Overview of the Geotechnical Damages and the Technical Problems Posed after the 2011 Off the Pacific Coast of Tohoku Earthquake

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ABSTRACT: The 2011 Off the Pacific Coast of Tohoku Earthquake which occurred on March 11, caused serious damage to the infrastructural facilities in Tohoku and Kanto districts due to the strong motion of the earthquake and the subsequent tsunami. This paper includes a brief outline of the earthquake, the earthquake damage to various facilities, and the main geotechnical engineering problems which have emerged after this disaster

1. GREAT EAST JAPAN EARTHQUAKE DISASTER

1.1 Earthquake[1)]

At 14:46 on March 11, 2011, a moment magnitude (M) 9.0 earthquake occurred with its epicenter off the coast of Sanriku. This, the strongest earthquake experienced by Japan since measurements have been taken, was named "The 2011 Off the Pacific Coast of Tohoku Earthquake" by the Japan Meteorological Agency. The Japanese Diet decided to call the disaster caused by this earthquake the "Great East Japan Earthquake Disaster".

According to the Japan Meteorological Agency, the epicenter of the earthquake was 130 km east-southeast of the Oshika Peninsula at 38° 06.2' north latitude and 142° 51.6' east longitude at a depth of 24 km. It was a large ocean-type and reverse fault earthquake occurring at a plate boundary with a west-northwest to east-southeast compression axis.

The parameters of the main earthquake and M7 and higher aftershocks are shown in Figure 1. The largest aftershock occurred on the same day at 15:15 off the coast of Ibaraki Prefecture. On March 9, two days prior to the main earthquake, an M7.3 earthquake, which should be regarded as a foreshock, occurred off the coast of Sanriku. The aftershock activity of this earthquake was extremely vigorous; in the 3 months up to June 11, there were 5 aftershocks that were M7.0 or higher, 82 aftershocks that were M6.0 or higher, and 506 aftershocks that were M5.0 or higher. Figure 2 shows the seismic intensity measured for the main earthquake.

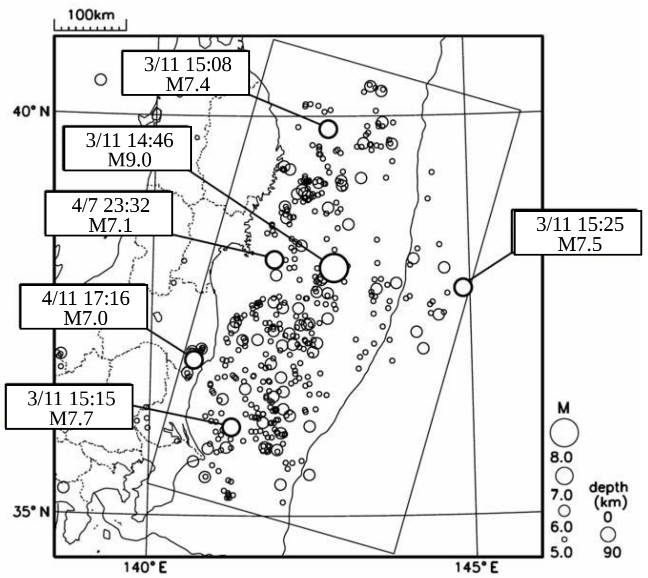


Figure 1 Epicenters of the series of the earthquakes. [2)]

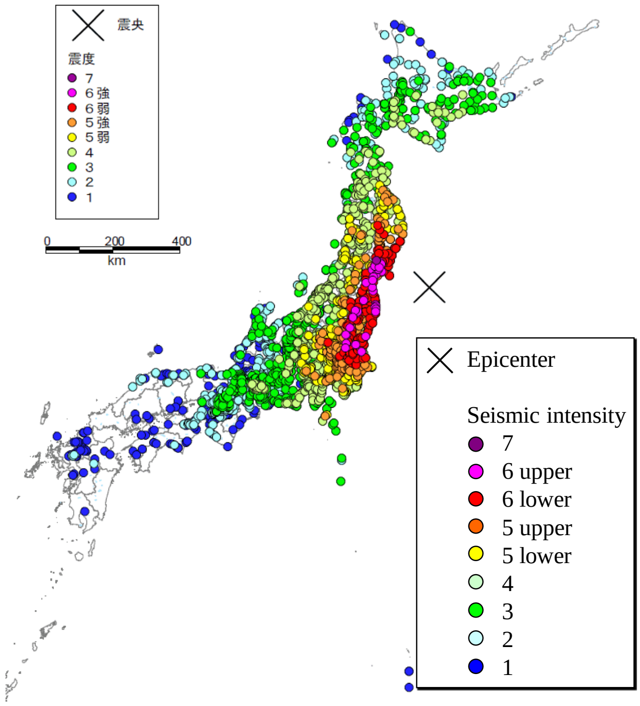


Figure 2 Seismic intensities observed during the mainshock. [3)]

1.2 Tsunami

Tsunamis associated with the earthquake were measured over a wide area from Hokkaido to Okinawa, mainly along the Pacific side of Tohoku Region and the northern part of Kanto Region. As shown in Table 1, very high tsunamis were measured at Soma in Fukushima Prefecture, at 9.3 m or higher, and Ayukawa, Ishinomaki City, Miyagi Prefecture, at 8.6 m or higher.

