Report on the Western Tottori Prefecture earthquake of October 6, 2000

by

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ABSTRACT

The Western Tottori Prefecture earthquake of October 6, 2000 hit the western part of Tottori prefecture and its vicinity, causing damage to residential houses and various types of engineering structures. Immediately after the quake, the Public Works Research Institute (PWRI) dispatched a reconnaissance team, followed by seven teams within one month. The paper presents the output from the reconnaissance survey and the following study, highlighting the major damage.

KEY WORDS: Western Tottori Prefecture earthquake, Damage

1. INTRODUCTION

An earthquake of magnitude 7.3 struck the western part of Tottori Prefecture at 13:30, October 6, 2000, named as the Western Tottori Prefecture earthquake by the Japan Meteorological Agency (JMA). It was the largest earthquake to hit Japan since the devastating Kobe earthquake in 1995, and at the same time the largest earthquake in Tottori Prefecture since the 1943 Eastern Tottori earthquake in which approximately one thousand people were dead. Distribution of the JMA seismic intensity and the peak ground acceleration together with the epicenter are presented in **Figures 1** and **2**, respectively.

Statistics of the damage caused by the earthquake are tabulated in **Table 1**. Although the quake did not cause any fatality, 138 were injured. More than 17,000 houses were damaged, including 395 collapsed. The collapsed houses were concentrated at the epicentral area.

This report presents an overview of the damage obtained from the post-earthquake survey and some additional study.

2.GROUND DISASTERS: LIQUEFACTION

Overview

Soil liquefaction and the associated ground distortion were observed in reclaimed lands located along the coastline of Yumigahama peninsula and the Nakaumi (see **Figure 3**). The Yumigahama peninsula is of a sand bar with a length of 18 km and a shortest width of 2.5 km. The land is a lowland with an elevation of less than 6 m. The subsoil mainly consists of sand and the SPT blow counts usually exceed 10. Despite the moderate intensity of peak ground acceleration, recording 0.25 g PGA at the north of and 0.39 g PGA at the south of the peninsula, soil liquefaction was hardly observed in the natural deposit. On the contrary, soil liquefaction was widespread in reclaimed lands around the peninsula. The reclaimed lands had been constructed in the last three dacades to serve as farm land, industry complex yard, or residential land. The underwater soils were used for the fill materials by dredging. Therefore, the soil in the fill layers were very much nonuniform, comprising sand, silty sand, silt and plastic silt.

Liquefaction at Takenouchi Industry Complex

Figure 5 illustrates the soil profile at Takenouchi Industry Complex (see **Figure 4** for location). Thickness of the fill is about 10 meters. The seabed deposit consists of, from the top, silt to sandy silt
deposit consists of, from the top, silt to sandy silt layer(AM-S), and silt layer (AM). The layers are Holocene deposits.

Figure 6 shows a representative boring data

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obtained from an area where extensive sand boil was observed. Also presented in **Figure 7** is the soil gradation data of the reclaimed deposit. It is obvious from the figures that the fill materials exhibit a considerable range of nonuniformity, however, the fines contents are generally high. Although which depths of the soils had liquefied during the earthquake is not known, it is clear that soils with at least 60 percent fines content liquefied. This fact has been attracting geotechnical earthquake engineers' interest. Design Specifications for Highway Bridges (Japan Road Association, 1996) revised after the 1995 Hyogoken Nanbu (Kobe) earthquake specifies liquefiable soils as follows: soils with a fines content less than 35 %, or with a plasticity index less than 15. The question on whether the soils with a plasticity index larger than 15 had liquefied is left to be studied.

Seismogram recorded in the affected area

Among the seismograms recorded in the affected area, two sets of data presented in **Figure 8** are of much interest from the viewpoint of soil liquefaction. At Arashima site, a three component accelerometer was placed near a toe of an embankment (see **Figure 4** for the location). The figure shows that the predominant frequencies of the NS and EW components of the records significantly changed after the main pulse had reached, suggesting that drastic softening of the subsoil has occurred. As a matter of fact, sand boiling was observed at the site. The figure also shows strong motion records obtained at ground surface of a reclaimed land in Sakai-minato (PHRI, 2000). Similarly to the records at Arashima site, the NS and EW components of the recording have dominant low frequency periodic motions after the main pulse had reached. According to the acceleration response spectra in the figure, the dominant period is about two seconds. These recording strongly indicate that the subsoils had liquefied during the earthquake.

3. SLOPE FAILURES

A total of 19 slope failures occurred near and around the earthquake fault. The majority of the area was covered by granite and weathered granite, which is called "masado" and ranges from gravel to soil in particle size. Among the 19 sites, small scale shallow slope failures occurred at 16 sites and slope movements associated with formation of scarps but with limited deformation occurred at 3 sites. Shallow slope failures took place at the perimeter of terrace, originating from the slope shoulders. The thickness of the failed mass was estimated within one meter, which presumably corresponded to loosened thickness due to weathering or vegetation roots.

Rockfalls also took place at many sites. At several locations, falling rocks hit the roads. As an example, **Figure 9** and **Photo 1** show a rockfall damage that occurred at the Hino-Mizoguchi Line (regional road), Mizoguchi town. A total of about 30 rocks with diameters of approximately one to 3 meters fell down the neighbouring steep slope from a scarp of about 70 meters high. The rocks rolled down the hillslope, crushing down trees. Many of them stopped at the slope toe but some crossed a paved road. Unfortunately, one of the rocks hit a car that parked at the parkway locating at the slope side. The front side of the car was flattened by the large rock, resulting two aged passengers injured but very fortunately survived.

