Preliminary Report on Disasters Observed in Narashino City due to Liquefaction During Great East Japan Earthquake

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ABSTRACT:
During 2011, 11th of March, Tohoku off Pacific Ocean Earthquake, the reclaimed land area of Narashino City, Chiba Pref. in Japan, located at the north part of the Tokyo Bay was heavily damaged due to the sand liquefaction. The maximum subsidence of ground was about 30 to 40 cm, and about five thousand houses were settled and inclined. Following conclusions were obtained temporarily in this study. ①There is no difference in the degree of damage of houses due to sand liquefaction between the first period and second period of reclaimed lands. ②The major factors to cause sand liquefction of the reclaimed land area are high ground water table and the loose surface fill layer of sand with SPT N-value lower than ten. ③In the non-reclaimed area, damaged areas of houses almost agree with the areas of old river or valley, and most of damage was caused by large deformation of foundation soil consist of embankment.

Keywords: Sand, Liquefaction, Reclaimed land, Settlement,enbankment

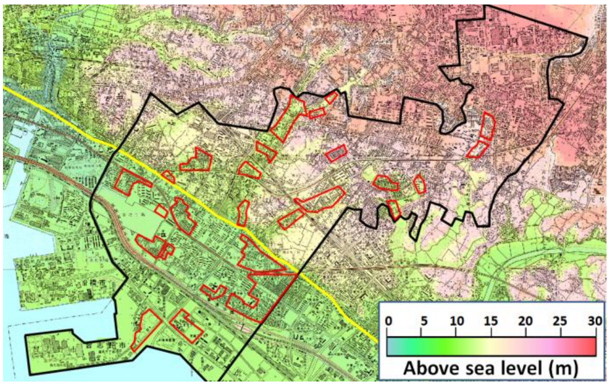
1. INTRODUCTION

During 2011, 11th of March, Tohoku off Pacific Ocean Earthquake (Great East Japan Earthquake) with a magnitude of 9.0, the reclaimed land area of Narashino City, Chiba Pref. in Japan located at the north part of the Tokyo Bay, even far from the hypocenter of the earthquake, was seriously damaged due to sand liquefaction. About five thousand houses were settled and inclined. The severe damage to sewer pipes and rainwater drainage system, manholes uplifted high above road surfaces, destruction of road and settlement of electric poles were observed. The houses in the north area of the city, where is not the reclaimed land, were also damaged mainly caused by the large deformation of foundation soils due to earthquake ground motions. This paper reports ①the outline of the damage mainly observed in the residential areas, ②the soil profile and SPT N-value of reclaimed areas, ③the causes of damage of houses occurred both in reclaimed land and in non-reclaimed land. ④the applicability of the simplified procedure proposed by Architectural Institute of Japan (AIJ) to evaluate the liquefaction potential and the settlement of the foundation soils due to sand liquefaction by comparing the calculation results with observations.

2. LOCATION OF NARASHINO CITY

Narashino city locates at the north coastal area of Tokyo Bay as shown in Figure 1. Narashino city consists of two regions, an area south of Route 14 (indicated in a yellow line in Figure 2) is an artificially reclaimed land, and north part is a natural deposit as shown in Figure 2. The land height of the city above sea level of Tokyo Bay (TP) is indicated by color in Figure 2. The height of the reclaimed area is almost lower than five meters above sea level. The areas enclosed with a red line in Figure 2 show the areas of houses damaged due to Great East Japan Earthquake. The damage was investigated and clarified based on the inclination of houses, and reported by Narashino city [1).

Figure 1. Location of Narashino city in Japan



—Major damaged area — City boundary — Route 14

Figure 2. Major damaged area of houses in Narashino city

3. CONSTRUCTION AND SOIL PROFILE OF RECLAIMED LAND

Figures 3 (a) and (b) are aerial photographs showing the reclamation of sea south of the Route 14. The reclamation was peformed in two periods, the first period of reclamation (Sodegaura area, 94 ha) was conducted between 1964 and 1966, and the second period of reclamation (Akitsu, Kasumi, Shibazono and Akanehama areas, 503 ha) was done during 1971 and 1977. The interval between two periods of reclamation is about 10 years. The maximum sea depth in the reclaimed area is about 4 to 5 meters.