Table 1 Tsunami height observed during the mainshock. [4)]

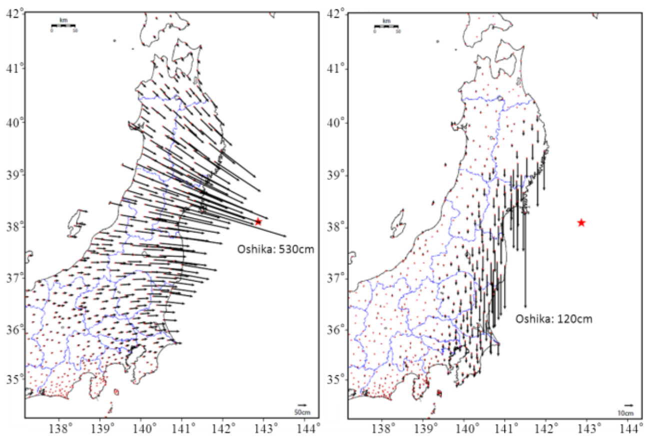
Place		Time	Height
Tide station	Erimocho Shoya	15:44	3.5 m
	Miyako	15:26	over 8.5 m
	Ohfunato	15:18	over 8.0 m
	Kamaishi	15:21	over 4.2m
	Ishinomaki City, Ayukawa	15:26	over 8.6 m
	Soma	15:31	over 9.3 m
	Ooarai	16:52	4.0 m
GPS	Iwate, off Kamaishi	15:12	over 6.61 m
	Iwate, off Miyako	15:13	over 6.23 m
	Kesen-numa, off Hirota Bay	15:15	over 5.63 m

1.3 Crustal movement

Land settlement due to crustal movement occurred over a wide area[5]. At the electronic control point in Onagawa, extremely large crustal movements were measured: about 5.3 m in the horizontal direction and about 1.2 m in the vertical direction as shown in Figure 3. The Geospatial Information Authority of Japan has electronic control points installed at about 20-km intervals at 1,240 locations throughout the country for continuous observation using GPS satellites. Some of their results are shown in Table 2. It was found that after the main-shock, gentle crustal movements that were smaller than those of the main-shock continued to occur.

Table 2 Land subsidence of electrical survey points due to Earthquake (resolution :about 1cm) [6]

City in Iwate prefecture		City in Miyagi prefecture	
Miyako	42 cm	Oshika	120 cm
Yamada	52 cm	Kesennuma	65 cm
Kamaishi	56 cm	Yamoto	48 cm
Ohfunato	76 cm	Rifu	28 cm
Rikuzen-Takada	84 cm	Watari	21 cm



(a) Horizontal displacement (b) Vertical displacement

Figure 3 Crustal deformations in horizontal and vertical direction. [7]

2. OVERVIEW OF THE DAMAGE

2.1 Statistics concerning human casualties and damaged houses

According to an announcement by the National Police Agency[8], as of December 22, 9 months after the earthquake, 15,843 people were confirmed to have died as a result of the earthquake (including the tsunami and aftershocks), and 3,469 people were still missing. The breakdown according to prefecture shows that almost all of these people were in Iwate, Miyagi, and Fukushima prefectures, as can be seen in Fig. 4. In the Kanto Region the number of deaths (persons missing) was in the double digits in Ibaraki and Chiba Prefectures, with 24 (1) and 20 (2) people having died there, respectively. More than 60% of the dead and missing persons were aged 60 years or older, and many firefighters and police were also victims[8].

As of December 22, 9 months after the earthquake, the number of houses considered totally destroyed or half destroyed was 127,091 and 230,896, respectively. As can be seen in Fig. 4, the number of houses considered totally destroyed in Miyagi prefecture is conspicuously high in the breakdown according to prefectures.

The damage to private housing is broadly divided into houses along the coast that were washed away by the tsunami and houses along the coast and inland that were damaged by the ground shaking. In the former case, there were many places where whole areas were destroyed. In the latter case, there were many cases of damage due to foundation deformation in residential land formed in hilly areas and damage due to liquefaction on old river courses and reclaimed land in Kanto Region. The relatively small amount of damage due to the ground shaking alone can be attributed to the small periodic components, of this earthquake, despite its large magnitude. It is the size of the periodic components which determine the amount of damage done to buildings.

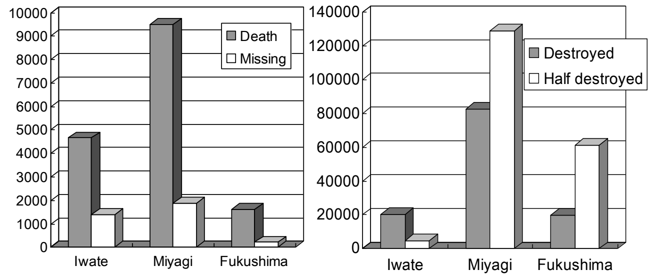


Figure 4 Number of casualties and damaged residential buildings[8].

2.2 Estimated cost of the damage

An overall perspective of the earthquake damage has still not been sufficiently produced, but Table 3 shows the amounts estimated by the Cabinet Office of Japan as of June 24, 2011[9]. The ranges for the estimates in the middle column of the table arose from estimated rates of damage to buildings and are due to the difference resulting from assuming that the damage in tsunami-affected areas is about twice that of the Great Hanshin Earthquake Disaster or substantially more.

