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EFFECTS OF LOCAL SITE CONDITIONS ON LIQUEFACTION DAMAGE IN MIHAMA WARD OF CHIBA CITY

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ABSTRACT: The distribution of liquefaction damage in Mihama ward of Chiba city during the 2011 Great East Japan earthquake was investigated by conducting an exhaustive search for all the public roads and parks immediately after the earthquake. The effects of local site conditions on the damage distribution in the region were examined based on the research, microtremor measurements, the boring logs and the aerial photography.

Key Words: Great East Japan earthquake, liquefaction, reclaimed ground, boring log

INTRODUCTION

The 2011 Great East Japan earthquake (M_W 9.0) that struck the east area of Japan on March 11 caused Tsunami and extensive damage resulting in about 20,000 fatalities. In Mihama ward of Chiba city that is located in the east of Tokyo, more than 300 km away from the epicenter and consists entirely of the reclaimed ground along Tokyo Bay, a huge number of liquefaction damage, such as sand boiling, ground deformation and floor incline of buildings including 21 fully destroyed houses, occurred, and strong motions at the grounds with peak ground accelerations (PGA) of more than 3 m/s^2 were recorded.

Although small sand boiling was found on the main road, narrower streets inside a block were almost completely covered with sand boiling as thick as 45 cm. One of the interesting phenomena, however, is that there are some no-damage blocks right next to heavily damaged blocks.

The objective of this study is to evaluate the effects of the local site conditions on the liquefaction damage distribution in Mihama ward of Chiba city during the 2011 Great East Japan earthquake based on the damage investigation immediately after the earthquake and the boring data.

INVESTIGATION OF LIQUEFACTION DAMAGE DISTRIBUTION

Fig. 1 shows the map of Mihama ward with the districts. Mihama ward is located in the western part of Chiba city along the coast of Tokyo Bay and consists entirely of the reclaimed ground. It was reclaimed by dredge soil consisting of sand or sandy silt from the sea bed of Tokyo Bay sequentially from the southeastern side from 1960s to mid-1980.

A huge number of sand boiling due to soil liquefaction occurred in Mihama ward during the earthquake. Sand boiling was hardly found on the main road and small sand boiling was found at the edge of the asphaltic pavement or the sidewalk of the main road. On the other hand, some narrower streets inside a block were almost completely covered with sand boiling as thick as 45 cm.

The sand which spouted out on the roads was removed by Chuo-Mihama civil engineering office of Chiba city in one week just after the earthquake. The amount of the removed sand reached 8,500 m^3.

The liquefaction damage distribution was surveyed on public roads in Mihama ward immediately after the earthquake from March 12 to 20. The target area of the investigation is all the public roads and parks which could be entered in Mihama ward. The damage of sand boiling is classified into 3 levels ; heavy, minor and none. The case that the overflow area of the sand boiling found in the spot is more than about 1 m is classified as 'heavy'. The case that the overflow area is less than about 1 m is classified as 'minor'. The case that no sand boiling was found is classified as 'none'.

Fig. 2 shows the distribution of sand boiling using 100 m square grids together with the locations of emergency restoration of road conducted by the Chuo-Mihama civil engineering office. White grids mean the areas which could not be entered. Heavy sand boiling and road restoration locations are densely distributed in the coastal area when compared to the inland area. Many spots with minor sand boiling are found in the inland area. The districts where widespread heavy sand boiling was found are Nakase, Hibino, Isobe, Takasu, Takahama and western part of Shinminato shown in Fig. 1. On the other hand, there are some districts where small sand boiling was found in areas such as Utase, the area between Isobe and Takahama and the inland part of Shinminato.

Fig. 3 shows the distribution of liquefaction during the 1987 East-Off-Chiba earthquake (Wakamatsu, 1991) and contour lines of basement depth of alluvial deposit (Kaizuka, 1993). Most of the past liquefaction areas are included by the damage area in Fig. 2. The liquefaction damage area of the earthquake in 2011 is more widespread than that of the past earthquake.

At the districts of Nakase, Hibino, Takasu and Takahama where heavy sand boiling was found, the basement depth of alluvial deposit is deep and the districts are on the valley which is accumulated by thick alluvial deposit. The districts of the northern part of Isobe and the western part of Shinminato where heavy sand boiling was also found are, however, situated on the ridge in the old times presently covered with thin alluvial deposit.