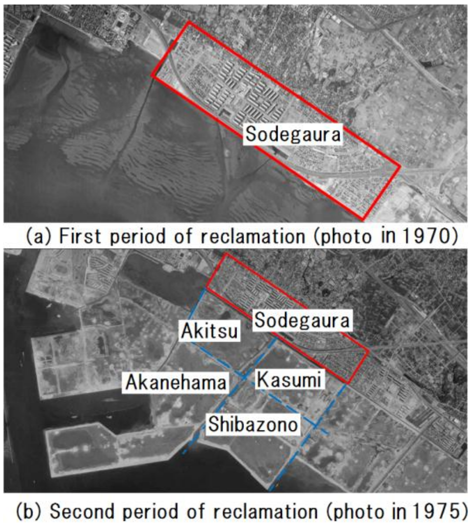


Figure 3. Aerial photographs of reclaimed land

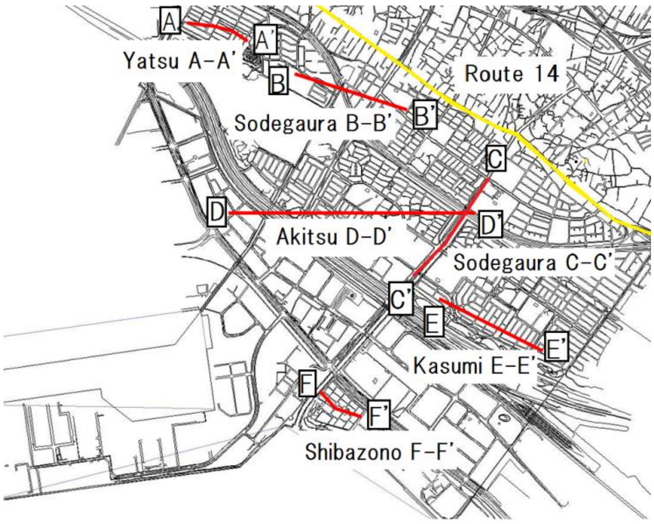


Figure 4. Location of cross sections at reclaimed land

In order to investigate the soil profile of the reclaimed land, soil investigation at twelve points was newly performed by Narashino city, and the existing boring data in this area were also gathered in this study. Figures 5 to 10 indicate cross sections showing soil profiles with SPT N-value. Figure 4 shows the locations of these cross sections. In these cross sections, ground height (TP), soil profile and SPT N-value, and ground water level (blue lines in all figures) are shown. As shown in Figures 5 to 10, the height of the reclaimed land is about 2 to 5 meters higher than the average sea level of Tokyo bay. The thickness of the reclaimed soil layer is about 2 to 4 meters. The ground water level is about 1 to 3 meters from the ground surface. Beneath the surface fill layer, there is a loose alluvial soil layer with SPT N-value almost lower than 10, but its thickness differs in places.

