from parking spaces.

Fig. 18 Comparison of Grain Size Distribution Curves of Boiled Sands in Tokyo and Christchurch

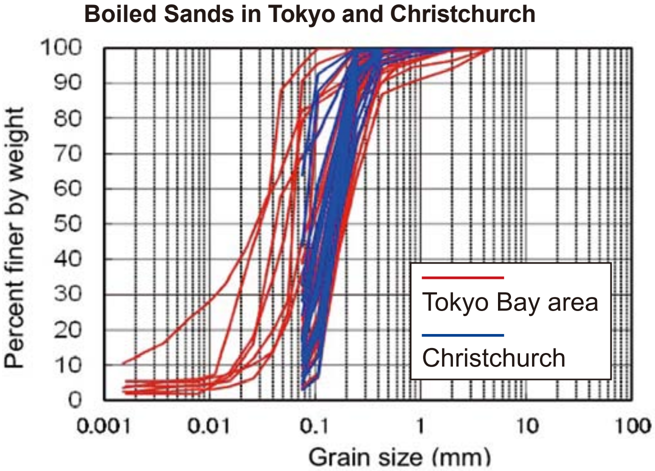
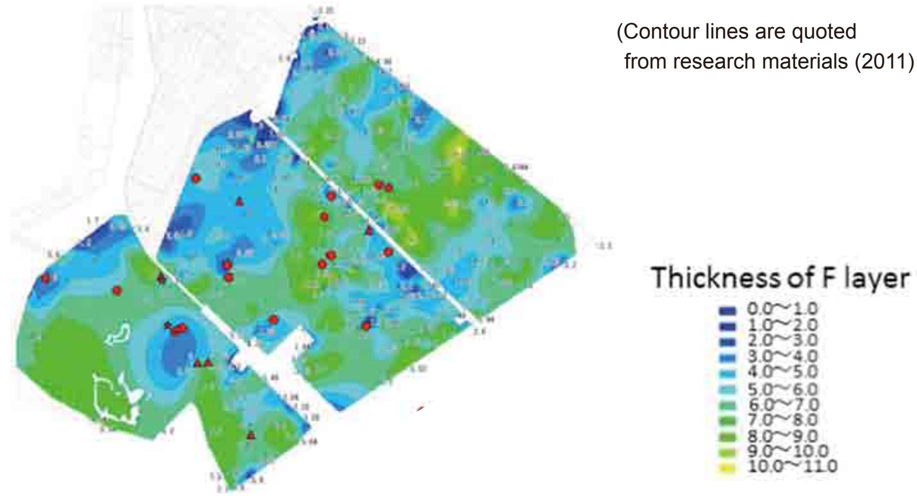


Fig. 16 Heaved Footways or Alleys in Urayasu City together with Contour Lines of the Thickness of the F Layer under the Ground Water Table



Conclusions

Severe liquefaction occurred by the 2011 Great East Japan Earthquake in Tokyo Bay area. Seismic intensities in the liquefied zones were not high, though the liquefied ground was covered by boiled sands. The very long duration of the main shock and an aftershock 29 minutes later should have induced the severe liquefaction. Many houses settled substantially and tilted seriously due to liquefaction. Sewage pipes meandered or were broken, joints were extruded from the ground, and pipes were filled with muddy water. Many manholes were sheared horizontally and filled with muddy water, whereas few manholes were uplifted. This remarkable damage to buried pipes and manholes might have occurred due to a kind of sloshing of liquefied ground.

Acknowledgments

Some of the results cited in this text are quoted from the report by the Technical Committee on Measures against Liquefaction chaired by Prof. K. Ishihara and organized by the Urayasu City Government. Mr. K. Ogawa provided us important photos. The authors would like to express their sincere appreciation to them.

Source

Yasuda, S. and Ishikawa, K.: Several features of liquefaction-induced damage to houses and buried lifelines during the 2011 Great East Japan earthquake, Proc. of the International Symposium on Engineering Lessons Learned from the Giant Earthquake, Paper No. 46, 2012.

