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EFFECTIVENESS OF TECHNIQUES FOR STABILIZING OUTSIDE TELECOMMUNICATION FACILITIES AGAINST LIQUEFACTION

Masahiro NAKANO[1], Hiroaki HATTORI[2], Susumu SAITO[2], and Masaaki YOSHIKAWA[3]

1) Senior Engineer Superviser Civil Engineering Project Group, NTT Tsukuba Field Engineering Development Center, 1−7−1, Hanabatake, Tsukuba-City, Ibaraki, 305, Japan
2) Engineer, Civil Engineering Project Group, NTT Tsukuba Field Engineering Development Center, 1−7−1, Hanabatake, Tsukuba-City, Ibaraki, 305, Japan
3) Chief Researcher, Aseismic Engineering Section, Tsukuba Research Institute, Okumura, Co., 387 Oh-aza Ohsuna, Tsukuba-City, Ibaraki, 300−33, Japan

SUMMARY

Past large earthquakes have caused damage to outside telecommunication facilities, with typical damage being the floating of manholes or sinking of telephone poles due to liquefaction. Techniques were evaluated for stabilizing facilities against such liquefaction damage. A 1: 5 scale model shaking table test was conducted to confirm the effectiveness of various measures for protection against floating of buried manholes and leaning or sinking of telephone poles. The most effective of these techniques is to be applied to onsite construction.

INTRODUCTION

The interruption of telecommunication services due to earthquakes is a temporary phenomenon. In an information society, however, even a temporary interruption invites major societal chaos. For this reason, it is necessary to plan for increased earthquake proofing of outside telecommunication facilities and to secure information functions that can be used when an earthquake strikes, both to prevent a major disaster when an earthquake occurs and to permit a speedy recovery afterward.

In the past, damage to outside telecommunication facilities from earthquakes in regions where the ground has changed due to liquefaction has caused manholes to float upward, cant or sink, and telephone poles to sink or lean. It is therefore necessary to develop measures to prevent these kinds of damage. (Ref. 1)

In this study scale model vibrational experiments were conducted with a combined system made up of ground of loosely-packed saturated sand, a scale model manhole, and telephone pole. Vibration was caused by a 3-dimensional, 6-degree-of-freedom controllable shaking table. The shaking table was vibrated in the horizontal direction only, in order to derive the dynamic characteristics when liquefaction occurs and the manhole and telephone pole rize. The variables studied include excessive pore pressure, response acceleration, settlement, and other changes over time. This study compares and evaluates the results of these experiments using the frequency-dependent properties and response displacement at the time of liquefaction before preventive measures were taken. It attempts to assess the effectiveness in earthquake-proofing design of various preventive measures. In the case of manholes the movement of the ground was also studied in order to investigate the reason for manhole floating that occurs during earthquakes.

THE EXPERIMENTAL PROCEDURE

Experimental Facility Vibration was applied in only the horizontal direction, this being thought sufficient for the experiment to derive the liquefaction characteristics.

For the manhole, as shown in Fig. 1, the flexible shear vessel is a square with each side measuring 2m, made up of 15 thin layers of lightweight steel frame laid on top of one another and separated by ball bearings.(Ref. 2) It has been constructed so the scale model ground can reproduce distortion modes during the vertical transmission of SH waves. For the telephone pole, the straight displacement-type vessel is square, with sides measuring 1.25m×0.50m, a height of 0.91m, and hinged at the bottom of the sides.(Fig. 2)(Ref. 3)

The material used for the scale model ground was Sengenyama sand with an average particle diameter D_{50} of 0.33mm to 0.40mm, a uniformity coefficient U_C of 2.2, and dry density maximum and minimum values of approximately 1.7g/cm^3 and 1.4g/cm^3, respectively. When the shear wave velocity V_S is derived with the board-striking method, the relative density Dr is approximately 40%, while V_s of the scale model saturated ground is approximately 50 m/s.

Based on the size of the upper vessels, both the manhole and telephone pole models are 1:5 scale.

Case studied The experiments were run for the following cases: the ground system without manhole (telephone pole), the ground system and manhole (telephone pole) with no preventive measures taken (standard); and each of the earthquake-proof measures.

Fig. 3 and Fig. 4 show the preventive measures for the manhole and telephone pole, respectively.

Input waves Input waves were applied, first, to derive the resonance characteristics of the entire manhole/ground system and telephone pole/ground system in a linear area. They consisted of (a)20 seconds of continuous white noise including equal vibrational frequency elements of 1Hz to 30Hz at 10 gal input acceleration, and (b) periodic swept wave motion with vibrational frequencies of 30Hz to 1Hz applied in 0.5Hz increments.These waves were used with respect to identical scale models.