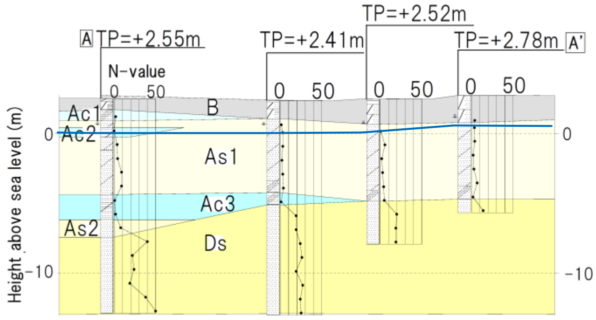


Figure 5. A-A'cross section at Yatsu district

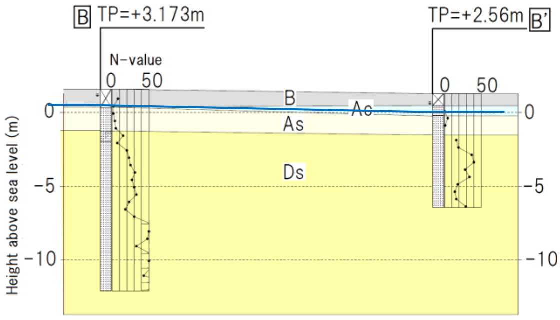


Figure 6. B-B'cross section at Sodegaura ditrict

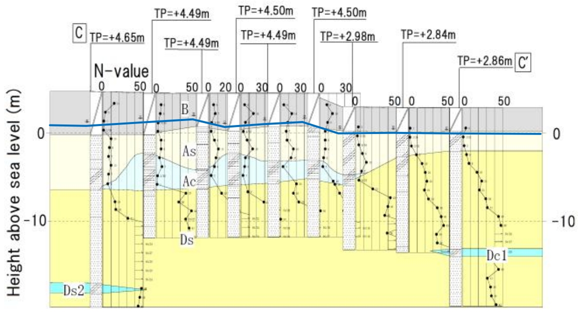


Figure 7. C-C'cross section at Sodegaura distict

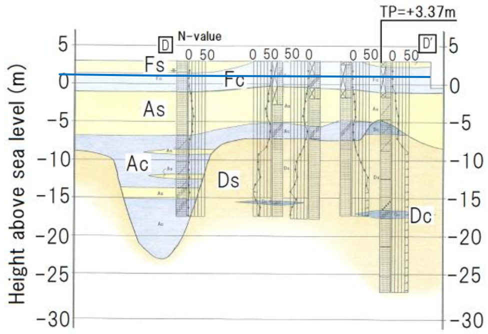


Figure 8. D-D'cross section at Akitsu disrict

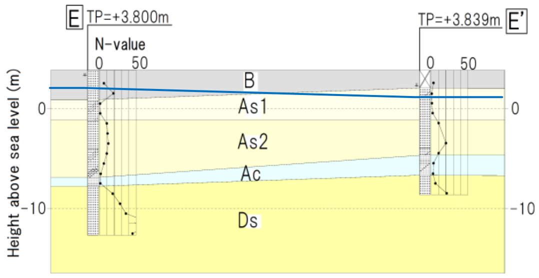


Figure 9 E-E'cross section at Kasumi district

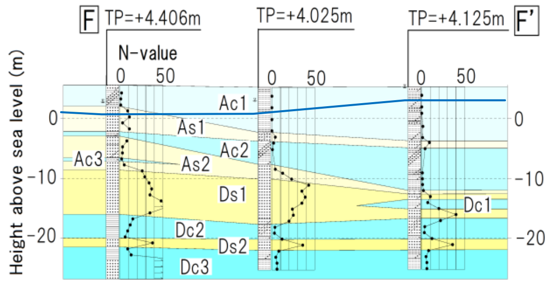


Figure 10 F-F'cross section at Shibazono district

3.2 SAND LIQUEFACTION AND DAMAGE OBSERVED

Figure 11 shows a moment of sand volcano occurred just during the Great East Japan Earthquake at Akanehama district. A large amount of sand spread can be seen. Figure 12 indicates a large amount of sand spread over the road and many electric poles were settled and inclined at Sodegaura district. Figure 13 shows a two-story wooden house settled and seriously tilted, and it was not able to live after the earthquake. Figure 14 also indicates a sand spread and an inclined wall at Kasumi. Figure 15 shows the destruction of a side ditch at Sodegaura district. Figure 16 indicates the distribution of the damaged houses in residential area of reclaimed land obtained in the first damage investigation performed by Narashino city. The degree of damage of houses was clarified in three categories, heavily damaged, half damaged, and partially damaged, only based on the inclination of the houses.

Figure 11. The moment of sand volcano at Akanehama district (photo by Kunikyo)

Figure 12 Sand spread over the road and inclined electric poles at Sodegaura district

Figure 13. Settlement and inclination of a house at Kasumi district

Figure 14. Sand spread and an inclined wall at Kasumi district

Figure 15. Damage of side ditch along the road at Sodegaura district.

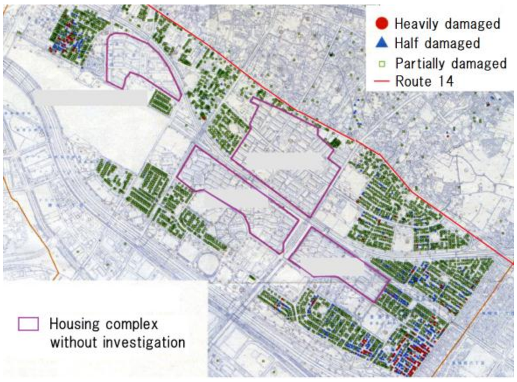


Figure 16. Distribution of damage of houses in reclaimed area investigated by Narashino city

As shown in Figure 16, the major heavily damaged houses (red circles) located on both the first and second reclamation lands. This result implies that such a short interval of about 10 years has little effect on the liquefaction strength of the reclaimed land.On the otherhand, even in the area constructed in the same period of recalamation, there is a big difference in the degree of damage of houses, depnding on the locations as shown in Figure 16. This result suggests that, not the duration after the completion of the reclamation, but the method and the soil materials used for reclamation may have more significant effect on the liquefaction strength of these reclaimed land. However, there is no detail data about them now. The local difference in the depth of the ground water table, thickness and compactness of the fill layer may have siginficant effects on the occurrence of the liquefaction. As a result, it needs more data on soil profile to analyze the difference in the degree of damage for indivisual houses.