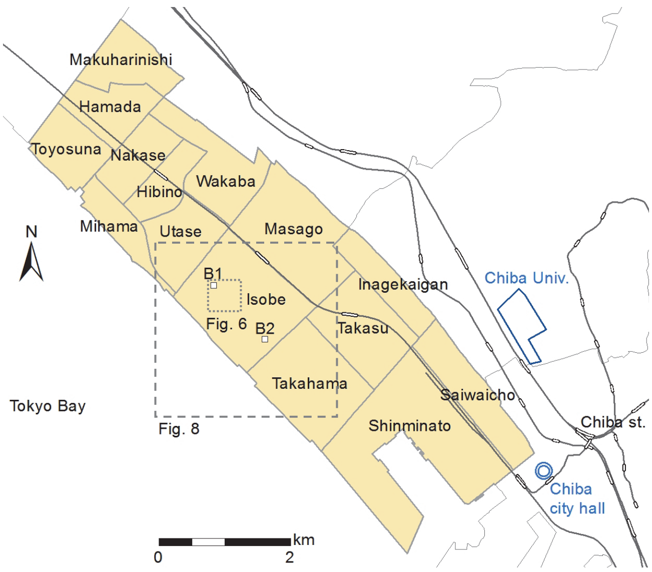

Fig. 1 Map of Mihama ward, Chiba city

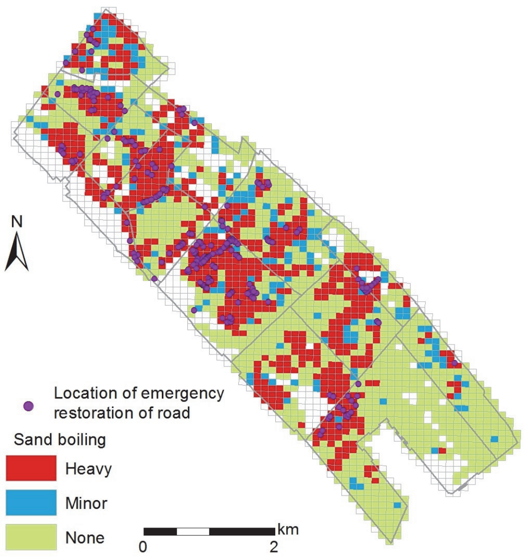

Fig. 2 Distribution of sand boiling

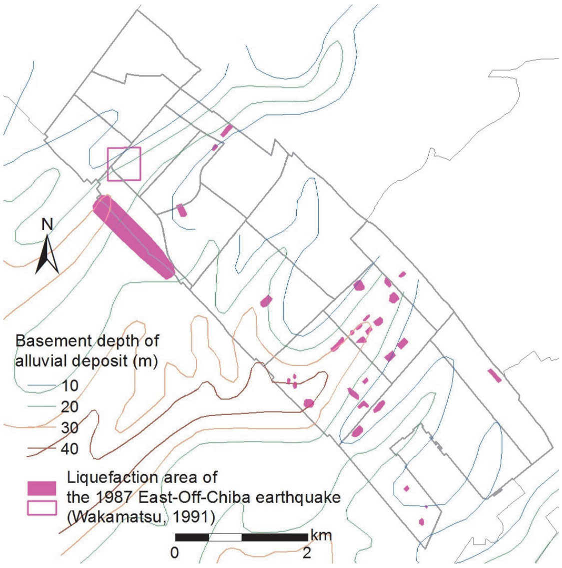

Fig. 3 Map of historical liquefaction sites and contour lines of basement depth of alluvial deposit