Table 3 Estimation amount of damage [9]

	Great east Japan Disaster by Cabinet office	Great Hanshin Disaster by National Land agency
Buildings	about 11～20 trillion yen	about 6.3 trillion yen
Lifeline facilities	about 1 trillion	about 0.6 trillion yen
Infrastructural Facilities	about 2 trillion	about 2.2 trillion yen
Others	about 2 trillion yen	about 0.5 trillion yen
Amount	about 16～25 trillion	about 9.6 trillion yen

3. DAMAGE TO INFRASTRUCTURE FACILITIES

3.1 Road facilities[10]

The tsunami caused damage to road facilities, in particular to National Route 45, which connects the Pacific coastal part of Tohoku Region running north-south. Because the main north-south route along the coast was closed, the Ministry of Land, Infrastructure, Transport (MLIT) Tohoku Regional Development Bureau adopted a road-opening strategy that was referred to as the "teeth of a comb strategy." The strategy was to first open the inland National Route 4, in the backbone of the Tohoku Region, and then to secure road transport to the disaster-stricken areas along the coast, like the teeth of a comb (see Figure 5).

Figures 6 and 7 show the damaged parts of road facilities on National Route 45 and National Routes 4 and 6, respectively. The main forms of damage were the erosion of embankments at bridges (1), road embankments washed away by the tsunami (2), bridge decks washed away (3)-(10), the collapse of slope surfaces (11), the collapse of road embankments and slope collapse (12)-(14), etc.

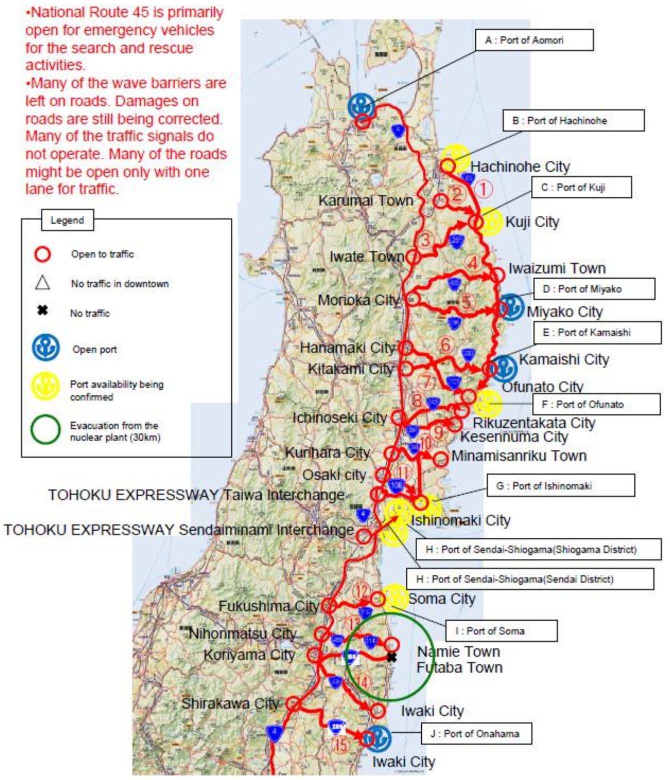


Figure 5 Road opening strategy taken by the national government

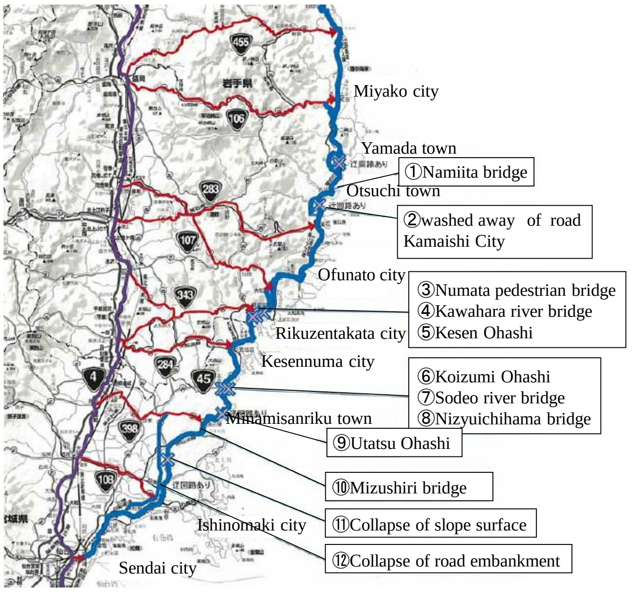


Figure 6 Damage to roads in the north part of the Tohoku district

On the other hand, damage was caused to a total of 20 stretches of expressways with a totalled a length of 870 km[11]. The main damage included the collapse of main roads and road surfaces at 2 locations, large-scale cracking in main roads at 13 locations, subsidence of the road surface at 23 locations (maximum depth 30 cm), road surface level differences of 2 cm or more at 174 locations, damage to bridge bearings (5 bearings on 3 bridges), damage to bridge joints at 56 locations on 46 bridges, IC damage, and so on. There was no major damage to bridge or tunnel structures, so by March 24, emergency repairs had been completed for about 813 km of the above-mentioned damaged stretches (about 93%). (Restoration of the approximately 10-km section between Sendai Wakabayashi JCT on the Sendai Tobu Road and the Sendai Port North Interchange and the approximately 4-km section from Sanriku Jidoshado Sendai Port IC to Rifu JCT were completed by March 30.)