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2) National Research Institute for Earth Science and Disaster Prevention (NIED) "K-NET WWW service." Japan (http://www.k-net.bosai.go.jp/)
3) Research material of the technical committee organized by Urayasu City Government. http://www.city.urayasu.chiba.jp/menu11324.html (in Japanese)
4) Yasuda, S. and Harada. K. (2011) "Liquefaction-induced damage in the reclaimed lands along Tokyo Bay." Geotechnical Engineering Magazine, JGS, Vol.59, No.7, pp. 38-41, 2011 (in Japanese)
5) Yasuda, S., Harada, K. and Ishikawa, K. (2012). "Damage to structures in Chiba Prefecture during the 2011 Tohoku-Pacific Ocean Earthquake." Geotechnical Journal, JGS (in Japanese, in printing)

Treatment of Debris and Tsunami Deposits, and Their Effective Utilization for Restoration and Reconstruction

by Takeshi Katsumi, Professor, Kyoto University Graduate School of Global Environmental Studies

The Great East Japan Earthquake of March 2011 produced tsunamis that generated a great amount of debris and deposits, the appropriate treatment of which has become a major task in the reconstruction and restoration of the disaster-stricken areas. In the three stricken prefectures of Iwate, Miyagi and Fukushima, these materials exceed 22 million tons. In Iwate Prefecture, for example, it is said that the waste generated by the earthquake in a single moment is equivalent to 11 years of normal accumulation. Photos 1~3 show tsunami deposits piled in a rice field, a temporary storage site mainly for tsunami deposits, and a site for mixed waste, respectively.

Guidelines for the Treatment and Recycling of Debris and Tsunami Deposits

It is necessary to examine the treatment of debris and tsunami deposits from two perspectives: the treatment processing capacity of the disaster-stricken areas and the structuring of the recycling-oriented society currently being promoted in Japan. Accordingly, two major lines of treatment are being followed: one is the separation and related processing needed to recycle and effectively utilize as much debris and disaster-related waste as possible, while the other one is the appropriate treatment and disposal of debris and tsunami deposits that, unfortunately, cannot be recycled. These two paths were articulated as national policy soon after the earthquake occurred. The role of the construction and reconstruction-operation sectors will be important in promoting the effective utilization of debris and tsunami deposits.

In this regard, two guidelines have been worked out by the Ministry of Land, Infrastructure, Transport and Tourism, into which the author has participated—namely, "Technical Guidelines Concerning Improvements to Parks and Green Tracts Involved in Reconstruction Related to the Great East Japan Earthquake," and "Basic Concepts for the Use of Recycled Materials in Banking for Building Lot Development: Materials Suitable to be Conducive to Prompt Reconstruction and Restoration (Guidelines for Recycled Materials Banking in Building Lot Development)". These two guidelines offer commonly accepted, basic concepts for improving parks and raising submerged ground by the optimum use of various materials recycled from disaster waste.

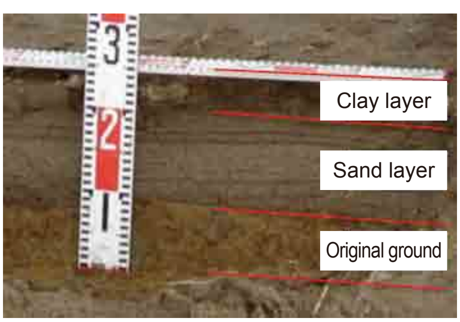


Photo 1 Tsunami deposits (courtesy: T. Yasutaka)