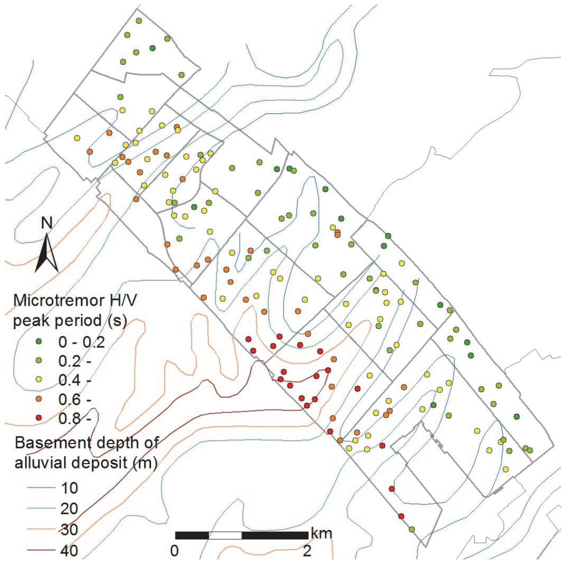

Fig. 4 Distribution of microtremor H/V peak periods

MICROTREMOR MEASUREMENTS

In order to estimate the natural period of the surface soil, microtremor measurements with a three-component sensor were conducted at 163 sites in Mihama ward. Fig. 4 shows the peak periods of H/V spectra calculated from the three component motions of observed microtremor. The peak periods of microtremor H/V spectra are in fairly good agreement with the basement depth of alluvial deposit. The peak periods in the coastal area tend to be longer than those in the inland area. The peak periods at the districts of Nakase, Isobe, Takahama and the western part of Shinminato with heavy sand boiling tend to be longer than those at the other district. In addition the peak periods at Utase district with small sand boiling are short. But small sand boiling was found at the area between Isobe and Takahama in spite of the long peak periods of microtremor H/V spectra.

SOIL PROFILES

Fig. 5 shows the borehole logs at site B1 with heavy sand boiling and site B2 with no sand boiling shown in Fig. 1. The thickness of the reclaimed soil are estimated to be 5 - 10 m at the district. At site B1 with heavy sand boiling whose natural period is estimated to be long from microtremor measurements, fine sand and silt with low *N* values accumulate alternately. At site B2 with no sand boiling whose natural period is also estimated to be long, the surface soil, in contrast, consists of fill soil with *N* value of about 10 and silt with low *N* value with a thickness of 11 m, which is underlain by fine sand with *N* value of more than 10. It seems that this is a reason why the liquefaction damage is different between the two site in spite of the similar peak periods of microtremor H/V spectra.

Longitudinal research using CPT logging was conducted along heavy and less damaged area in Isobe district shown with the area where sand boiling occurred in Fig. 6. Fig. 7 shows the estimated profiles of soil types based on CPT logging at 6 sites. At sites C1 and C2 near the damaged area by sand boiling, sand is predominant to a depth of about 10 m. At sties C3, C4, C5 and C6 with no sand boiling, silt and clay are predominant to a depth of 20 m except for site C4.

The above findings and discussions indicate that the difference in type of surface soil as well as the soil amplification characteristics should significantly have affected the difference in liquefaction damage in Mihama ward during the Great East Japan earthquake.

