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RELATIONSHIP BETWEEN AGE OF GROUND AND LIQUEFACTION OCCURRENCE IN THE 2011 GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: Significant damage was caused in the northern part of the Tokyo Bay by soil liquefaction in 2011 Great East Japan Earthquake. The areas where boiled sands due to liquefaction were observed extensively were distributed mainly in recently reclaimed land. Therefore, this research gathered amount of data on boring conducted in Kanto region and relationships between occurring of liquefaction and SPT N-values were organized. As the result some differences between recently reclaimed land and, reclaimed land in old time or natural bed ground were confirmed.

Key Words: liquefaction, reclaimed land, age of ground, Great East Japan earthquake

INTRODUCTION

Sand boils and water gushing due to liquefaction occurred in extended areas of reclamation grounds in the northern part of the Tokyo Bay and the downstream section of the Tone River in the Great East Japan earthquake. Especially in the northern part of the Tokyo Bay amount of boiled sand and gushing water interfered with the lives of residents and many private houses, sewage manholes, pipes and etc. were damaged due to liquefaction (JGS 2011, etc).

The damage was mainly caused on the east side of the northern part of the Tokyo Bay, Chiba prefecture. Areas where liquefaction occurred in the earthquake are limited to mainly reclaimed land.

In other hand, areas where liquefaction occurred in the west side of the northern part of the Tokyo Bay, Tokyo Metropolitan, were quite smaller than the east side, although reclamation works have been conducted after the 16th century in the west side. These areas were limited the reclaimed land beside the coast.

A point in common between the reclaimed land where liquefaction was observed in the east and in the west was recently reclaimed land after the Showa era (after 1926). Therefore, it is pointed out that young grounds are likely to have a smaller resistance against liquefaction and, old grounds and natural grounds are likely to have a stronger resistance.

Koseki and Ohta (2001) reported that liquefaction resistance is influenced by the aging of the sample based on element tests. But, the mechanism of improvement of liquefaction resistance due to aging has not been clarified sufficiently.

In this research amount of data on boring conducted in Kanto region was collected, and relationships between occurring of liquefaction in the earthquake and SPT N-values were organized. In addition, a map showing distribution of thickness of liquefiable sandy soil created in order to be applied to future investigation will be introduced.

COLLECTION OF DATA ON BORING

A total of 173 pieces of data on boring was gathered from the locations shown in Fig. 1. These data were collected based on the following perspectives.

a) In the Kanto Region, locations with liquefaction in the northern part of the Tokyo Bay where the occurrence of liquefaction was significant and nearby areas without liquefaction
b) Among river levees damaged chiefly by liquefaction, such as the downstream section of the Tone River and along the Kokai River and the Naka River, locations where a boring investigation was conducted after the earthquake
c) Other locations around the Kanto Region

The existence of liquefaction was determined based on the investigations by the Kanto Regional Development Bureau and the Japanese Geotechnical Society. Furthermore, the investigations were based on the traces of sand boils and water gushing.

In addition, the following conditions were applied when selecting data on boring from the above sites.

d) A sand layer which will be the target of a liquefaction evaluation is present.
e) The data must represent its area, meaning that multiple pieces of data on boring with similar soil layer configurations from nearby areas should not be selected.
f) The depth of boring is sufficient, and the groundwater level is recorded. Even when the selected boring does not clarify that the liquefaction layer is not located at a deeper location than the depth of boring, the data is accepted if the investigations on boring conducted in nearby areas confirm such a condition. The same rule applies to the groundwater; the data is accepted if the groundwater level can be estimated based on boring investigations conducted in nearby areas.
g) The period of reclamation is roughly known (Endoh 2004, etc.).

The data on boring is provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) Kanto Regional Development Bureau as well as the Civil Engineering Center of the Tokyo Metropolitan Government, Water quality Division of the Chiba Prefectural Government (Information bank), and Public Works Department of the Chiba Prefectural Government. Some of them are organized into a database and made available to the public.

Table 1 shows the number of boring sites at each period of reclamation. One fourth of the sites were located in the area where liquefaction was observed. The numbers does not make much sense because the data on boring is collected as described above.