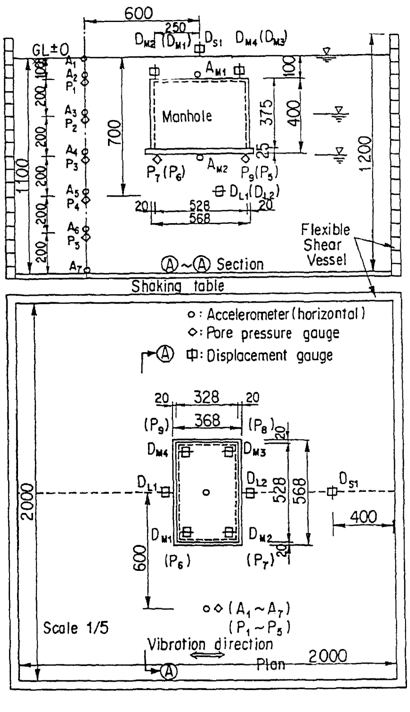

Fig. 1 Outline of Manhole Scale Model Vibration Experiment

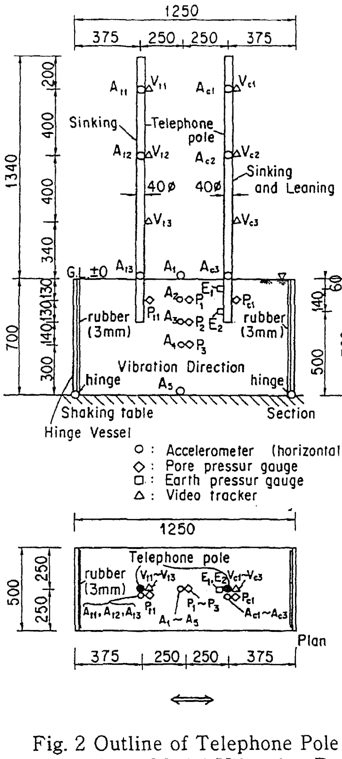

Fig. 2 Outline of Telephone Pole Scale Model Vibration Experiment

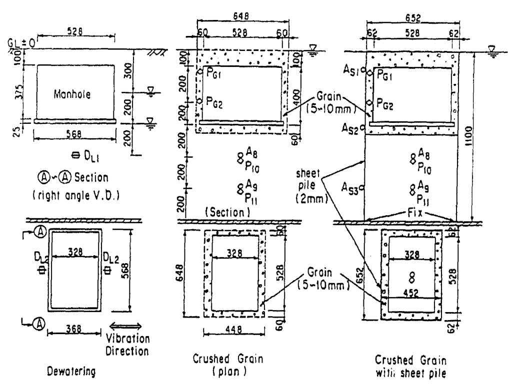

Fig. 3 Preventive Measures for Manhole

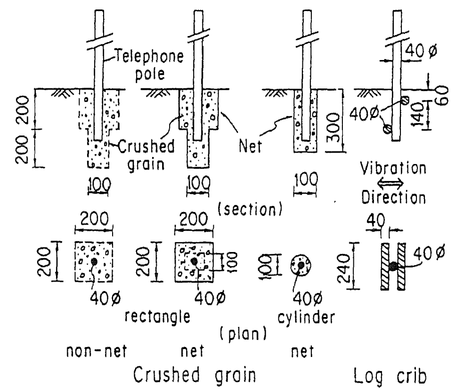

Fig. 4 Preventive Measures for Telephone Pole

Table. 1 Items for Measurement

Case studied / items for measurement		Manhole: Manhole	Manhole: ground	Telephone pole: Telephone pole	Telephone pole: ground	References
horizontal acceleration		○	○	○	○	
excessive pore pressure		—	○	—	○	
displacement	horizontal	—	○	○	—	1) potensio-meter 2) Video-tracker 3) Level and Video-tracker
	vertical	○	○	○	○	
earth pressure		—	—	—	○	

Next, in sinusoidal vibration, preliminary tests were conducted in which the input acceleration was changed between 30, 60, 90, 120 and 220 gal, and the distribution of excessive pore pressure was used to derive the condition when liquefaction occurs. As a result, when sinusoidal vibrations (20 input waves at a frequency of 20Hz) were applied, up to input acceleration of 120 gal complete liquefaction was not observed, although liquefaction was in progress [see notes 4), 5)]. At an input acceleration of 220 gal complete liquefaction occurrd.