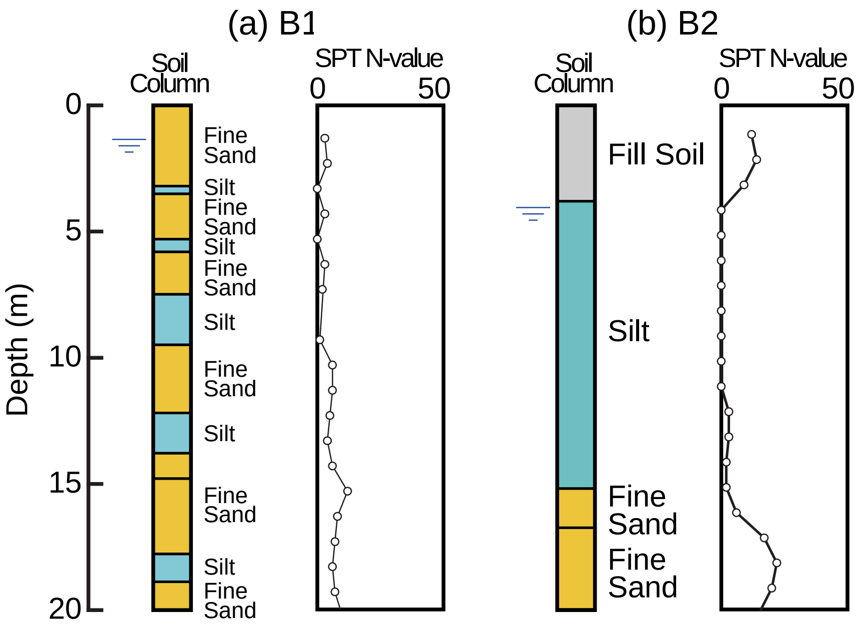

Fig. 5 Boring logs in Isobe district

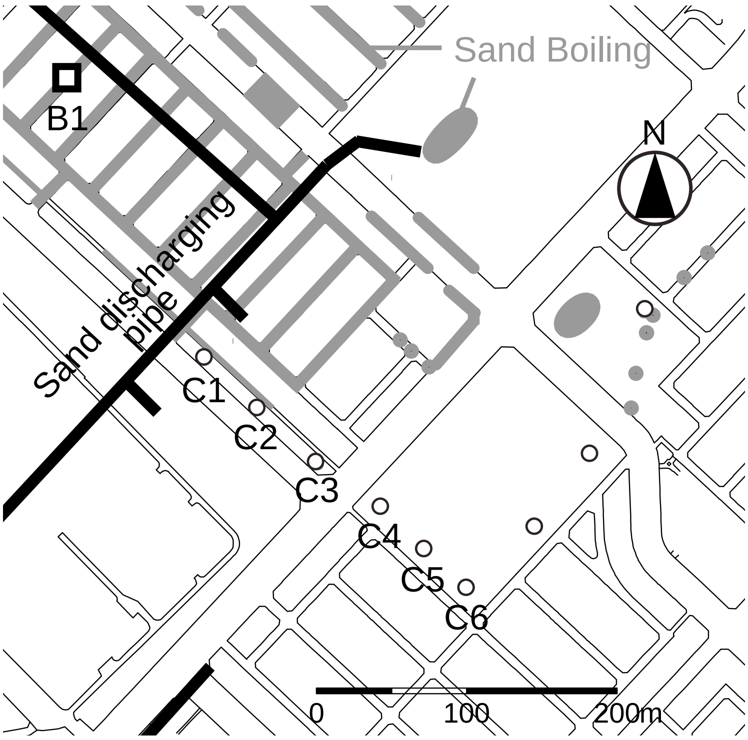

Fig. 6 Locations of sand boiling, CPT logging and sand discharging pipe in Isobe district