Table 1 The number of boring sites at each era

	Number of boring sites		
		With liquefaction	Without liquefaction
Natural ground	61	9	52
Old reclaimed land until 1925 (Edo, Meiji, Taisyo era)	29	3	26
Recent reclaimed land after 1926 (Showa era)	83	34	49
Total	173	46	127

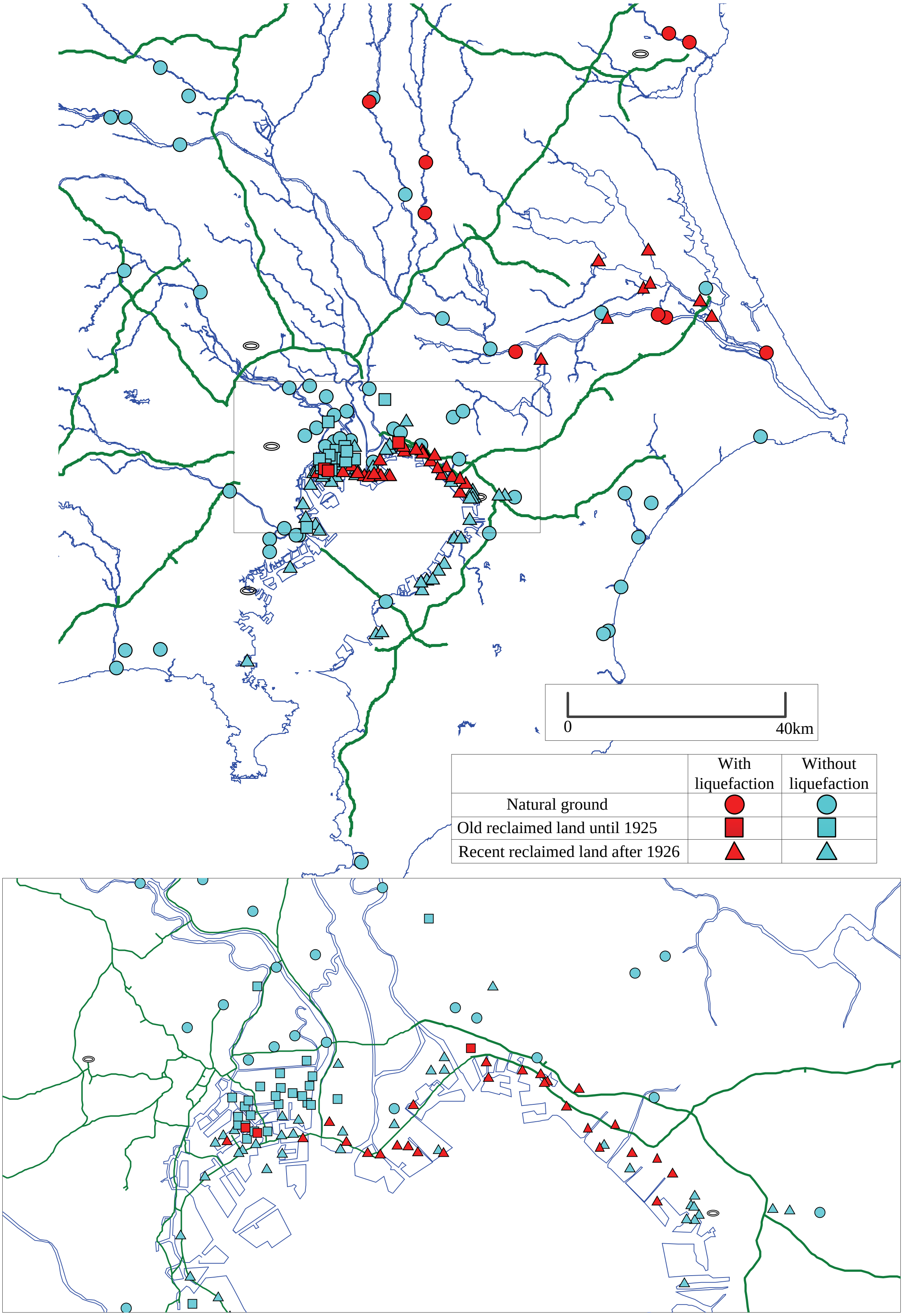

Fig. 1 Locations of the collected data on boring

RELATIONSHIP BETWEEN SHEAR STRESS RATIO AND CONVERTED N VALUE

A relationship between maximum shear stress ration during the earthquake and N-value converted to correspond to effective overburden pressure of 98 kN/m^2 was organized. The maximum shear stress ration, L was obtained by the following equation from Specifications for Highway Bridges (2002).

$$L = \gamma_d k_{hg} \sigma_v / \sigma_v' \quad (1)$$

where, γ_d is reduction coefficient in the depth direction of the shear stress ratio and k_{hg} is horizontal seismic coefficient at the ground surface.

The maximum acceleration distribution (Kataoka 2011) produced based on strong motion observation records of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Japan Meteorological Agency, and the National Research Institute for Earth Science and Disaster Prevention normalized by the gravitational acceleration was used as the horizontal seismic coefficient.