4. DAMAGE TO ROADS AND BRIDGES

Overview

Damage to roads and bridges were concentrated around the epicentral area where recorded peak ground acceleration ranged about 0.4 to 0.9 g, but the damage were mostly minor. The epicentral area is hilly or mountaineous therefore the roads usually ran the side of slopes. Among the national roads and prefectural roads, the damage subjected to traffic control amounted to 37 sites (Tottori Prefecture, 2000). The types of road damage included slope failure (10 sites), rockfall (12), differential settlement and cracking at road surface(16), road shoulder failure and collapse of retaining wall (6), and differential settlement of approaching fill with bridge abutments (2). Although closing of road traffic amounted to 12 routes, most of them were reopened in one or two days with one-lane traffic control. In cut-and-bank roads, settlement of road shoulder and associated longitudinal cracking were most frequently observed. Rockfalls also occurred in many places as already shown in **Figure 9** and **Photo 1**. A number of differential settlements of approaching fill with bridge abutment took place, ranging from a few centimeters to 20 centimeters. They were rapidly repaired by overlaying crushed stone within half a day after the quake.

Bridges

Damage to bridge structures occurred at bearing shoes, abutments, and hair cracking to piers, all of which were minor. One exception was a collapse of single-span bridge. The Harada bridge that is located in Seihaku town and is about 20 km away from the epicenter, is a single-span bridge with a length of 7 meters and a skewness of 40 degrees. The girder fell down as shown in **Photo 2**. One side of the girder was supported directly by a masonry retaining wall, which broke down due to seismic earth pressure, eventually leading to collapse of the girder. The masonry was made from natural boulder, presumably constructed as a revetment to protect the slope surface of the small river.

Another example is interesting to note from the geotechnical point of view. Yumeminato bridge connects the Takenouchi Industry Complex (a reclaimed fill) and Yumigahama peninsula crossing over a channel called Takamatsu-gawa. During the earthquake, extensive sand boiling were observed at both sides of the bridge (see **Photo 3**). The land-side ground spreaded out laterally due to subsoil liquefaction, causing the outward displacement of the revetment as large as 2 meters. As illustrated in **Photo 4**, road shoulder concrete blocks of the approaching road in the land side was pushed up due to the ground displacement. The ground displacement also caused the abutment of the Yumeminato bridge to push the girder and tilt back (see **Photo 5**). As can be seen in **Figure 10**, the land-side abutment (A1) was supported by steel pipe piles with a diameter of 500 milimeters and a length of 27 meters. The abutment collided with the girder. But as the girder propped the abutment head to move outward like a strut member, only the abutment bottom was allowed to move outward, thus resulting the abutment to tilt back with an inclination of 3 degrees. From the evidence of the ground lateral spreading and the distortion mode of the abutment, it is readily understood that the abutment and the pile foundation was pushed by the soil.

5. DAMAGE TO RIVER FACILITIES

River and reclamation embankments

Embankments surrounding the reclamation lands located in Nakaumi Inland Sea slumped and cracked. Most seriously damaged were the embankments surrounding the Yumigahama and the Hikona reclamation lands. These lands were constructed in 1970's to 1980's by filling the dredged waterbed soils in Nakaumi. In Yumigahama, the embankment had a height of 2.0 to 2.5 m from the normal water level, a crest width of 5.5 m, and slope inclination of 1:2.0-3.0. In most part of the length, the embankments were protected with berms from being washed out by wave action. The most seriously damaged was the embankment locating at the south-east corner of the land. As illustrated in **Figure 11** and **Photo 6**, the front side slope spreaded out laterally (the lateral movement of the parapet wall was 2.5 meters) and the crest settled 1.2 m. Sand boiling was observed widely in the area. Form the boring data given in Figure 10 and the evidence of sand boiling, it is no doubt that the embankment distortion was induced by the subsoil liquefaction.

Dams

In the epicentral area and the vicinity, there existed a lot of dams. In general, all dams constructed in the legislative rivers performed well with little or no damage. According to the inspection conducted immediately after the quake by the dam maintennance offices, minor damage were reported for two dams located in the epicentral area. At Kasho dam, a gravity-type concrete dam with a height of 46.4 m, peak accelerations of 0.54 g (NS), 0.54 g (EW) and 0.49 g (UD) were recorded in the inspection gallery at the base elevation of the dam and 2.09 g (NS), 1.44 g (EW) and 0.90 g (UD) at the top of the elevator tower, as shown in **Figure 12**. Hair cracks appeared at the wall and base of the auxiliary gate room. At Sugesawa dam, a gravity-type concrete dam with a height of 73.5 m, peak accelerations of 0.16 g (transversal), 0.13 g (longitudinal) and 0.11 g (UD) were recorded in the inspection gallery at the base elevation. Hair cracks were observed in the auxiliary gate room. Unoike dam, a gravity-type concrete dama with a height of 14 m, was located only one kilometer away from the earthquake fault estimated by the Geographical Survey Institute (2000). At the reservoir side, about 20 m away from the dam, the Hino Strong Motion Observation Station was situated. Peak accelerations of 1.16 g and 0.62 g were observed at the ground surface and a hundred meter depth, respectively. Despite such strong ground motion, the dam performed well with only slight cracking at a side wall of the spillway.

Among irrigation dams in Tottori Prefecture constructed out of the legislaive rivers, all of which were generally small-sized earth dams, damage to 40 dams were reported. Most of the damaged dams were located in the epicentral region. Damage included cracking to auxiliary structures, longitudinal cracking at the crest, and displacement of the concrete block revetment on the upstream slope, however, no functional damage took place. **Figure 13** shows sliding failure of the upstream slope at Kanayatani Irrigation dam made from weathered granite soil (called "masado" in Japanese) with a height of 4.5 m. The upstream slope spreaded out through the entire length, while the sliding occured over seven meters length.

6. DAMAGE TO SEWAGE TREATMENT FACILITIES

Sewage treatment facilities and pipelines sustained damage. The damage was concentrated in the Yumigahama peninsula and its coastal area. Structural damage were reported at four sewage treatment plants, all of which were located in the Yumigahama Peninsula. The damage included ground settlement at perimeters of buildings and the associated breaking of pipes and underground collidors (see **Photo 7**). The buildings were supported by pile foundations. Soil liquefaction and associated ground settlements were observed only in the region within a few meters away from the structures. This proved that the soils refilled during construction of the buildings liquefied, whereas natural deposits did not liquefy. Compaction of refilled soil may not have been adequate.