Tsunami Deposits

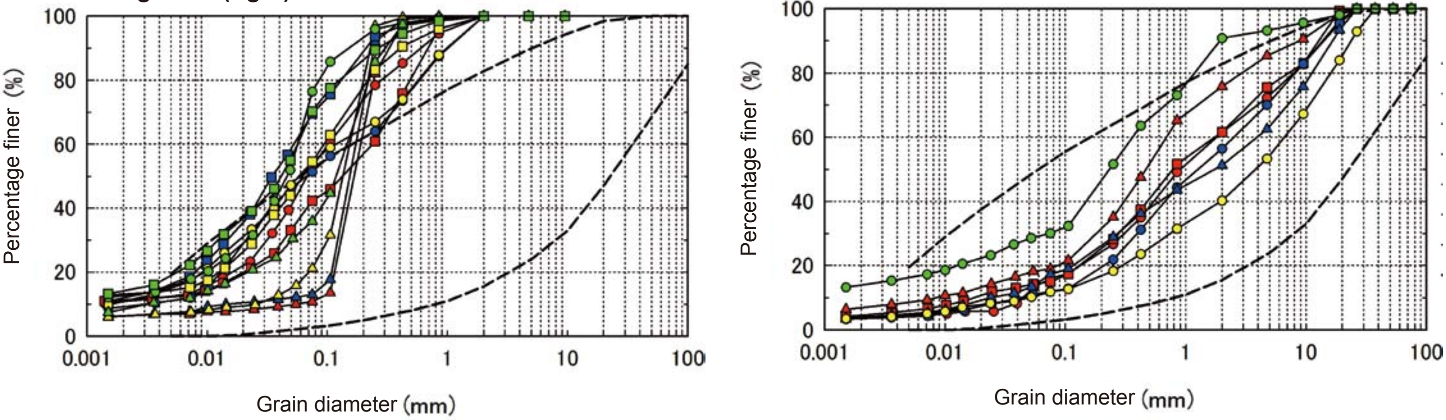
Included among the many kinds of debris and waste materials generated by the disaster are great amounts of soils called tsunami deposits. Accordingly, when using these deposits as construction and reconstruction materials, it is necessary to appropriately separate the soils and similar deposits from other materials. There are many sorts of tsunami deposits with correspondingly diverse physical properties. For example, the grain distribution of the tsunami deposits piled in rice fields is high in silt content, placing the distribution level outside the appropriate grain range shown in the commonly-applied Manual for Earthworks in Rivers. But the grain distribution of the soils contained in the tsunami deposits piled in temporary storage sites are acceptable (Fig. 1)[1), 2)].

One concern in the practical application of these soils and tsunami deposits is salinity. Fig. 2 shows the measured results for chloride contained in tsunami deposits in the rice fields of a local coastal community in Fukushima Prefecture. The measurements were conducted by extracting 38 specimens from those rice fields in December 2011. The chloride content of two-thirds of the 38 specimens was 2 mg/g or lower, while the number of specimens containing a chloride content of 1 mg/g or lower fell to one-third, or 13 specimens[1)]. Conventionally, the chloride content of earthwork materials has been restricted to 1 mg/g

Photo 2 Temporary storage site mainly for tsunami deposits

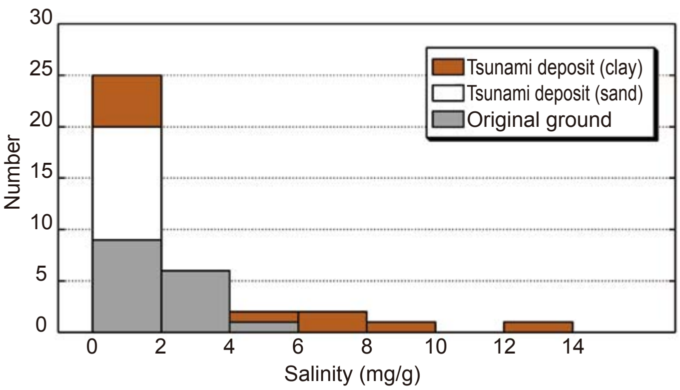
Photo 3 Temporary storage site for mixed disaster wastes

Fig. 1 Tsunami Deposits Accumulated in Rice Field (left) and Tsunami Deposits and Soils Transported and Piled in Temporary Storage Site (right)[1,2]