Set of L and N_1 is obtained at each depth from one boring site. The existence of liquefaction is evaluated based on the existence of trace of sand boils or water gushing; thus, liquefaction is likely to have occurred at a relatively shallow sand layer. In addition, if liquefaction is contained within a limited thin layer, the event is not likely to result in sand boil or water gushing. Therefore, the second smallest N_1 and L at the depth where N_1 was the second smallest up to a depth of 10m was extract from a boring site.

The relationship between maximum shear stress ration and converted N-value was shown in Fig. 2. Black curved lines in these graphs are the relationship between cyclic triaxial strength ratio, same as liquefaction resistance, and converted N-value at fine contents of 0 % to 10% that was stipulated in Specifications of Highway Bridges. A point above the curved line was labeled as having liquefaction in liquefaction assessment. Therefore, it is to be desired that the curved line locates at the border

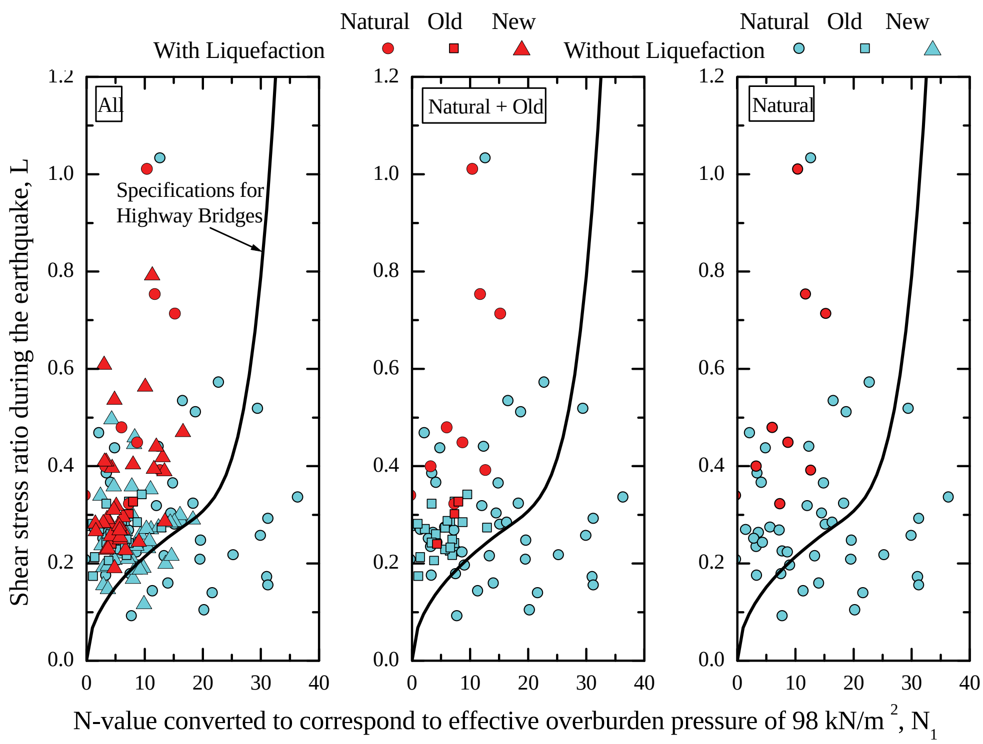

Fig. 2 Relationship between the shear stress ratio during the earthquake at each fine-grained fraction and converted N values Locations of the collected data on boring.

between the points with liquefaction and without liquefaction (Seed 1971). But, if the line envelopes the points with liquefaction at least, the relationship could evaluate liquefaction resistance in safety side.

All points were plotted in the left graph. Some points with liquefaction located above the curved line in the range between shear stress ratio of 0.2 and 0.3. Points except recently reclaimed land were plotted in the center graph. In the center graph, some points with liquefaction locating above the curved line in the left graph were erased in the center graph. It means that liquefaction of old reclaimed land and natural ground needs stronger shear stress ratio than recently reclaimed land. Therefore, it is cleared that old reclaimed land and natural ground have higher liquefaction resistance than recently reclaimed land.

In order to evaluate the influence of age of ground to liquefaction, additional ground surveys and elemental tests are necessary. A map of Koto city in Tokyo Metropolitan as shown Fig. 3 was prepared for future ground survey. In Koto city, reclamation works starts from the 16th century, and sand boils were observed in this earthquake and the Great Kanto earthquake of 1923. Total thicknesses of liquefiable sand layer and silty sand layer up to depth of 10m at boring sites were summarized in Fig.