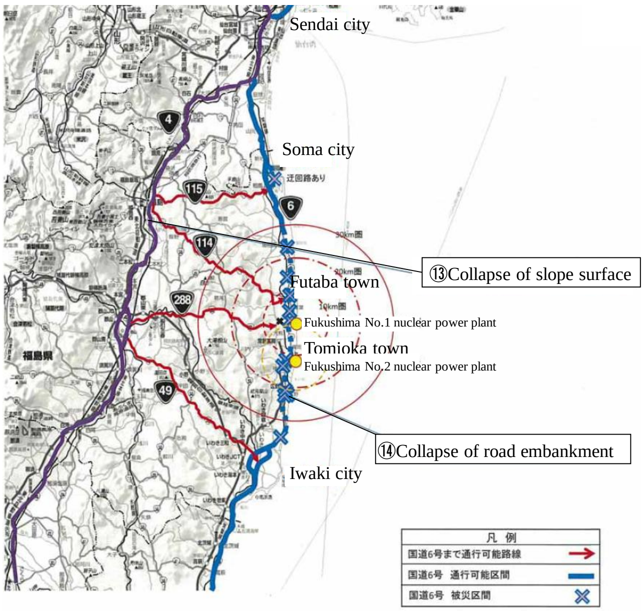


Figure 7 Damage to the roads in the south part of the Tohoku district

3.2 River levees and coastal facilities[12-13)]

Of the 12 water drainage systems managed by the Tohoku Regional Development Bureau, damage was incurred in 1195 locations in 5 water drainage systems and along 9 rivers on the Pacific Ocean side. Emergency restoration was carried out to restore the 29 locations which had been most damaged, and by July 11, all the emergency restoration was complete. On the other hand, 10 rivers in 4 river systems managed by the Kanto Regional Development Bureau were damaged. More locations were damaged with the aftershocks, and as many as 939 locations had been damaged as of July 31. Emergency work was carried out to restore the 24 locations which had sustained the most damage, and by June 2, emergency work at all 24 locations was complete.

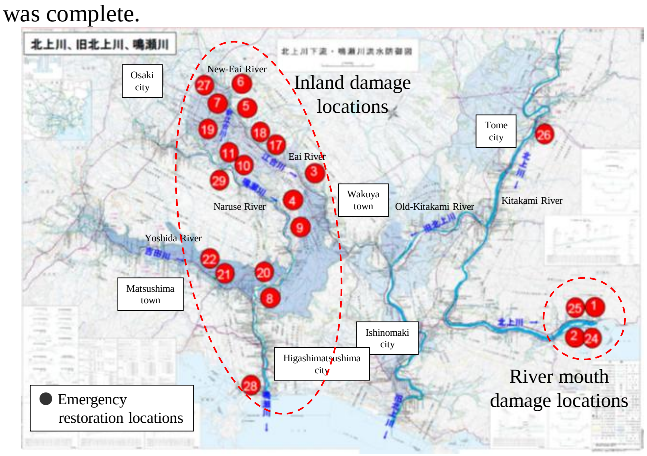


Figure 8 Damage to river embankments in the Tohoku district

The causes of the damage in almost all cases were the tsunami at the mouths of the rivers and liquefaction in inland areas. Figure 8 shows the positions of the major damage locations along the Kitakami River and the Naruse River in the Tohoku Region. Also, almost all the damage in the Kanto Region was caused by liquefaction (see Figure 9). In addition, it was reported that in areas where countermeasures were taken against liquefaction, there was either no damage or the damage was slight.

Regarding coastal facilities, major damage was caused mainly on the south coast of Sendai Bay, where almost all sections of the coastal levee were either completely or half destroyed. The result was major damage houses along the coast were washed away, agricultural land was flooded, etc. Emergency work was carried out to restore about 20 km at 7 locations directly managed by the national government.