Underground sewage treatment conduits were also damaged at several locations. In Takenouchi Industry Complex yard, a lot of manholes were projected with respect to the ground surface, as shown in **Photo 8**. This projection was deemed to have been caused by the settlement of the ground and the uplift of the manholes due to buoyant force of the liquefied soils. In conclusion, most of the damage to sewage treatment facilities were caused by soil liquefaction.

7. SUMMARY AND CONCLUSIONS

The paper briefly described overview of the major damage caused by the Western Tottori Prefecture earthquake of October 6, 2000. The damage was estimated to have reached about ten billion yens loss. About half of that was from liquefaction induced damage. In general, major damage in the epicentral region were damage to residential houses, various types of slope failures including rockfalls, and damage to bridges. In the Yumigahama Peninsula and its perimeters, liquefaction-induced damage occurred to various types of engineering structures. From technical point of view, liquefaction of soils with high fines content attracted the interest of geotechnical earthquake engineers, and should be further studied.

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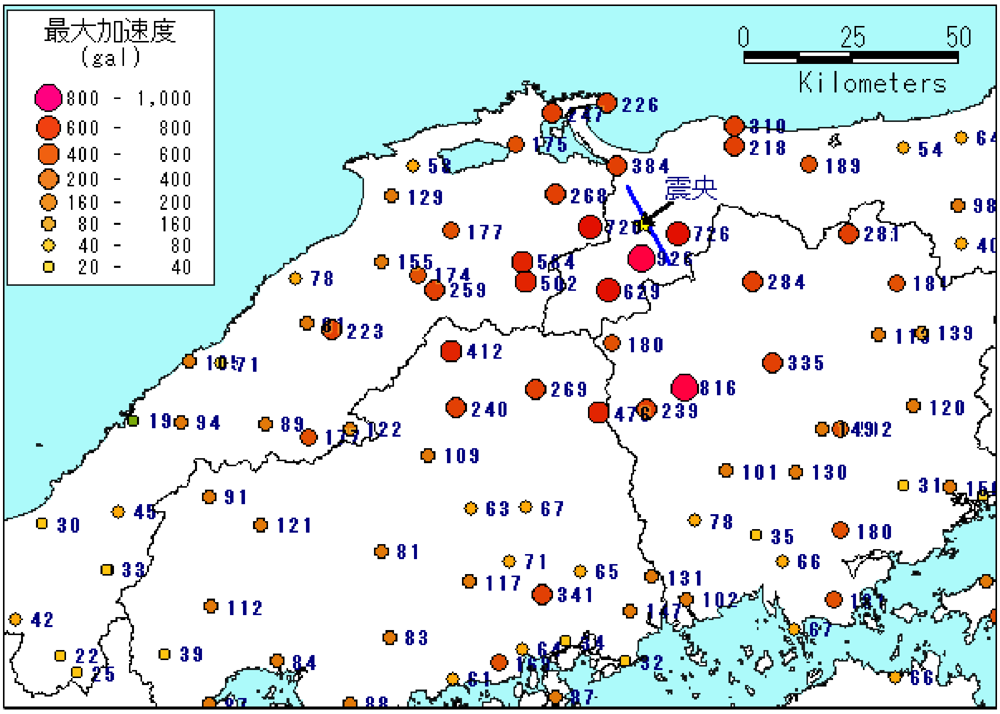
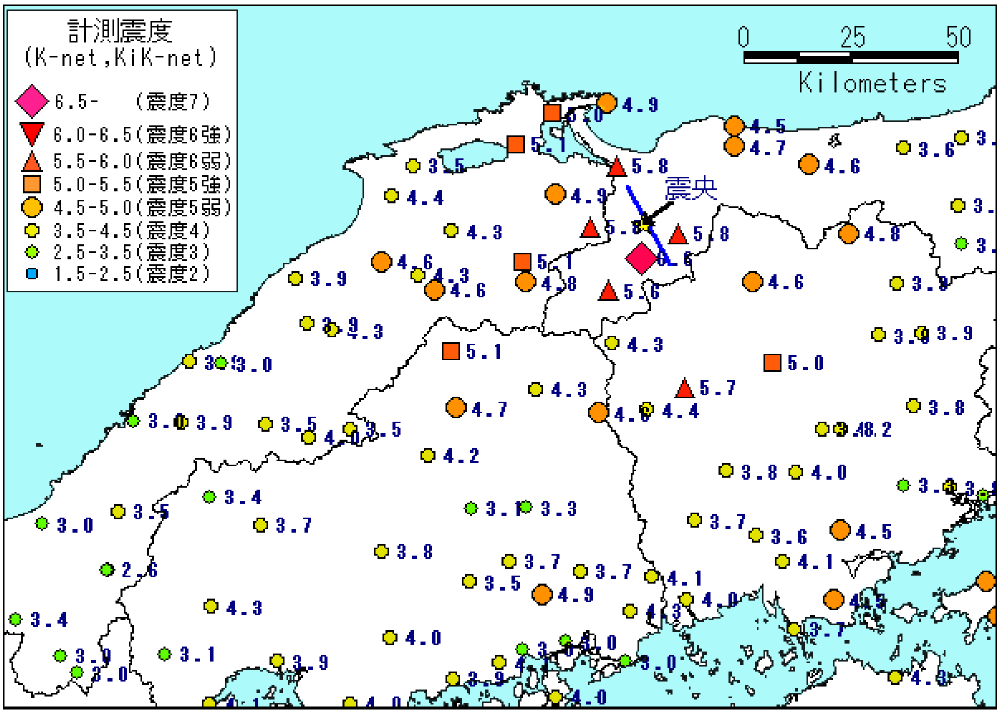
Table 1 Statistics of the earthquake damage （FDMA, 2000）