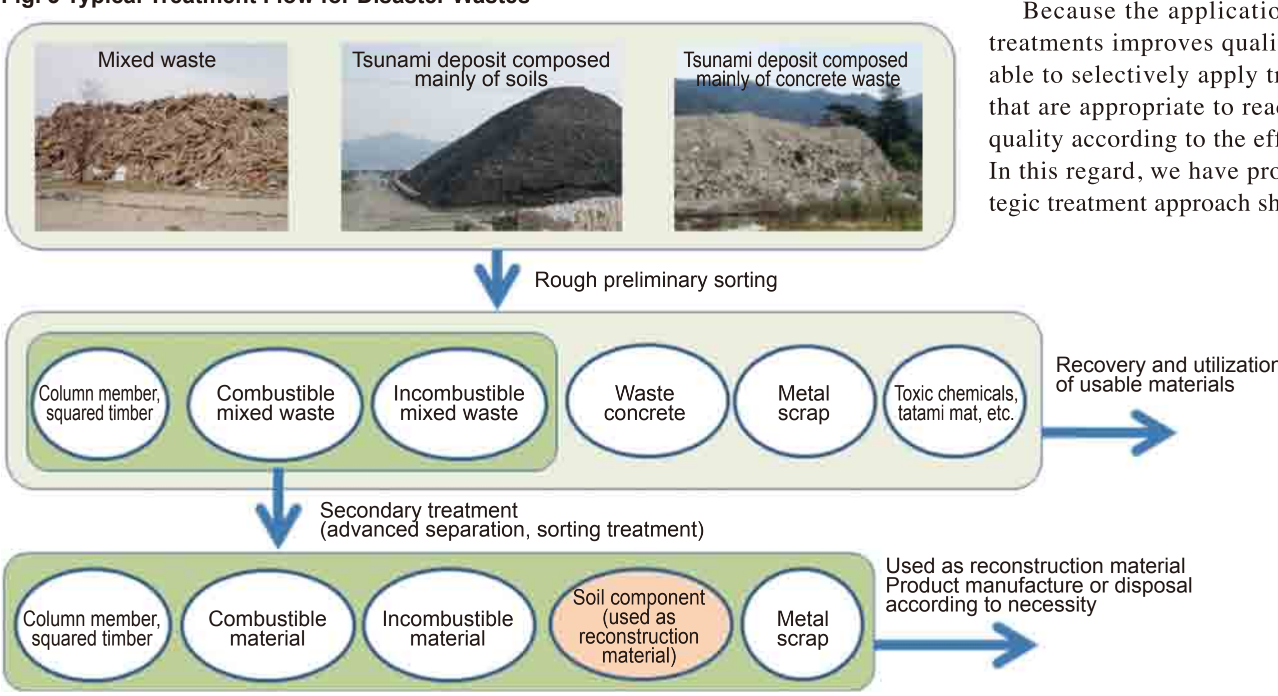
(Dotted line: Appropriate range of grain size shown in Manual for Earthworks in Rivers)

Fig. 2 Salinity of Tsunami Deposits[1]



or lower in order to prevent corrosion in steel pipe piles and other steel products applied underground. The Guidelines for Recycled Material Banking in Building Lot Development allows this guidepost. However, when considering the use of these tsunami deposits to raise subsided ground along the coast, it is only rational to permit the application of soils containing more chloride than the specified value because the salinity in the area's underground water is high to begin with. The Guidelines implicitly suggest such applications.

Fig. 3 Typical Treatment Flow for Disaster Wastes



Debris and Waste

As shown in Fig. 3, the debris and waste are subjected to a rough preliminary sorting, and then to a secondary treatment consisting of crushing, sifting, wet or dry separation, and manual sorting. Tests were conducted on soil specimens at several temporary and secondary sorting sites. The test results show that high compaction performance can be obtained when the presence of wood chips and other impurities is reduced (Fig. 4)[2]. These results demand that the level of organic substances must be verified to be within allowable limits, in view of the potential for long-term subsidence caused by the decomposition of organic substances, and that secondary treatment must also be properly conducted.

Because the application of advanced treatments improves quality, it is reasonable to selectively apply treatment levels that are appropriate to reach the required quality according to the effective volume. In this regard, we have proposed the strategic treatment approach shown in Fig. 5[3].

Fig. 4 Compaction Characteristics of Separated Soils[2)]

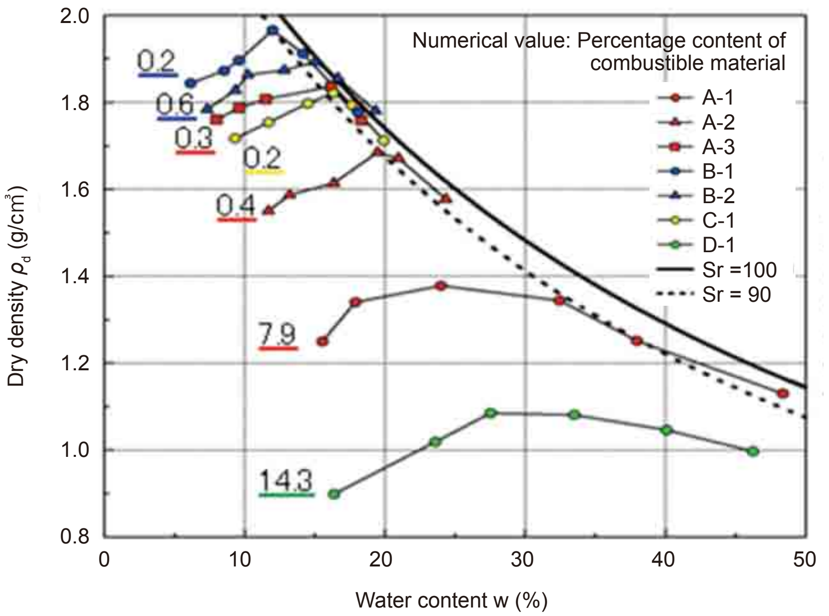


Fig. 5 Image of Strategic Treatment Approach Taking into Account the Quality Required for Application Purpose and Effective Applicable Amount[3)]