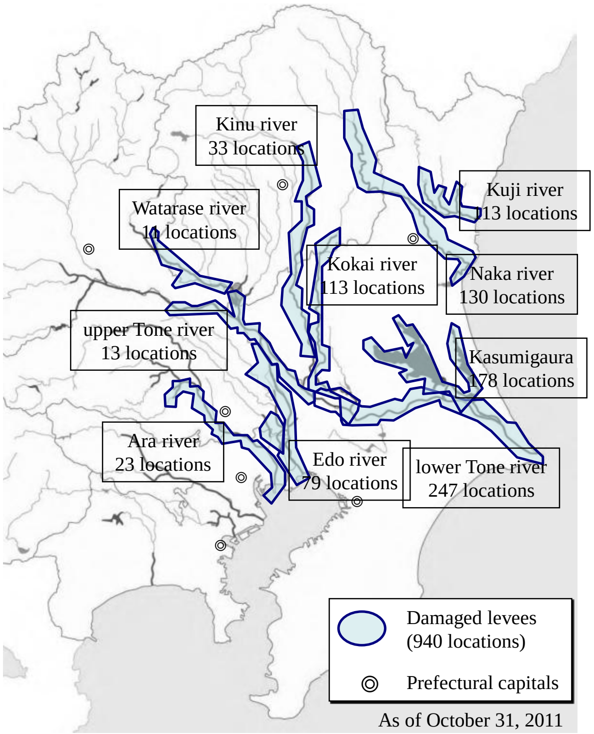


Figure 9 Damage to river embankments in the Kanto district

3.3 Port facilities

Port structures were subjected to the external forces of the seismic motions and the subsequent tsunami. Whether the cause of the damage was one or the other or due to a combination of the two remains unclear at present. Generally speaking, the damage done to breakwaters (including tsunami barriers) can be mainly attributed to the tsunami, and the damage to quay walls can be mainly attributed the seismic motion and liquefaction. Also, the significant damage done to the ports in the north of the Tohoku Region can be attributed to the tsunami, whereas it was the earthquake force which was largely responsible for the damage to the port south of Ishinomaki and to Sendai Shiogama Port.

Photo 1 Re-liquefaction evidence caused by 2011/4/11 aftershock at Onahama Port, Fukushima prefecture.(by Tohoku Regional Development Bureau, MLIT)

Normally, traces of liquefaction on coasts that have been subjected to the effects of a tsunami are wiped out by the tsunami, so traces of sand boils cannot be used as evidence of whether liquefaction occurred or not. However, it is known that liquefaction occurred to a certain extent based on the many photographs and images taken of sand boils caused by liquefaction before the tsunami and the liquefaction that occurred during the aftershocks. Photograph 1 shows the (re)liquefaction at Onahama Port caused by the earthquake that occurred at Hama Dori in Fukushima prefecture on April 11.

3.4 Railway facilities (JR-East)[14-]

Various types of damage were caused to the Tohoku Shinkansen, including the bending, slanting, and cracking of electrification columns; the severing of overhead wires, damage to elevated bridge columns; the displacement of and damage to tracks; the breakdown of transformer facilities; and the collapse, tilting, detachment, etc. of noise barriers. In the main earthquake, there was damage to electrification columns at approximately 540 locations. As of April 7, 60 locations in the process of being restored remained unfinished; however, the aftershock on April 7 resulted to damage at 270 new locations. Among these locations were locations that had already been restored from previous damage, so a large amount of work had to be done again.

After the Great Hanshin Earthquake, the columns and piers of elevated bridges of the Tohoku Shinkansen were steadily seismically retrofitted, so in this earthquake disaster, there was no catastrophic damage, such as toppling over or collapse of elevated bridges, which would have lengthened the restoration period. However, there was a very large number of bent, tilted, or cracked electrification columns, which are ancillary facilities, and because of the sheer scale of the damage, the high-speed mass passenger transport system was out of operation for a long period of time.

In addition, there was significant damage to 7 local railway lines that were affected by the tsunami, with 325 km of these 7 lines damaged. The economic effect of the disaster as announced by JR East Japan amounted to an estimated restoration cost of ¥59 billion, excluding the lines damaged by the tsunami, plus about ¥8 billion in capital expenditures associated with restoration from the disaster.

3.5 Telecommunication facilities [15)-16)]

The damage to communication facilities from this earthquake is classified as follows.

1) Suspension of service due to damage to or depletion of power supply devices
2) Communication building damaged / flooded / washed away by the tsunami
3) Relay network severed by the tsunami
4) The severing of overhead cables and the collapse of electricity poles

In the Tohoku Region, the damage can largely be attributed to the tsunami, and in the Kanto Region, the interruption of services can be mostly attributed to liquefaction damage.

3.6 Electrical power facilities

3.6.1 Nuclear Power Stations[17)]

Several nuclear power stations (NPS) were affected by the severity of the earthquake motion and the subsequent tsunami. From the north going south along the Pacific coast, there are five stations: Higashidori and Onagawa (the Tohoku Electric Power Co. Ltd. (TE)), Fukushima Daiichi, Daini and Tokai Daini (the Tokyo Electric Power Company (TEPCO)). All eleven reactors, all of which were operating at the time, were automatically shut down at the onset of the earthquake shaking. However, the subsequent tsunami affected these facilities to varying degrees, with the most serious damage incurred at the TEPCO owned Fukushima Daiichi plant. Figure 10 shows the status of the NPSs in Japan as of May 15, 2011. Only 17 of 54 units are in operation. At present (December 20, 2011), only 7 units of 54 units are in operation, which is equivalent to an output base of 14% of the total 48,960,000 kW output from the 54 plants.

Regarding the Onagawa nuclear power stations, TE reported that "Unit No. 1 and Unit No. 3 were operating normally, and the Unit No. 2 nuclear reactor was starting up. When the earthquake occurred, all units automatically shut down. The measured acceleration was 567.5 Gal" [18)].

Regarding the Fukushima Daiichi NPS, located near Okuma and Futaba towns in Futaba County, in Fukushima Prefecture, there are six reactors, all of which commenced operation between 1971 and 1979. Since the accident is still ongoing at the time this paper is being written, and no detailed summary of the situation has been provided, no summary will be included in this report. With regard to the nuclear safety issues resulting from the Fukushima Daiichi accident, the IAEA report[19] is available.