Human damage	dead	0
	injured	138
Property damage	residential house	
	totally collapsed	395
	moderately collapsed	2,583
	partially collaped	14,938
	non-residential public building	202
	other non-residential building	1,513
	school building	685
	hospital	45
	sanitation facility	6
	roads and highways	676
	bridge	5
	river facility	77
	port and harbour	120
	airport	1
	flood control dam	2
	debris control facility	30
	slope failure	360
	railway	4
	water supply	7,283
	electricity	12,293
	telecommunication	136
	gas supply	71



K-net,KiK-netの波形記録より読みとった値
断層位置は Yagi&Kikuchi(2000)[東大地震研 HP]による

Figure1 Distribution of JMA seismic intensity (data from NIED, 2000)



K-net,KiK-netの波形記録より計算した値
断層位置は Yagi&Kikuchi(2000)[東大地震研 HP]による

Figure 2 Distribution of peak ground acceleration (data from NIED)

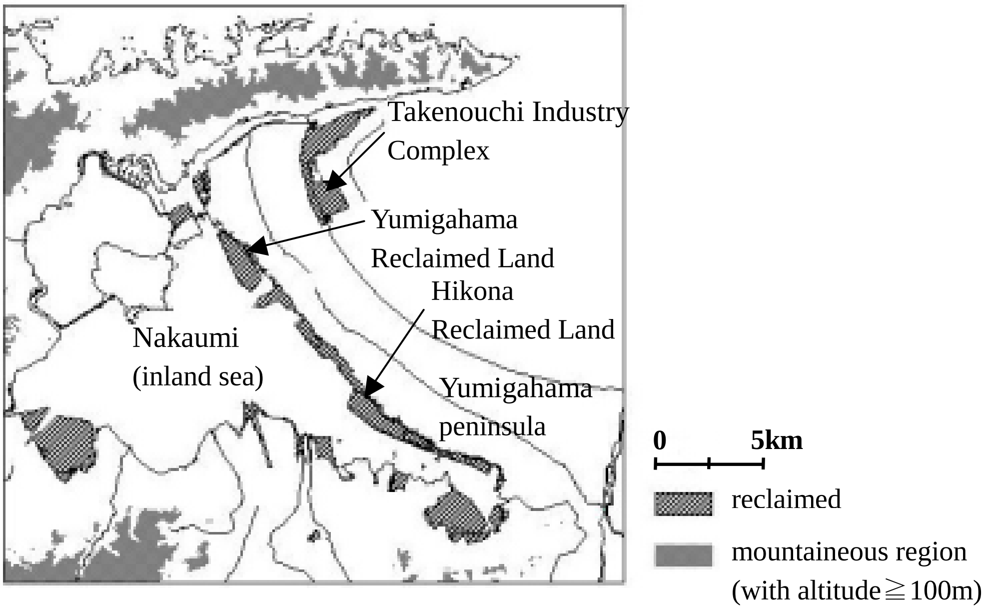
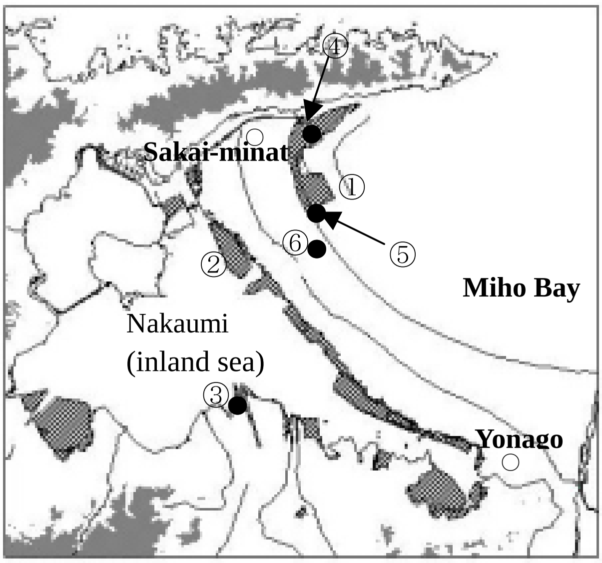


Figure 3 Distribution of liquefied area



① Takenouchi Industry Complex
② Yumigahama Reclaimed Land
③ Arashima strong motion observation station
④ Sakai-minato strong motion observation station
⑤ Yumeminato bridge
⑥ Sakai-minato sewage Treatment Center

Figure 4 Reference map showing location of major damaged site (only for coastal area)