3.3 A CASE STUDY TO INVESTIGATE THE GROUND SETTLEMENT DUE TO SAND LIQUEFACTION AT AKANEHAMA DISTRICT

In the residential area of reclaimed land, most of the damaged houses have spread foundation. In these cases, both the houses and foundation soils settled. As a result, it is very difficult to exactly determine the subsidence of foundation soils induced by the sand liquefaction. In this section, a case study on a reinforced concrete building with pile foundation was performed. There was no damage of this building because it is supported by pile foundation. However, surrounding ground was liquefied. The subsidence of the ground can be determined as 5 to 10 cm based on the level difference between the building and the surrounding ground, as shown in Figure 22. The settlement of surrounding ground was also estimated by using the simplified procedure introduced in 「Recommendations for Design of Building Foundations」 proposed by Architectural Institute of Japan. The applicability of the simplified procedure was investigated by comparing the calculation results with observations. Figure 17 shows the locations of ground settlement measurements (M1 point and M2 point) and the boring logs around these points (No.1 to No.4). The soil formation, soil properties with SPT N-value of boring No.1 to No.4 are indicated in Figures 18 to 21. The magnitude of the earthquake was assumed to be 9.0 for calculation same as the Great East Japan Earthquake. The maximum ground acceleration was assumed to 175 gal based on the accelerations recorded around Narashino city. The calculation results of ground settlement are listed in Table1 with the observations. In this method of calculation, the ground settlement was estimated based on the factor of safety against liquefaction and its distribution with depth. As shown in Figures 18 and 19, the ground water level at M1 point is about 2.0m from the ground surface, it is high. The SPT N-value of the top sand fill layer to a depth of about 6.0m from the ground surface is much less than 10, and even the alluvial sand underlain the sand fill has a N-value lower than 10. As a result, the ground subsidence was estimated to be 6.5 cm to 7.5 cm. This value of subsidence almost agrees with the observed value of 5 cm to 10 cm as shown in Figure 22. On the other hand, at the point M2, even though many large cracks were observed as shown in Figure 23, the subsidence of the ground is only 1cm to 2 cm. This small value of subsidence almost agrees with the estimation. The difference of ground subsidence between point M1 and M2 can be explained by the difference in the depth of the ground water table and the soil properties of top soil layers. As shown in Figures 18 and 19, the ground height at M2 point is about 3 to 5 m higher than that at M1 point. This is due to the additional embankment ("Em" layer) at point M2 for constructing athletic ground at M2 area. As a result, the ground water table at M2 point is much lower than M1 point. Moreover, the additional embankment consists of cohesive soil (loam), which is a non-liquefiable soil.

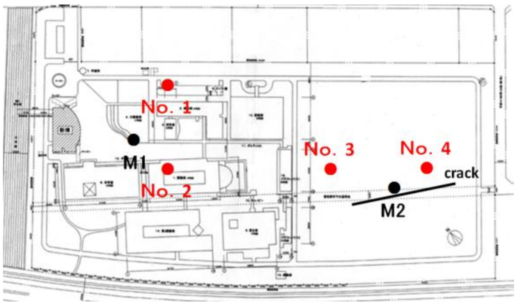


Figure 17. Locations of ground subsidence measurements and soil investigation

Table 1. Comparison of observed ground subsidence with estimation

Location	Subsidence of ground in cm	
	Estimation	Observation
No.1	7.5	5～10
No.2	6.5	
No.3	0.5	1 ～2
No.4	0.0	

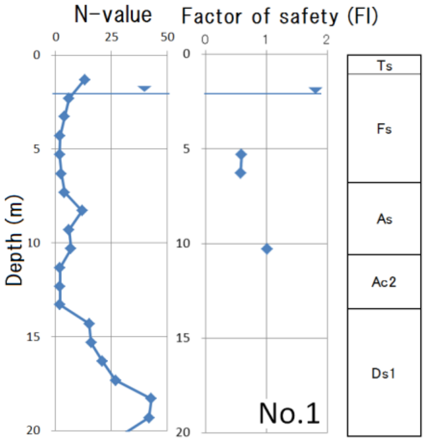


Figure 18. Soil profile, N-value and factor of safety against liquefaction (No.1)