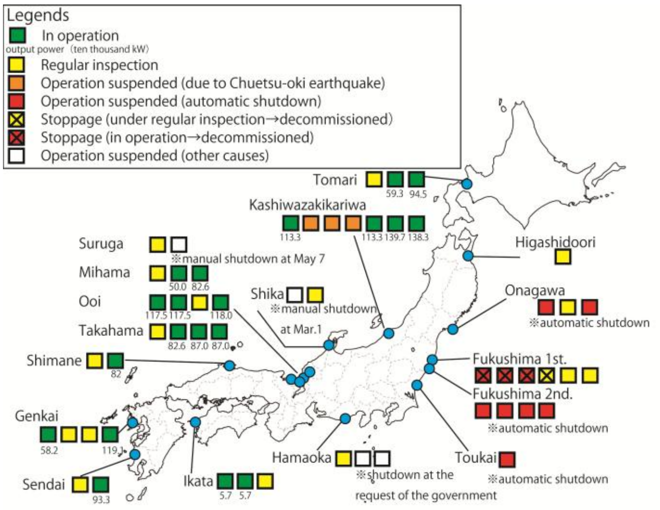


Figure 10 Current status of the NPSs in Japan as of May 15, 2011

3.6.2 Other power stations [20)-21)]

Of the 20 fossil-fired and geothermal power stations of TE that were operating, 12 stopped operating immediately after the onset of the earthquake. As a result, the gross capacity (plant capacity) of the fossil-fired and geothermal plants was reduced by 4.926 GW (about 55%). Of the 4 fossil-fired power stations on the Pacific coast, 3 of the 4 plants that were operating shut down due to the earthquake, and 1 shut down due to the tsunami. The damage caused by the earthquake included the shifting of vibration isolators, etc.; in addition, major damage was caused to coal unloaders by the tsunami, and it was reported that this damage also occurred at 2 power stations that were shut down. Of the 63 fossil-fired power stations owned by TEPCO that were in operation, 13 were shut down immediately after the onset of the earthquake. As a result, the gross output of the fossil-fired power stations (plant capacity) was reduced by 8.475 GW (about 30%). In the 3 fossil-fired power stations along the Pacific coast, a total of 7 units that were in operation were shut down. It was reported that in addition to liquefaction damage, electrical equipment was flooded by the tsunami at 5 plants that were not in operation. Liquefaction occurred in areas along the coastline and in reclaimed lands. Damage to electrical power equipment at power stations included the exposure of foundation piles due to the settlement of the foundation soil, the sideways flow of shore protection, the tilting of tanks and other structures, etc. Damage to electricity transmission facilities included damage to connections in buried structures, tilting, damage, and the collapse of electricity poles, etc.

After electricity was restored to the 4.4 million homes that suffered power outages due to the main earthquake on March 11, power outages occurred again due to the aftershock on April 7. This aftershock affected not only the electricity supply, but also other lifelines, such as the gas and water supplies.

3.7 Other facilities [22)-23)]

Gas is supplied in Sendai City by the Gas Bureau of Sendai city, and the supply of gas was restored to about 310,000 homes by April 16. Restoration activities were carried out with the support of 100,000 workers from 49 gas companies from all over Japan, from Hokkaido to Kyushu, including members of the Japan Gas Association[24].

Regarding the water supply, the peak number of cities, towns, and villages to which water supply was cut off was 187, and water supply was cut off to about 2.3 million homes (survey by the Ministry of Health, Labour and Welfare). In Miyagi Prefecture, there was damage to water distribution pipes for several kilometers downstream of the water purification plants for the Sennan and Senen region waterworks, the Ishinomaki region waterworks, and the Osaki region waterworks. Also, damage to the pipes caused leakage and the separation of the joints of ductile cast iron water distribution pipes at a number of locations.

Regarding sewage works, most end of flow sewage treatment plants are located along the Pacific coast, so they were subject to major damage caused by the tsunami. According to the MLIT, damage was confirmed at 72 sewage treatment works in 12 prefectures and the Tokyo area, and as of April 6, 22 of these sewage treatment works were not operational. Most of the facilities switched to a simple treatment system, and sewage treatment is being carried out. Besides treatment problems, there have been problems with sludge transport, the volume reduction of sludge, and finding adequate disposal locations.

4. SEISMIC DAMAGE TO HOUSING

In the eastern areas along the coast, most of the damage to housing structures can be attributed to the tsunami. In contrast, in the hilly areas within cities with large-scale areas of developed residential land, restoration of damaged housing had still not been achieved even after 9 months. Figure 11 shows the damage map of private dwellings. Detailed information about this matter will be available in Japanese Geotechnical Society articles to be published soon.

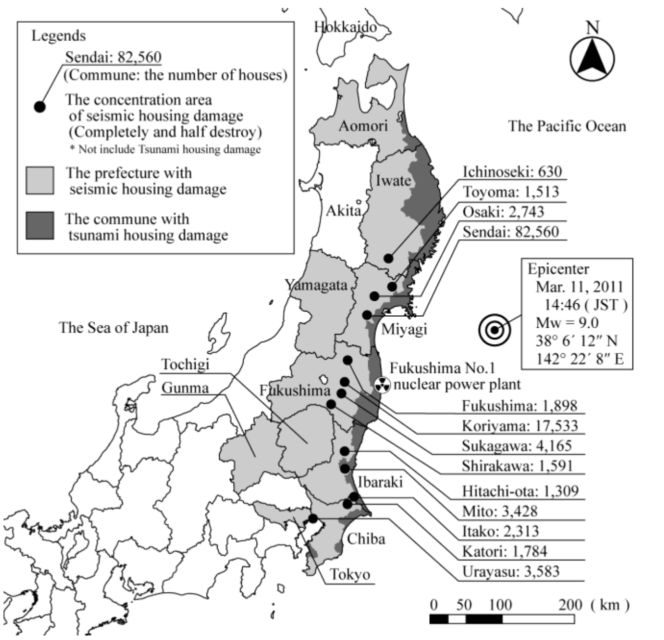


Figure 11 The damaged area and the number of dwellings damaged by seismic activity in a representative community