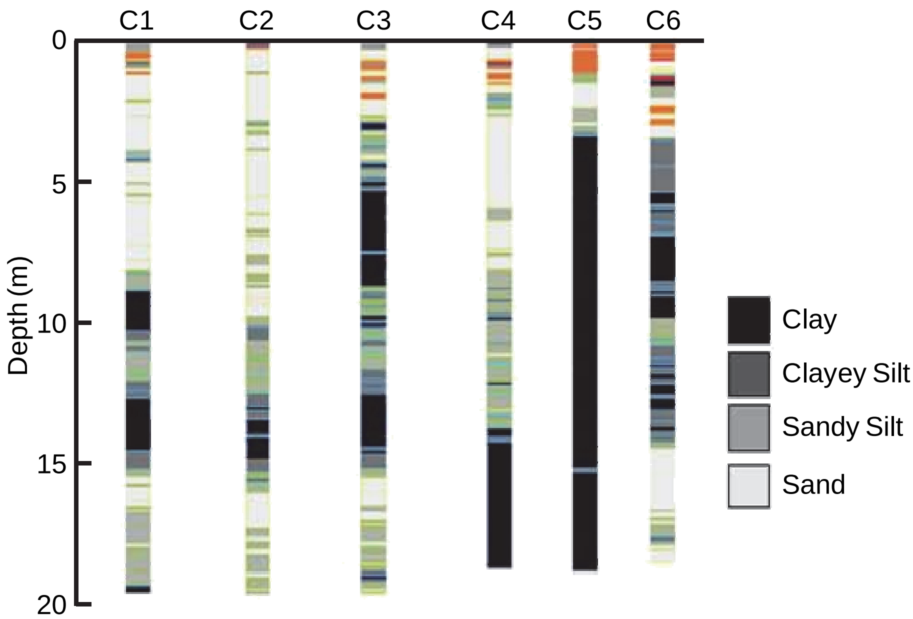

Fig. 7 Estimated soil profiles based on CPT logging

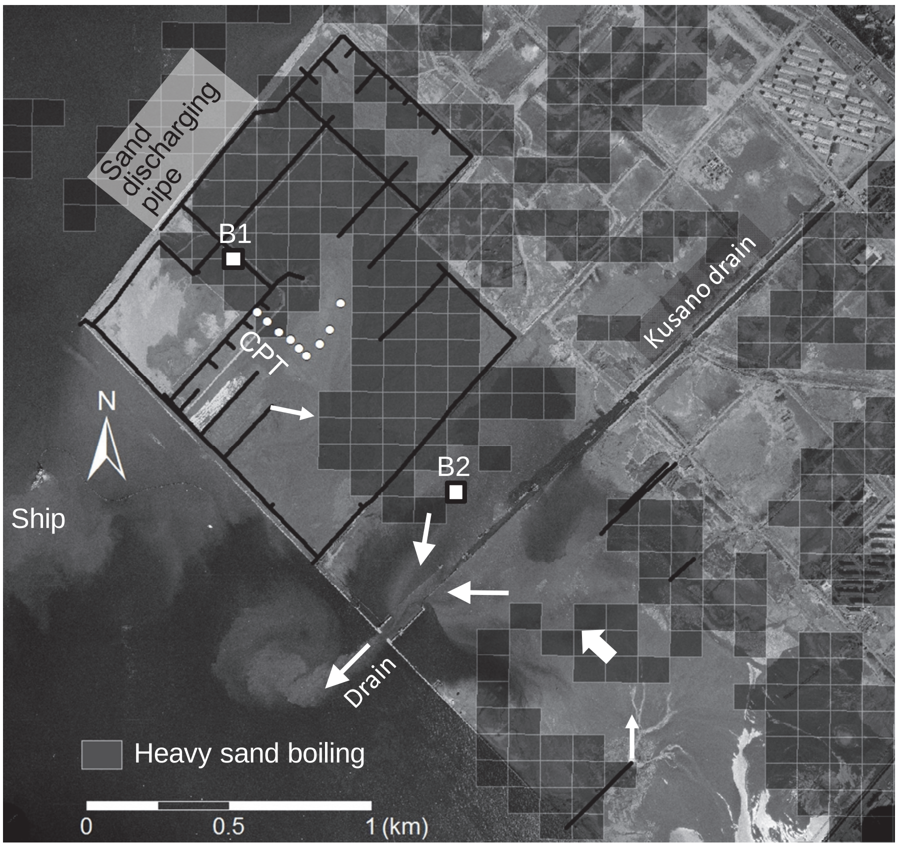

Fig. 8 Aerial photography of Isobe and Takahama district at the time of land reclamation in 1972, showing sand discharging pipes

EFFECTS OF METHOD OF LAND RECLAMATION

The sand pump method was used for reclaiming the land in Mihama ward, pumping the dredge soil consisting of sand and sandy silt taken from the sea bed of Tokyo Bay through sand discharging pipes. In this method, sand with low fine-grain content accumulates near the supply outlets of the sand discharging pipes, and silty sand with high fine-grain content accumulates in the area which is far from the outlets. Therefore it seems that it is likely to occur liquefaction near the outlets.

Fig. 8 shows the aerial photography of Isobe and Takahama district shown in Fig. 1 at the time of land reclamation in 1972. The sand discharging pipes are found in this photography and are indicated by black lines. The pipe layout are also indicated in Fig. 6. In Fig. 6, the sand boiling damage is found near the pipes such as sites C1 and C2. In Fig. 8, sites C3 and C4 whose surface soil mainly consist of silt are located between the pipes.

There is a drainage canal called Kusano canal that runs between Isobe and Takahama district crossing the reclaimed ground from landside to Tokyo Bay shown in Fig. 8. The surplus water which was pumped with the dredge soil was drained away through Kusano canal to Tokyo Bay. There are storage reservoirs which precipitate fine graces in the drained water at the both side of Kusano canal. It seems that site B2 whose surface soil mainly consists of silt is located in the reservoir.

From the above findings and discussions, it is possible to indicate that the distance from the sand discharging pipes might have affected the distribution of liquefaction damage in Mihama ward by the Great East Japan earthquake.

CONCLUSIONS

The distribution of liquefaction damage in Mihama ward of Chiba city during the 2011 Great East Japan earthquake was investigated by conducting an exhaustive search for all the public roads and parks. The effects of local site conditions on the damage distribution in the region were examined based on the research, microtremor measurements, the boring logs and the aerial photography. Based on the results and discussions, the following conclusions may be made:

1. Sand boiling occurred again at places where it occurred during the past earthquake in 1987.
2. The difference in type of surface soil as well as the soil amplification characteristics should significantly have affected the difference in liquefaction damage.
3. The distance from the sand discharging pipes might have affected the distribution of liquefaction damage.

ACKNOWLEDGMENTS

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