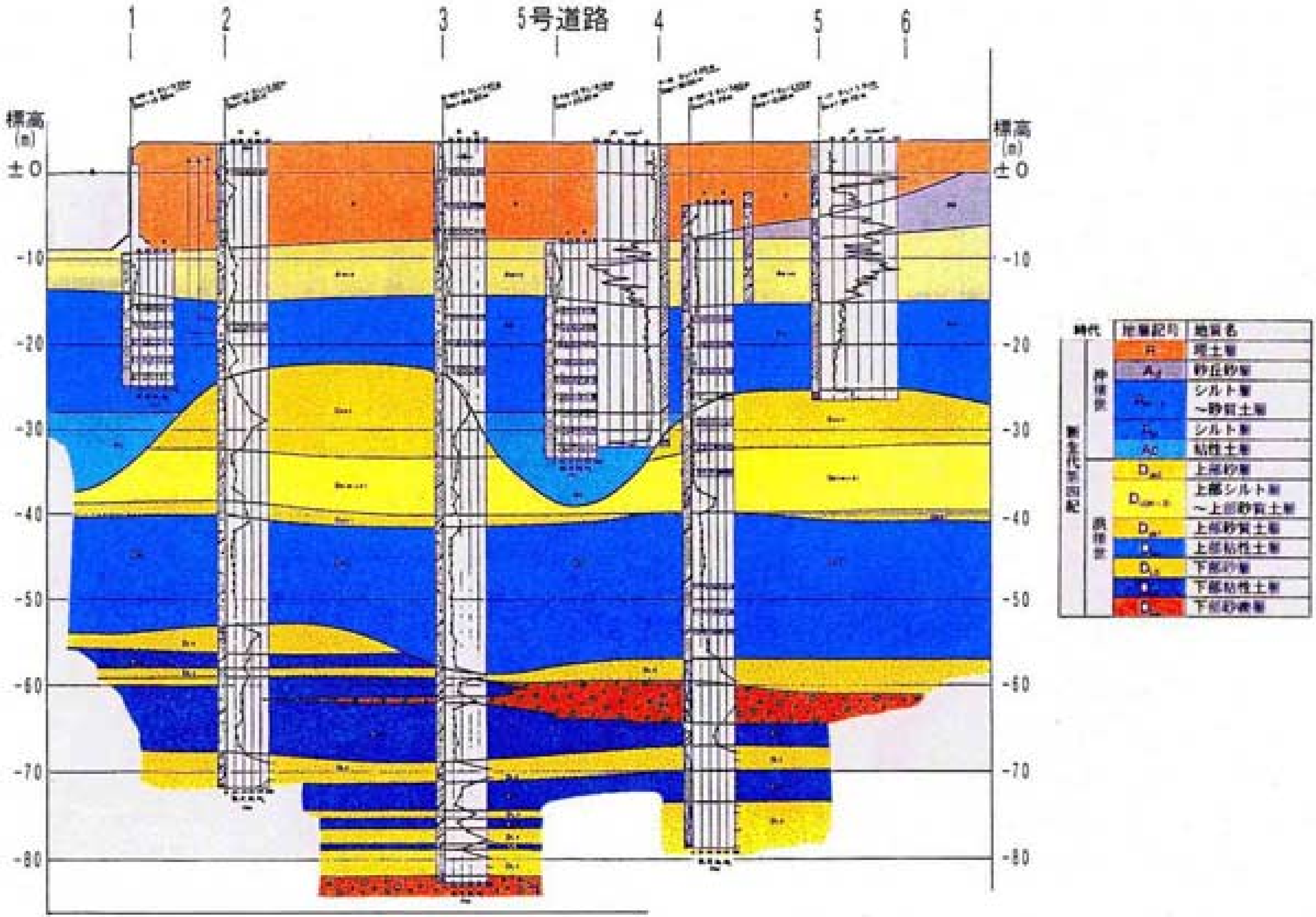
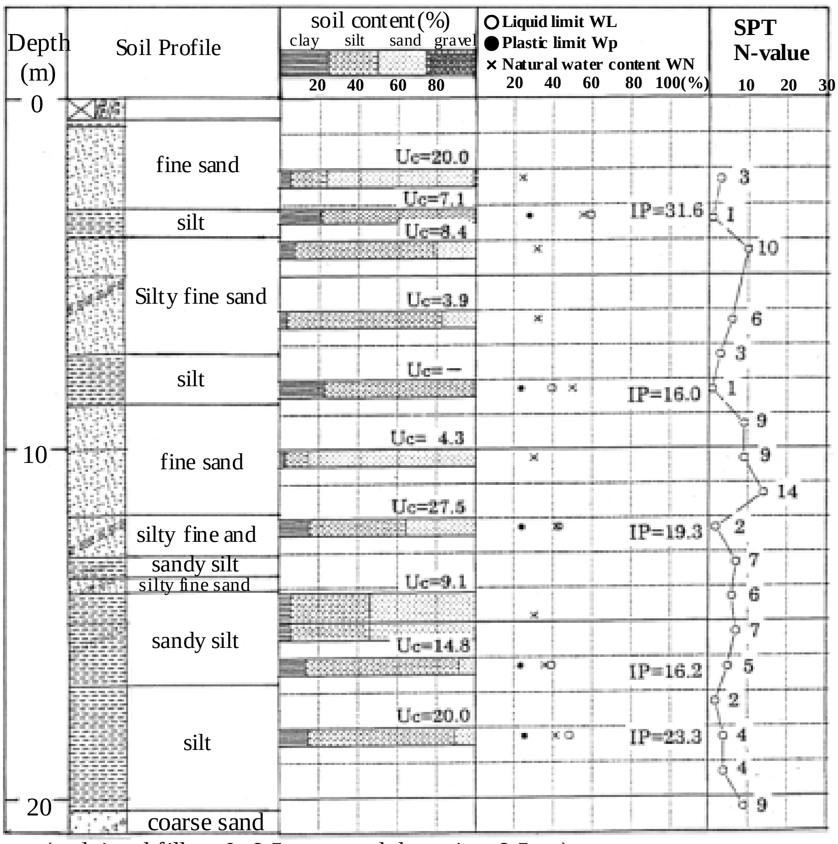


Figure 5 Soil profile at Takenouchi Industry Complex



(reclaimed fill = 0~8.5m, natural deposit = 8.5m~)