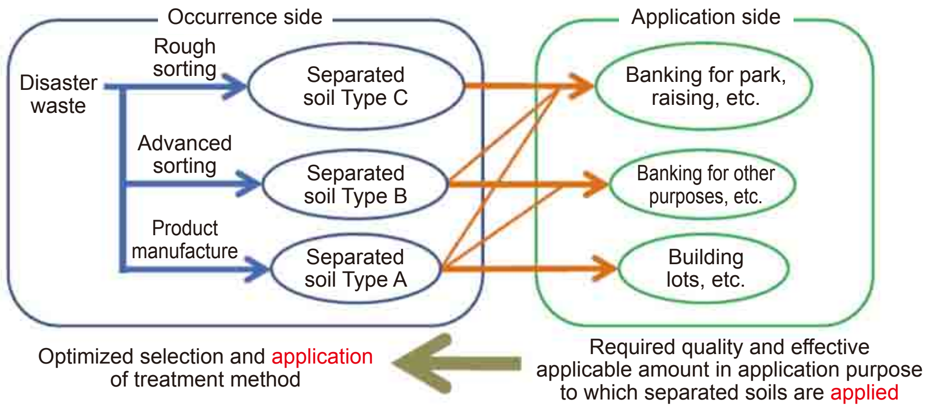


Table 1 Example of Properties of Tsunami Deposits[4)]

Specimen No.	Soil particle density (Mg/m^3)	Ignition loss (%)	Fluorine leaching (mg/L)	Arsenic leaching (mg/L)
No. 1	2.595	12.39	0.5	0.016
No. 2	2.708	1.05	0.2	0.004
No. 3	2.541	14.97	0.5	0.002
No. 4	2.743	3.62	0.2	0.002
No. 5	2.629	10.43	1.3	0.019
No. 6	2.781	2.52	0.2	N.D.
No. 7	2.838	4.95	0.5	0.004
No. 8	2.791	1.32	N.D.	N.D.
No. 9	2.801	9.65	0.4	N.D.

Effective Utilization of Disaster Wastes

In the Tohoku area, where the current earthquake occurred, the existence of natural heavy metals has been discussed. In the survey made by us, tsunami deposits were found to dissolve out arsenic and fluorine at rates surpassing the environmental standards (Table 1)[4)]. In light of the fact that these deposits consist of soils peculiar to the local area, appropriate measures based on suitable risk assessments will be required in the use of these tsunami deposits. Another task is to respond appropriately to asbestos and other harmful substances contained in demolished structures and to radioactive substances as well.

Meanwhile, tracing technology, employing an electronic toll collection system (ETC) and cell phone information terminals, is being applied in the management of waste. In order to effectively utilize disaster waste, it will be necessary to promote its application in public sites while at the same time discussing its treatment and effective utilization based on careful risk assessment in line with social consensus. Expectations are high that "science and technology" can be used in an optimal manner to pay close attention to local climatic conditions and will make effective and wise use of limited resources.

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Basic Details about Corrosion and Corrosion Protection

by Hidenori Hamada, Professor, Dept. of Civil and Structural Engineering, Kyushu University

Corrosion

The corrosion of metallic materials is a phenomenon in which metallic materials, subjected to environmental actions during their use, undergo surface changes due to chemical or electrochemical reactions.

Corrosion is classified into two types: dry corrosion and wet corrosion. Dry corrosion occurs when a metallic material is exposed to high temperatures under moisture-less conditions and develops due mainly to interaction with one or more gases. Wet corrosion results from the ionization of metals under conditions in which moisture is present. In addition to corrosion caused by natural ionization, wet corrosion also includes corrosion induced by stray electrical currents.

Further, corrosion is also classified as general corrosion or local corrosion. General corrosion denotes that a metallic material is uniformly corroded, and it occurs in cases when the environmental conditions are nearly identical over the entire surface of the metal. On the other hand, local corrosion denotes that the corrosive state is not uniform, that there is partial deep pitting corrosion or grooved corrosion, and that the cause of the corrosion is the uneven distribution of environmental factors, non-uniform material quality, or galvanic action (contact with a different metal).