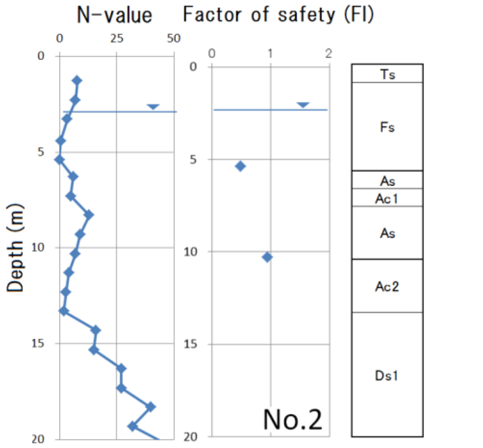


Figure 19. Soil profile, N-value and factor of safety against liquefaction (No.2)

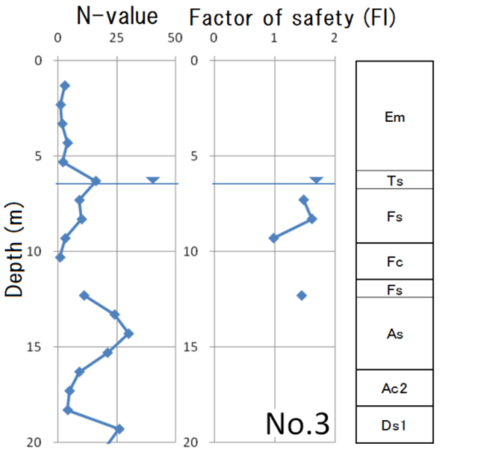


Figure 20. Soil profile, N-value and factor of safety against liquefaction (No.3)

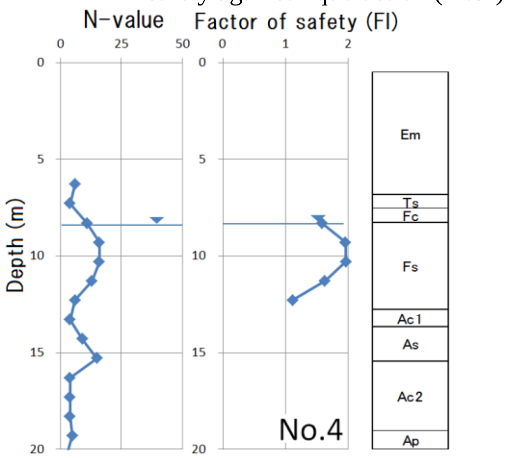


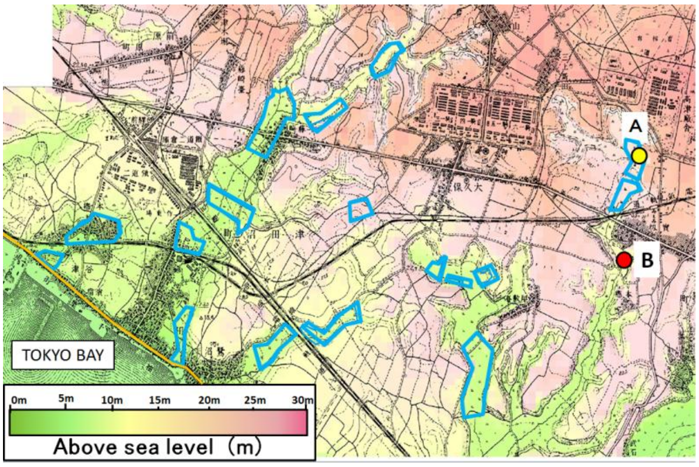
Figure 21. Soil profile, N-value and factor of safety against liquefaction (No.4)