Figure 6 Soil profile data at Takenouchi Industry Complex

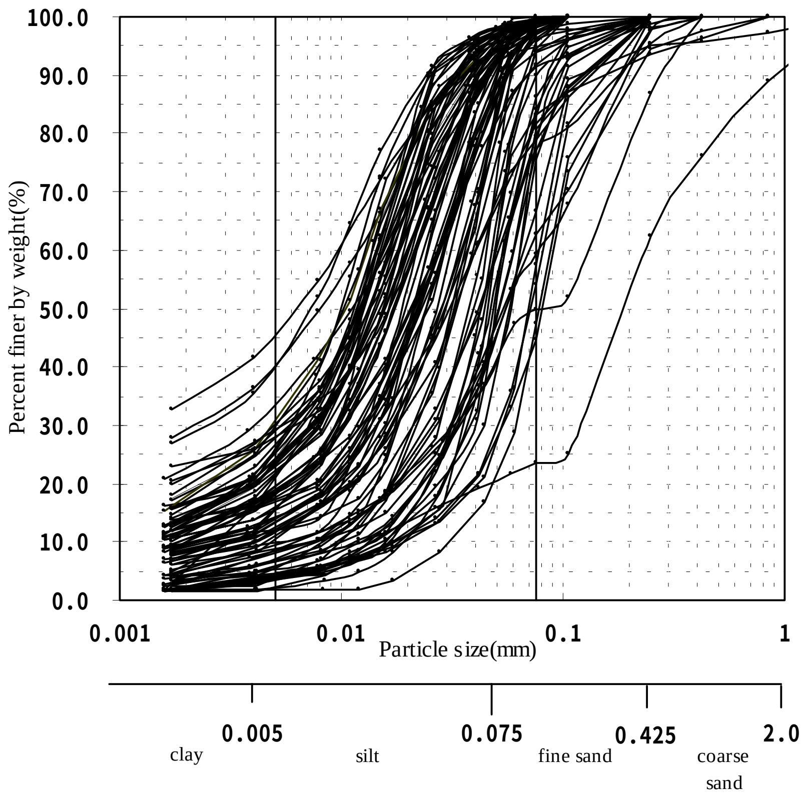
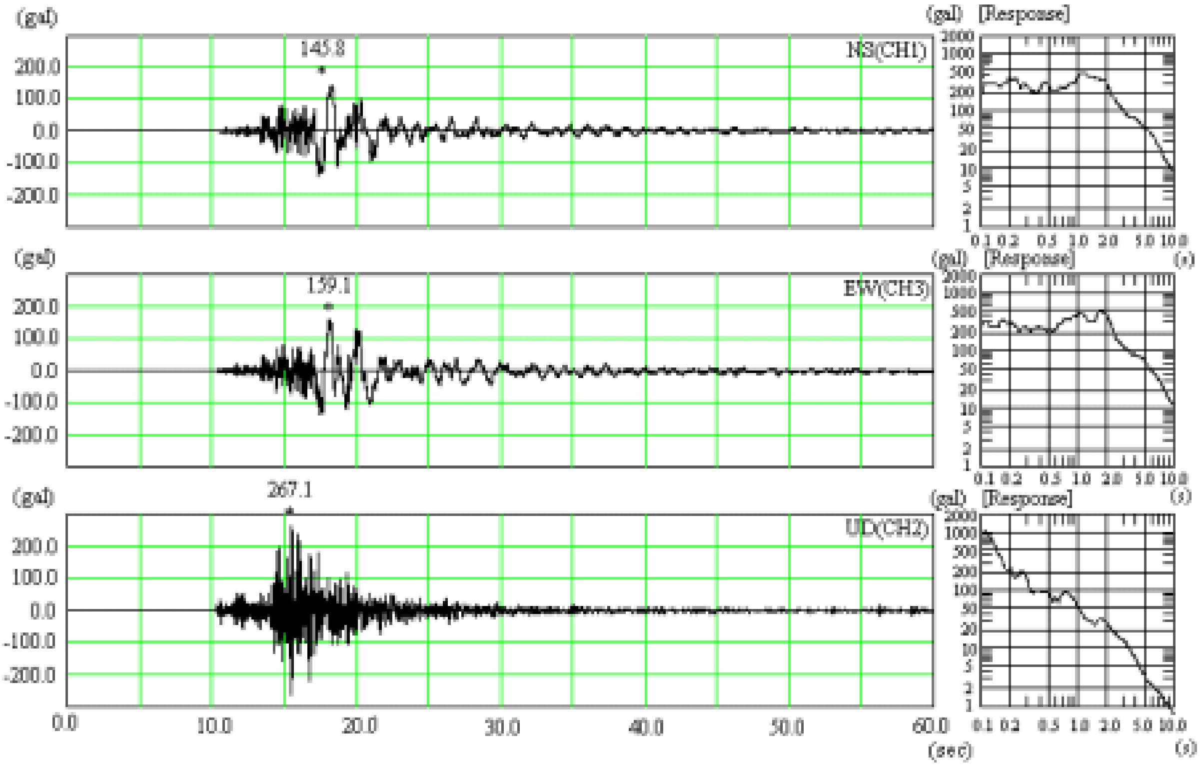


Figure 7 Soil gradation data

(a) Recorded at Arashima (Izump Construction Office, 2000)



(b) Recorded at Sakai – minato (PHRI, 2000)