5. GEOTECHNICAL PROBLEMS

Though this earthquake disaster offers ample learning opportunities in such as wide variety of fields regard to geotechnical engineering, the problems related to geotechnical engineering are considered in this section [24)-26)]. Table 4 shows a summary for different types of geotechnical failure. It is reported that extensive area liquefaction was occurred around Tokyo bay area, the area was at least 42km^2. However, several issues are not the subject of this report. Please see the other literature published by Japanese Geotechnical Society.

Table 4 Summary for different types of geotechnical failure)

Failure type	comment
Scouring and erosion (5.2)	Breakwater foundation, embankment in coastal area, backfill of bridge abutment, around a building foundation in a Tsunami affected area
Ground subsidence (5.3)	due to crustal movement over a very extensive area due to liquefaction of loose sandy deposits acceleration of consolidation may be found
Slope failure (5.4)	Residential areas where a seismic intensity over upper 5 was recorded. Common especially at fill slopes and embankments in inland areas
Liquefaction*	Severe liquefaction occurred around the Tokyo bay area, especially on reclaimed land area (at least 42km^2), tailing dams, the foundation of embankment sand port and airport fill.
Dam failure*	an agriculture earth fill dam failed (7 persons dead and one missing)
Others*	Pile foundations, buried pipes, cavities in underground, ground motion amplification, etc.
Geo-environmental issues (5.5)	Waste management., Tsunami deposits,

*: not the subject of this report

5.1 Control of a destructive performance when receiving beyond design basis events

Unlike the design of static external forces, for seismic resistant design, we will always only know the result of design performance once the earthquake is over. Furthermore, it is possible that facilities will experience very low probability extreme events not included in the original design. The very first lesson of the damage incurred by this earthquake and tsunami is that, even when the external force is beyond that considered in the design, engineers should consider how to avoid fatal damage. Although the concept of a reservation of toughness is already included in the design of the structure such as RC structure, no such consideration tends to made with regard to earth structures or in with regard to the liquefaction damage. The destructive performance of earth structures needs to be controlled, and further investigations need to be carried out to determine ways to evaluate the robustness of these structures and to improve the design codes. Furthermore, research needs to be done to determine the influence of the duration time of earthquake motion, as well as the influence of the number of times of repetition, and the results need to be incorporated into earthquake-proof design.

5.2 Tsunami-proof and erosion-proof performance of an earth structure

In this disaster, both the earth structures located along the coast and the river dikes were heavily eroded by the tsunami, which resulted in spills into the inland areas. Photo 2 shows one of the examples. On the other hand, the embankment of Sendai east express way stopped the tsunami from infiltrating into the Sendai plain, which dramatically decreased the amount of damage to areas inland from it. Now, as a multiple protection policy against tsunami damage, the use of a prefectural road with a padded embankment to provide protection against another tsunami event like this one is being considered. However, in foundation engineering, the technical requirements required to provide earth structures with tsunami-proof and erosion-proof performance have never been investigated, especially for the over flow case. There is much room for research.

Many breakwaters and RC buildings at the Tsunami affected area were also severely damaged as shown in Figure 12 and Photo 3. For breakwaters, research need to be done on foundation design subjected to the overflow of water. With regard to building foundations in Tsunami affected areas, the external design force of the Tsunami wave has to be evaluated. In addition to this, it is pointed out that the liquefaction that took place before the tsunami reduced the frictional resistance of the pile foundations.

Photo 2 Damage of the river dike caused by scouring at the mouth of the New-kitakami river

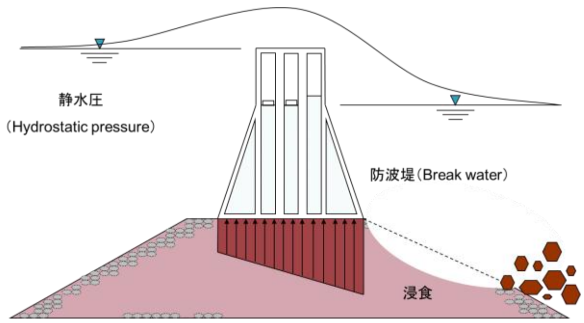


Figure 12 Schematic diagram of the failure mechanism of a breakwater mound due to the tsunami

Photo 3 A collapsed RC 4 story building with pile foundations due to the tsunami at Onagawa town in Miyagi prefecture

5.3 Ground subsidence due to crustal deformation

Due to this earthquake, tens of centimetres of land subsidence was noted in coastal areas. For example, in the Sendai plain, the area under the sea level increased from 3 km^2 to 16 km^2. Quay subsidence has interfered with the cargo work as shown in Photo 4. Such lowlands become not only vulnerable to flooding in the event of a tsunami but also in the event of freak high tides and weather. Many of the places where land subsidence occurred experienced problems in the storm surge disaster from typhoon No. 12 this summer. From another perspective, subsidence of the foundation is equivalent to a rise in the sea level. Although a rise in the sea level was thought to be a problem of the future as a long-term consequence of climate change, it has been actualized as a real problem by the events of March 11. Conquering the influence of land subsidence on the living environment is another subject which has been imposed on the geotechnical engineering community.