Items for Measurement   The items for measurement are shown in Table 1. In the manhole experiments in order to observe the movement of the ground beneath the base of the manhole that accompanies manhole floating, a thin layer of colored sand was spread in a lattice pattern in both vertical and lateral directions, in an attempt to show the residual deformation.

EXPERIMENTAL RESULT AND DISCUSSION

Manhole   Fig. 5 compares the results for each experimental case when the input acceleration is 220gal. From these results, the relative displacement of the manhole, i.e., the manhole upward displacement plus ground settlement by various preventive measures, is as follows (complete liquefaction at 220gal input, increasing in the following order from smallest to largest): crushed grain and sheet pile together (0.5cm), crushed grain (1.6cm), dewatering to the G, L.-50cm (1.9cm), and standard (14.4cm). Considering the surface of the ground (which sank after input) as a reference, the amount of floating before preventive measures were taken becomes 14.4cm; this is equivalent to about 70cm on a full scale. The order of mean excess pore pressure, which stands for the degree of ground liquefaction at the bottom of the manhole, is also almost the same as the results for relative displacement. These results confirmed that the relative displacement of the manhole increases as the degree of liquefaction rises. Therefore, of the various measures to prevent manhole floating during liquefaction, use of crushed grain and sheet pile together is the most effective.

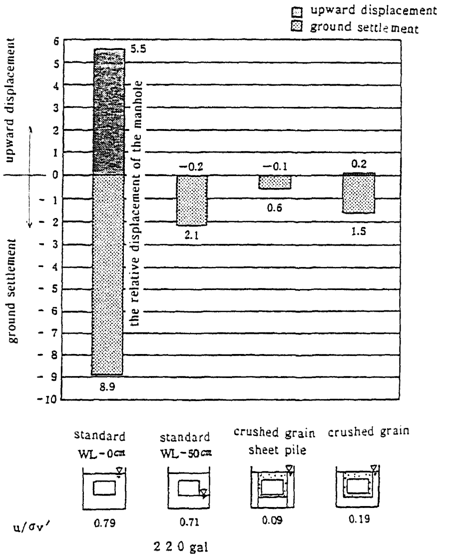

Fig. 5 Amount of Floating and Sinking of Manhole and Ground

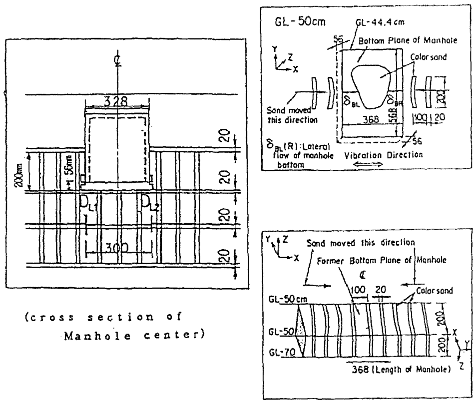

Fig. 6 Changes in the Colored Sand that Shows Sidewide Movement

In addition, the changes in the colored sand (showing which portion of sand moved to what degree) (Fig. 6) were taken into account when calculating the inflow (the amount of the triangular prism-shaped soil near the base plate of the manhole which flows beneath the manhole when manhole floating occurs), and the inflow resembles the amount of manhole floating.

The Effectiveness of Measures to Prevent Liquefaction

When the effectiveness with respect to manhole floating of the various preventive methods is considered from the standpoints of the time required to reach excessive pore pressure ratio, in ground response acceleration, the amount of manhole floating, the sideward movement curve in the area of the manhole base plate, and other factors, the amount of floating when the crushed grain method is employed is reduced to about 1/6 that before preventive measures are used (due to its effectiveness in dissipating the rise of U). As a result, layers of crushed grain can be expected to be effective in preventing floating of manholes. Furthermore, when both crushed grain and sheet pile are used together, the amount of floating can be reduced to about 1/18 of that before preventive measures are adopted. The crushed grain is effective in dissipating the rise of U, namely, it is reduced to about 0.24 that before preventive measures are used, while the sheet pile is effective in damping vibration. If can also be seen that the relationship between the level of underground water and the amount of floating is such that the farther the level of underground water is lowered below the bottom of the manhole, the more liquefaction is delayed and the smaller is the amount of floating. When the level of the underground water is lowered below the base of the manhole, the manhole does not float and instead sinks.