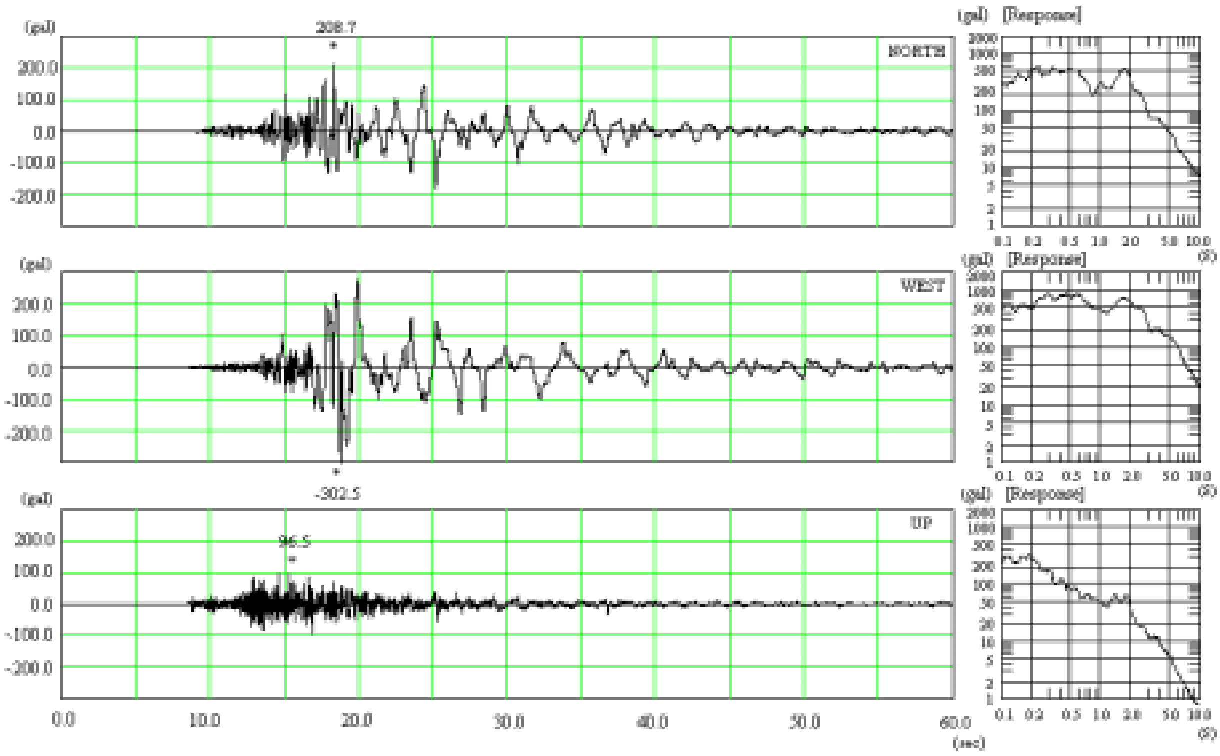


Figure 8 Strong motion records indicating subsoil liquefaction

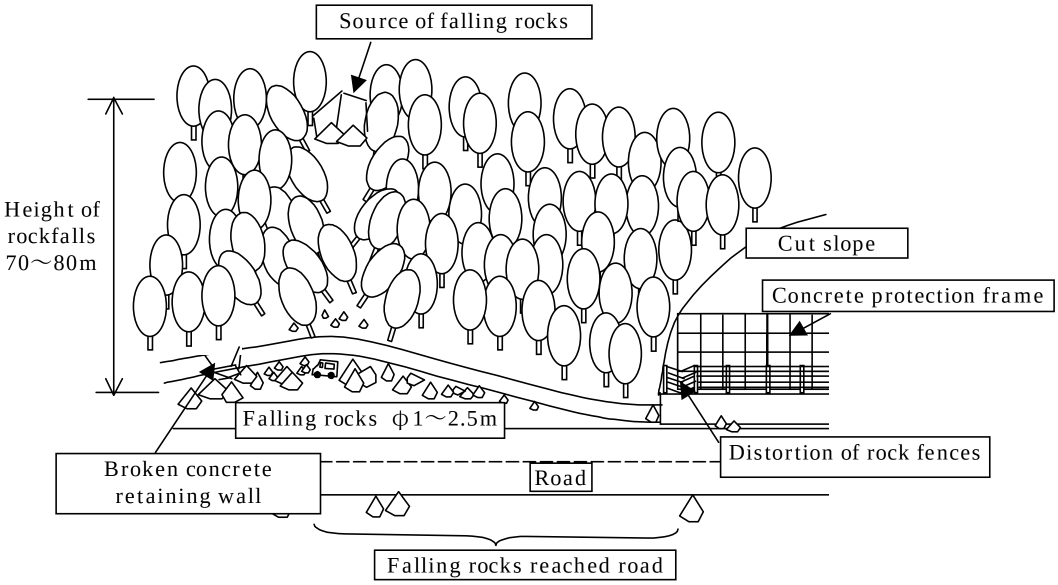


Figure 9 Rocksfalls at Mizoguchi town

Photo 1 Rockfalls at Mizoguchi town

Photo 2 Collapse of girder, Harada bridge, Akantani municipal road of Seihaku town

Photo 3-1 Extensive liquefaction near the Yumeminato bridge

Photo 3-2

Photo 4 Distortion of road shoulder concrete blocks due to ground displacement, near the Yumeminato bridge

Photo 5 Distorted revetment and Yumeminato bridge

Photo 5-2 Extensive amount of sand boiling at Takematsu-gawa (Looking from Yumeminato bridge)

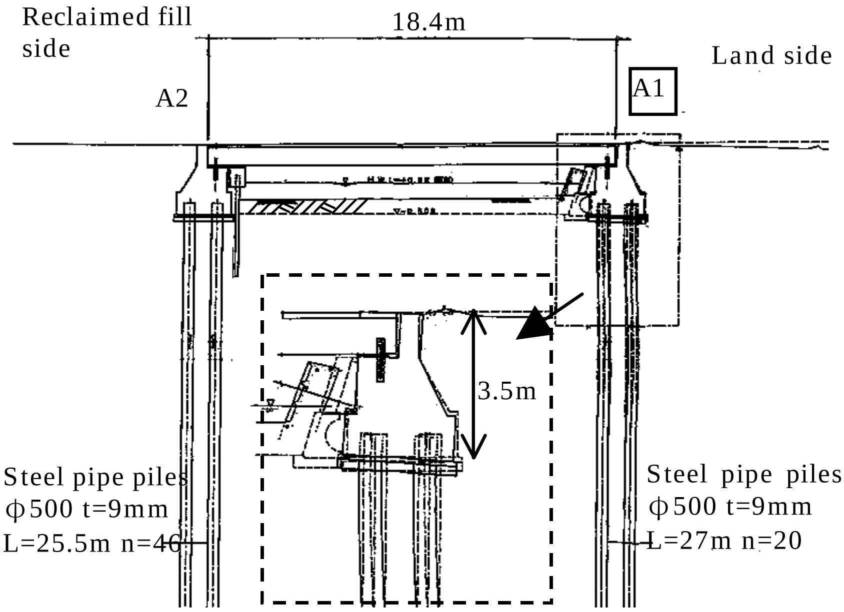


Figure 10 Cross section of Yumeminato bridge and distortion of the A1 abutment (inset)