Photo 1 shows local corrosion that occurred in steel sheet pile and steel pipe pile used for port structures. The structure in which local corrosion occurred is in a very dangerous condition.

Mechanism of Corrosion

The micro-observation of steel product surfaces shows that there are non-uniformities in the quality of steel products themselves, such as non-uniformity of mill scale and surface ruggedness. Further, the electric potential on the surface of a steel product may not be uniform due to uneven environmental conditions, such as differences in the moisture conditions (drying and wetting) on the product's surface. As a result, anodic and cathodic areas are formed on the product surface (Fig. 1). The chemical formula of the steel corrosion reaction is expressed as follows:

- Anodic reaction

  $Fe \rightarrow Fe^{2+}+2e^-$ (1)

  $Fe^{2+}+2(OH)^- \rightarrow Fe(OH)_2$ (2)

  $4Fe(OH)_2+O_2+2H_2O \rightarrow 4Fe(OH)_3$ (3)

- Cathodic reaction

  $2H^++2e^- \rightarrow 2H \rightarrow H_2$ (in acid solution) (4)

  $2H^++1/2O_2 \rightarrow H_2O$ (in solution including oxygen) (5)

  $1/2O_2+H_2O+2e^- \rightarrow 2OH^-$ (in neutral solution) (6)

Under conditions in which water and oxygen coexist, iron ions (Fe^{++}) dissolve out due to anodic reaction (Formulae 1), while hydroxide ions (OH^-) are generated due to cathodic reaction (Formula 4~6). This is the first stage of corrosion cell formation. Next, Fe^{++} and OH^- bond together (Formulae 2) to form $Fe(OH)^2$, which is then oxidized by dissolved oxygen to produce rust (corrosion) (Formulae 3).

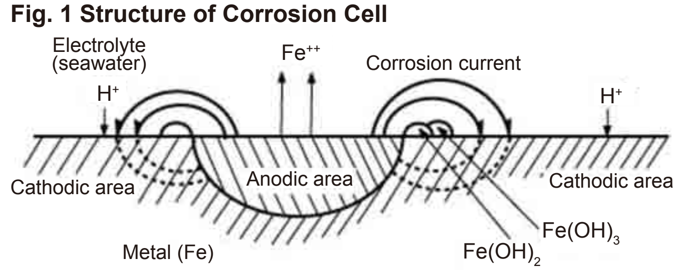
To demonstrate this, steel test pieces (A1, B1, A2, B2 and C) were placed in two different environments: clay and sand (see Fig. 2). When test pieces A1 and B1 were buried as shown in the figure, invisible minute anodic and cathodic areas occurred on their surfaces to form micro corrosion cells. In this instance, the minute anodic and cathodic areas that form micro corrosion cells were constantly changing their position along with the progress of the corrosion reaction, thereby resulting in general corrosion of the steel products. On the other hand, when a single test piece is buried so that it simultaneously extends into two environments (sand and clay) with different conditions, such as piece C, or when two pieces in different environments are electrically connected (test pieces A2 and B2 in the figure), macro corrosion cells are formed. In the formation of corrosion cells in different environments, an environment with a relatively high concentration of dissolved oxygen, i.e. sand environment (pieces B1 and C), is likely to become a cathodic site, while an environment with a low concentration of dissolved oxygen, i.e. a clay environment (A2 and C), is likely to become an anodic site.

Corrosion not only in steel but also in other metallic materials is a state change that occurs spontaneously in the natural environment. Controlling, or checking, the rate of this state change is the goal of corrosion protection. The study attitude differs greatly depending on how the corrosion is studied, whether in a macro prospective or micro perspective. From a micro perspective, the formation of anodic and cathodic areas is discussed by means of electrochemical theory, and the corrosion rate is examined using corrosion current. Conversely, from a macro perspective, structures and structural members are the topic of study and their corrosion rate is examined employing corrosion loss or corrosion area. In either case, the most important task in civil engineering is to accurately assess the level of structural soundness or, conversely speaking, the level of structural degradation.