Telephone Pole

The effectiveness of Measures to Prevent Liquefaction

In order to compare the effectiveness of each measure, the results for telephone pole model leaning and sinking are shown in Fig. 7. The amount of telephone pole settlement, increasing in the following order from smallest to largest is crushed grain with net (0.7cm), log crib (4.5cm), crushed grain without net (5.5cm), and standard (24.8cm). The amount of settlement in cases where preventive measures were taken is below 1/3 that of the standard. The gradients of telephone pole leaning are : crushed grain with net (6.5°), crushed grain without net (15.5°). Therefore, it was clarified that the most effective technique for preventing leaning and sinking is crushed grain with net, followed by crushed grain without net. The reason why crushed grain surrounded by net is effective is the net prevents the crushed grain from scattering and prevents excessive pore pressure from increasing as the ground undergoes liquefaction.

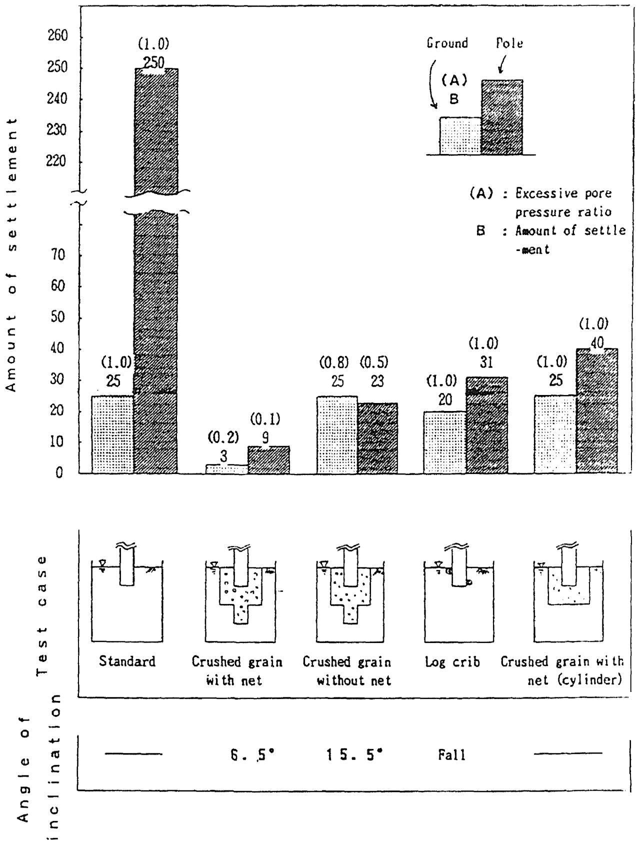

Fig. 7 Amount of Sinking and Leaning of Telephone Pole

CONCLUSION

A comparison of the results of preventive measures applied to the dynamic characteristics brought by ground liquefaction can be summeried as follows:

1. Manhole/ground system

① The displacement of the manhole was more pronounced as the degree of liquefaction progressed.

② The manhole is caused to float upward by the uplifting force of excessive pore pressure, and by inflow of ground at the base plate during liquefaction.

③ Effective preventive measures against liquefaction were crushed grain and crushed grain with sheet pile. Dewatering was an effective measure for dissipating the degree of liquefaction and also preventing liquefaction.

2. Telephone pole/ground System

① It was found that the telephone pole starts sinking when the .excessive pore pressure ratio is about 0.4, and leaning occurs before sinking.

② Although a log crib can prevent the telephone pole from sinking, it cannot prevent leaning because it does not provide resistance to sideward ground movement. Crushed grain is an effective measure against liquefaction, and can decrease displacement. The larger the surface area of the crushed grain, the less is the degree of telephone pole displacement surrounding the crushed grain with netting prevents the grain from scattering, increasing the effectiveness of this measure.

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REFERENCE

1) Nakano, M., K. Sawahashi: Improving Reliability of Underground Telecommunication Facilities during earthquakes, NTT SHISETSU, vol.37, No.12, pp.50~57, 1985.
2) Yoshikawa, M., Kuroiwa, M., Yamada, Y.: Model Vibration Test of Tower - Pile Foundation - Soil Systems, Proc. JSCE, No.334, pp.53-62, 1983-6.
3) Nakano, M., Yoshikawa, M., et.al.: An Experimental Study on the Telephone Pole Stabilizing Techniques Against liquefaction, Proc. JSCE, (under Contribution). (in Japanese)
4) Yoshikawa, M., Arano, M., Yamada, Y.: Dynamic Behavior of a Model Saturated Sand During Liquefaction, TSUCHI-TO-KISO JSSMFE No.1654 vol.34, No.12, December, 1986. (in Japanese)
5) Yoshikawa, M., Arano, M., Yamada, Y.: Liquefaction Characteristics of a Model Pile Foundation, TSUCHI-TO-KISO, JSSMFE SER, No.1687, pp.31-36, April, 1987 (in Japanese).