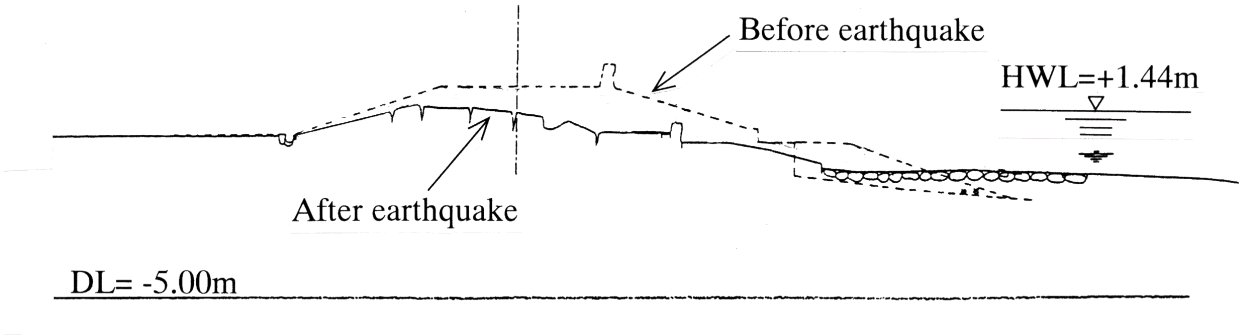
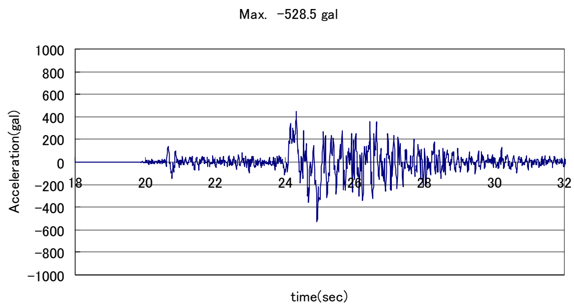
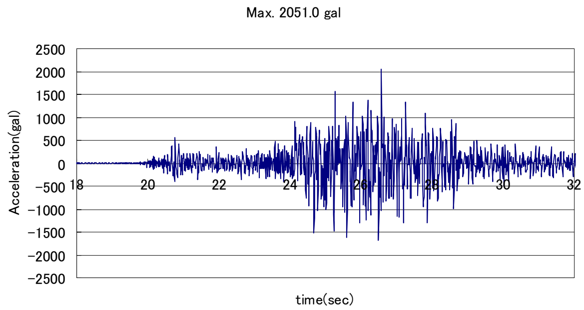


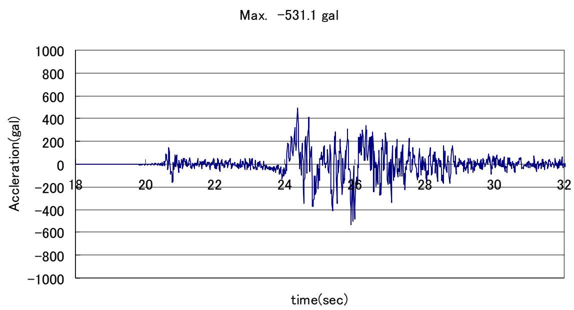
Figure 11 Cross section of the embankment at Yumigahama Reclaimed land

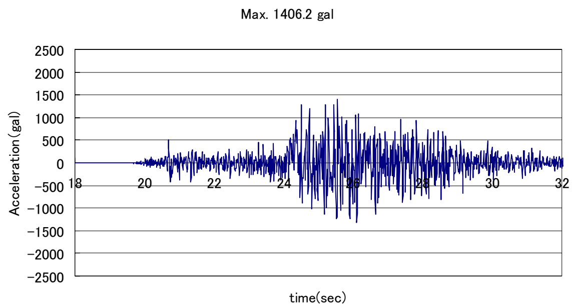
Photo 6　Damage to the embankment at Yumigahama Reclaimed Land



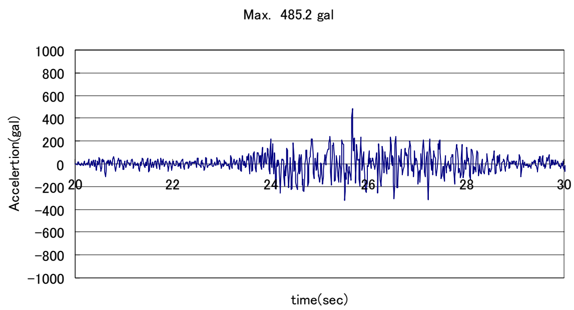


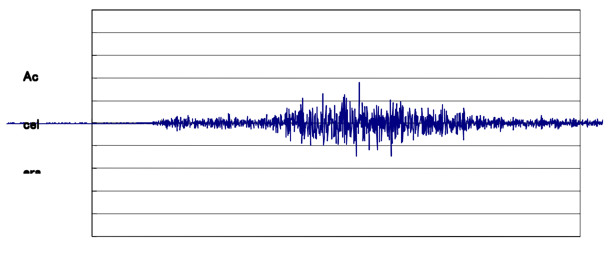
(a) North/south **(a) North/south**





(b) East/west **(b) East/west**





(c) Up/down **(c) Up/down**

(1) Lower Inspection Gallery **(2) Elevator Tower at Crest Elevation**

Figure 12 Strong motion records at the Kasho Dam

Figure 13 Sliding of upstream slope at Kanayatani Irrigation Dam

Photo 7 Settlement of the ground and associated breakage of pipes, Sakai-minato Sewage Treatment Center

Photo 8 Projection of a sewage treatment manhole, Takenouchi Industry Complex