Figure 22. Subsidence of ground at M1 point

Figure 23.Ground cracks with little sand spread at M2 point

4. DAMAGE IN NORTH REGION OF NON-RECLAIMED AREA

The major damaged area of houses in northern region of Narashino City (17 areas enclosed by blue lines in Figure 24) based on the first investigation performed by Narashino city were plotted on the old map of 1917. At that time, south of the Route 14 is still a sea. It is clearly shown in Figure 24, the damaged area well agrees with the area of old river and valley, such kinds of ground often consist of loose soil layers with high ground water level. The damage was also investigated in the present study about six months after the earthquake. In 17 areas unlike the southern region of reclaimed land, most of houses were damaged due to the deformation of foundation soils caused by the earthquake ground motions. Figure 25 shows such a case of damaged foundation of a two-story wooden house constructed on the embankment (Point A). Figure 26 shows the soil profile and the SPT N-value of this site. As shown in Figure 26, the surface soil layer to a depth of about 5 meter from the ground surface consists of soft cohesive soils, which is not a liquefiable soil but has a high possibility to deform. Moreover, the underlain sand layer has high SPT N-value of about 20. This alluvial sand layer is also a non-liquefiable soil layer, and it may transfer strong ground motion to the surface soil layer. Only a few houses damaged due to sand liquefaction in natural soil deposit area were observed. Figure 27 shows such a case of ground subsidence (Point B). The maximum subsidence of the ground surrounding a one-story wooden house with pile foundation due to sand liquefaction is about 40 cm as shown in Figure 27. Figure 28 indicates the soil profile and the SPT N-value at this site. The subsidence of ground estimated by using the simplified procedure is about 10 cm, which is smaller than the observation results. In this case, the shallow ground water table (GL:-1.5m) and about 4 m in thickness of the loose surface sand layer are the major factors to cause large amount of subsidence.



Liquefaction   Soil deformation   —Damaged area   — Route 14

Figure 24. Major damaged area of houses in natural soil deposit area north of Route 14

Figure 25. Defornmation of Foundation soil and damage of foundation (point A)

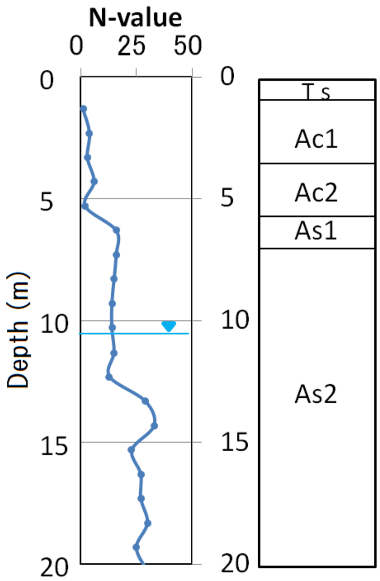


Figure 26. Soil profile and SPT N-value at point A

Figure 27. Subsidence of ground due to liquefaction at point B

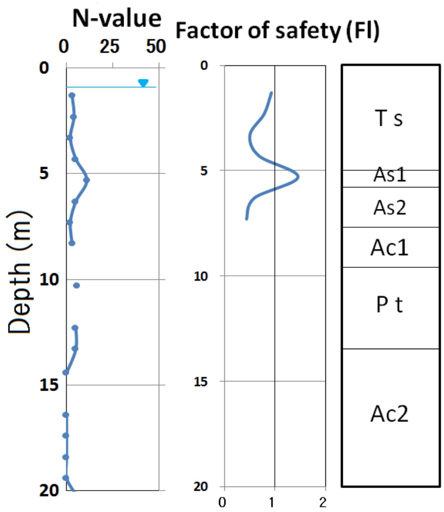


Figure 28. Soil profile and SPT N-value at point B

5. CONCLUDING REMARKS

Narashino City in Japan located at the north part of the Tokyo Bay was heavily damaged during the Great East Japan Earthquake. The factors to cause damage of houses, and the applicability of the simplified procedure proposed by AIJ to evaluate the settlement of the ground due to sand liquefaction were investigated. Following were concluded temporarily. ①Though there is an interval of about 10 years between two perids of reclamation, there is no difference in the degree of damage of houses between two periods of reclamation.②The major factors to cause sand liquefction of the reclaimed land area are high ground water table and the loose surface fill layer of sand with SPT N-value lower than ten, except the effect of the longer duration of the Great East Japan Earthquake. ③The heavily damaged area of houses in the north part of the city well agrees with the areas of old river or valley. The damage of houses in this area was mainly due to the large deformation of foundation soils.

Even at the present time, more than one year after the occurrence of the earthquake, only less than 20 % of the damaged houses have been repaired. It is because that there is no rational method to improve the foundation soil against liquefaction with existing houses. Much more efforts are required to develop new effective methods.

6. ACKNOWLEDGMENT

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7. REFERENCES

Study Committee on the Reconstruction of the Damaged Residential Area of Narashino city (2011) :「Report on the Reconstruction of the Damaged Residential Area of Narashino city」

Architectural Institute of Japan (2001):「Recommendations for Design of Building Foundations」,61-67.