Reference

Research Group on Corrosion Prevention of Steel Pipe Piles: Corrosion Prevention Technology of Marine Steel Structures, Gihodo, March 2010

Fig. 1 Structure of Corrosion Cell



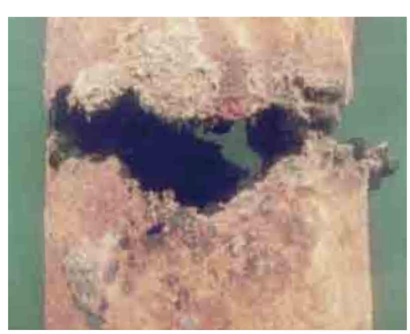
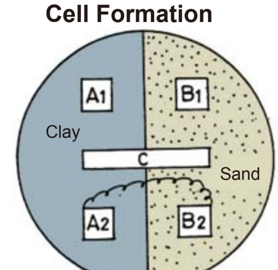


Photo 1 Local corrosion that occurred in port structures: steel sheet pile (left) and steel pipe pile (right)

Fig. 2 Model Test for Corrosion Cell Formation



A1, A2, B1, B2, C: Steel test pieces

JISF Symposium

Symposium on Research into Civil Engineering Steel Structures

The Japan Iron and Steel Federation (JISF) held its annual Symposium on Research into Civil Engineering Steel Structures on March 13, 2012 in Tokyo. The symposium was held with more than 300 people from a wide range of fields, such as government agencies, universities, highway and railway companies, general contractors, and consulting offices, thereby producing successful results.

The symposium has been held every year since 2005 with the aim of publicly disseminating research results produced by the "Steel-structure Research/Education Subsidy Program" promoted by JISF. The current 16th symposium focused especially on "Damage Resulting from the Great East Japan Earthquake and Subsequent Restoration and Reconstruction Efforts," featured lectures by prominent individuals in civil engineering in Japan, and was chaired by Prof. Yozo Fujino of the Graduate School of the University of Tokyo.

The lecture programs offered reports on diverse civil engineering fields in which damage and restoration/reconstruction measures were reported: port structures, railway structures, river levees, highway structures, tsunami deposits and debris, and ground liquefaction. (For details, see the lecture programs below. Certain presentations adapt partially to the articles used in the current issue.)

Emeritus Prof. Nobuo Shuto of Tohoku University, the foremost researcher on tsunamis in Japan, delivered the symposium's annual special lecture entitled: "Together with Tsunamis for 50 years." His coverage of specific themes demonstrated valuable knowledge acquired through 50 years of research on tsunamis, and touched on the types of damage caused by tsunamis, the importance of tsunami-prevention facilities, and the preparations for natural disasters including the usefulness of software countermeasures.

Lecture Programs

- Address by Chairman
  Prof. Yozo Fujino, Graduate School of the University of Tokyo
- Damage to Port Structures and Subsequent Restoration and Reconstruction Efforts
  Takahiro Sugano, Port and Airport Research Institute
- Damage to Railway Structures and Subsequent Restoration and Reconstruction Efforts
  Shinichiro Nozawa, East Japan Railway Company
- Damage to River Levees and Measures for Restoration and Reconstruction
  Ikuo Towhata, Professor, The University of Tokyo
- Damage to Highway Structures and Subsequent Restoration and Reconstruction Efforts
  Takashi Tamakoshi, National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism
- Treatment of Debris and Tsunami Deposits, and Their Effective Utilization for Restoration and Reconstruction
  Takeshi Katsumi, Professor, Kyoto University
- Liquefaction-induced Damage to Houses and Buried Lifelines
  Susumu Yasuda, Professor, Denki University
- Special Lecture: Together with Tsunamis for 50 years
  Nobuo Shuto, Emeritus Professor, Tohoku University
- Address by Vice Chairman
  Shigeo Takahashi, Port and Airport Research Institute

Prof. Y. Fujino delivers chairman address

Symposium scene

STEEL CONSTRUCTION TODAY & TOMORROW

Published jointly by

The Japan Iron and Steel Federation
3-2-10, Nihonbashi Kayabacho, Chuo-ku, Tokyo 103-0025, Japan
Phone: 81-3-3669-4815 Fax: 81-3-3667-0245
URL http://www.jisf.or.jp/en/index.html

Japanese Society of Steel Construction
Yotsuya Mitsubishi Bldg. 9th Fl., 3-2-1 Yotsuya, Shinjuku-ku, Tokyo 160-0004, Japan
Phone: 81-3-5919-1535 Fax: 81-3-5919-1536
URL http://www.jssc.or.jp/english/index.html

Edited by
Committee on Overseas Market Promotion The Japan Iron and Steel Federation
Chairman (Editor): Takeshi Oki

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