Photo 4 The quay submerged in water due to the ground subsidence at Kesen-numa Port in Miyagi prefecture

5.4 Earthquake resistance of the development housing site foundations

The earthquake damage to the fill ground of development housing areas has been a long time problem in geotechnical engineering. Although it seems likely that the amount of damage in Sendai was mitigated in almost all the parts that suffered damage from earthquakes off the Coast of Miyagi Prefecture in 1978, further damage was done due to this earthquake. Moreover, the liquefaction in the Tokyo Bay area in the Kanto region resulted in significant damage to residential areas. Citizens have become increasingly aware and concerned about foundations, particularly cut and fill foundations and the risk of liquefaction. As a direct result of this earthquake, public transparency with regard to providing information about foundation ground is expected to progress along with the earthquake-proofing of the development housing site foundations and technical developments and improvements in foundation engineering with a particular emphasis on restoration procedures.

Photo 5 shows an example of damaged residential area in Sendai city. In this case, three sliding failure blocks were presumed by damage investigation. However, about the view of the subterranean slide, a specialist's opinions were divided. One considers deep sliding surface between original ground surface and fill, the other considers shallow ground deformation due to ground shaking as shown in Figure 13. Though the restoration measures depend on the failure mechanism, it is very difficult to identify the sliding surface under the artificial inhomogeneous fill ground.

Photo 5 Damage to the residential area ground in Sendai city in Miyagi prefecture

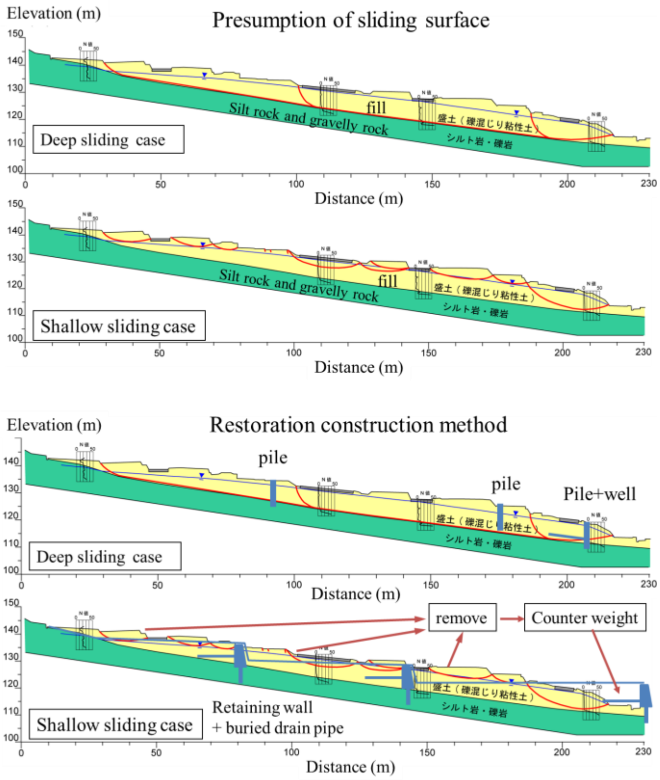


Figure 13 Restoration countermeasures depend on the failure mechanism, such as a presumption of a sliding surface

5.5 The effective use of earthquake disaster waste and tsunami deposited earth and sand

In this disaster, the sheer quantity of earthquake disaster waste and earth and sand deposited by the tsunami, an example of which is shown in Photo 6 has posed important considerations regarding how to use and process it all and how to do this economically. In order to make it possible to use such large quantities of earth and sand as resources and to use them effectively, improvements in the field of earth material management are required. The management measures ultimately employed should ideally also contribute to the preservation of the geotechnical environment. From this perspective, this disaster has provided an opportunity to rethink and improve the framework of regular waste treatment. Foundation engineering can make a significant contribution in this field.

Photo 6 Tsunami deposits, in Higashi-matsushima city in Miyagi prefecture (left) and a rice field in Soma city in Fukushima prefecture (right). The characteristics of the deposited soil from the tsunami change from area to area.

6. AFTERWORD AND ACKNOWLEDGEMNET

Knowledge in the field of seismic geotechnical engineering is based entirely on the learning which happens due to the experience of disasters, and it is continuously improving. As long as there is room for even a little improvement in the methods used by learning from disasters, then the move in the direction of improvement simply not allow for stagnation in the field of research. If there is nothing new that is learned from having experienced this disaster, it would be logical to consider it due to the negligence of engineers and researchers.

In the main text, we attempted to provide as much numerical data as possible to indicate the extent of the damage incurred due to this earthquake, but unfortunately, it all still seems insufficient to convey a sense of what has actually happened. For more detailed information regarding the damage to facilities, we suggest that you refer to the detailed reports in each individual specialty.

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