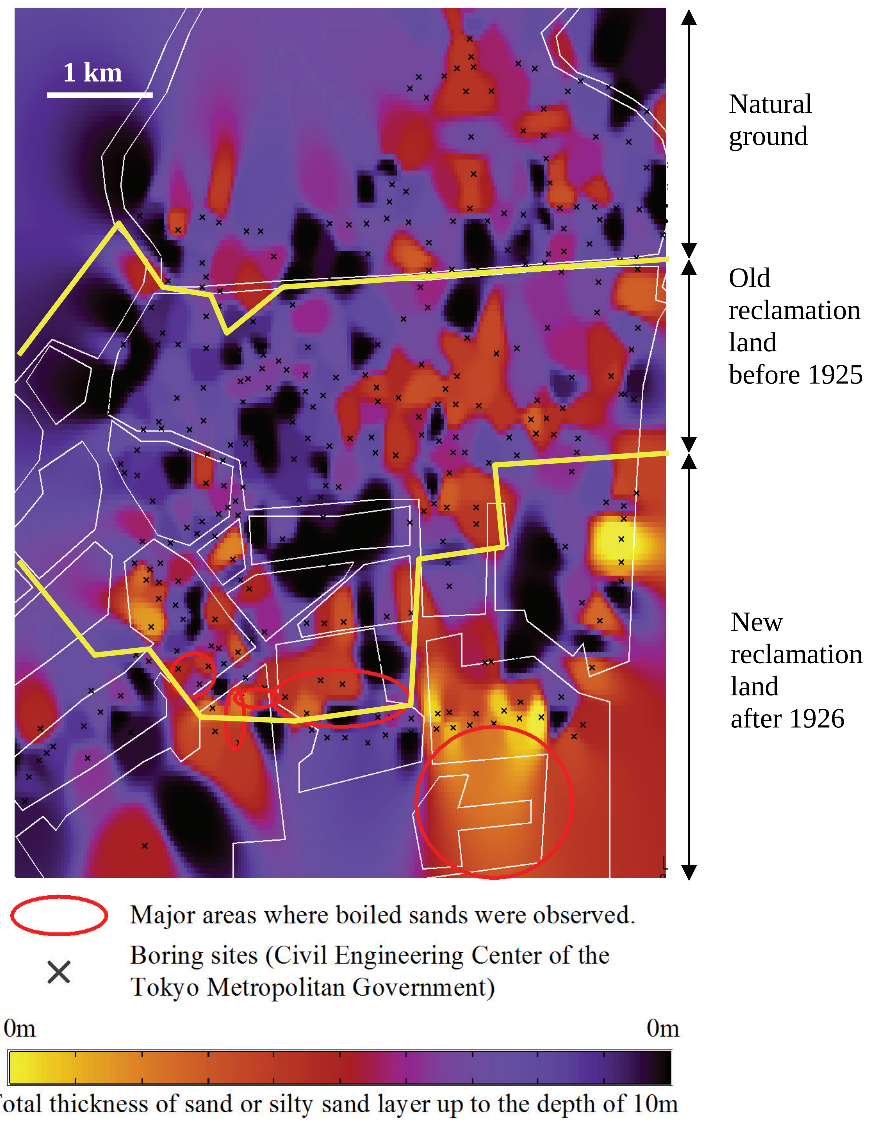

Fig. 3 Map of Koto City in Tokyo Metropolitan showing the total thickness of sand or silty sand layer up to the depth of 10m at the boring site

3. Amount of data on boring was gathered from web site of the Civil Engineering Center of the Tokyo Metropolitan Government. But Fig. 3 looks like a contour map, the interpolation between boring sites makes no sense. The color at the boring sites is important.

Area circled with red line at the bottom and right was area where the most severe liquefaction in Koto city was observed. The liquefiable layer in the area was thicker than other area. Hence, it is considered that the existence of liquefaction was influenced by thickness of the liquefiable layer as well as the liquefaction resistance. Incidentally, distribution of thickness in Fig. 3 was complex. It is likely to be a result of the complex history of reclamation works (Endoh 2004). Because scale of reclamation works in the old period was very small, there is a possibility that reclamation material and method changed every time. Therefore, locating of the ground survey is very important.

CONCLUSIONS

Amount of data on boring conducted in Kanto region was collected, and relationships between occurring of liquefaction in the earthquake and SPT N-values were organized. In addition, a map showing distribution of thickness of liquefiable sandy soil created in order to be applied to future investigation will be introduced.

a) It is cleared that old reclaimed land and natural ground have higher liquefaction resistance than recently reclaimed land.

b) It is considered that the existence of liquefaction was influenced by thickness of the liquefiable layer as well as the liquefaction resistance.

c) In order to evaluate the influence of age of ground to liquefaction, additional ground surveys and elemental tests are necessary. Because of the complexity of the ground, locating of the ground survey is very important.

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