INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

The paper was published in the proceedings of the 10th International Conference on Physical Modelling in Geotechnics and was edited by Moonkyung Chung, Sung-Ryul Kim, Nam-Ryong Kim, Tae-Hyuk Kwon, Heon-Joon Park, Seong-Bae Jo and Jae-Hyun Kim. The conference was held in Daejeon, South Korea from September 19th to September 23rd 2022.

Physical Modelling in Geotechnics
© 2022 KOREAN GEOTECHNICAL SOCIETY (KGS), Seoul, Korea, ISBN 978-89-952197-7-5

Dynamic centrifuge model tests on the uplift behavior of manholes and sewer pipes due to liquefaction

M. Muto
Planning Section, Planning and Coordination Division, Bureau of Sewerage, Tokyo Metropolitan Government, Tokyo, Japan

S.S. Suzuki, M. Nakano & K. Fukuda
R & D Center, Nippon Koei, Co., Ltd., Tsukuba, Japan

Y. Horiguchi, Y. Iwasa & M. Sato
Technical Development Section, Engineering Division, Tokyo Metropolitan Sewerage Service Corporation, Tokyo, Japan

T. Nakamura
Technical Construction Section, Sewerage-Related Businesses Division, Nippon Hume Corporation, Tokyo, Japan

ABSTRACT: Previous studies on the behavior of sewer pipelines during soil liquefaction are related only to the behavior of either the manholes or the pipes under such conditions. No research exists on the combined behavior of manholes and pipelines affected by soil liquefaction. The purpose of this study is to confirm the combined behavior of manholes and pipelines under soil liquefaction conditions, which is necessary information in implementing seismic retrofitting of sewer pipelines. The study was performed using dynamic centrifugal model tests on sewer pipeline models consisting of multiple pipes connected by joints and manholes connected at either the middle or at both pipe ends. In the model tests, time histories of ground liquefaction behaviors during earthquake were reproduced to clarify the relationship between the ground conditions and the behavior of the pipelines and manholes.

Keywords: liquefaction, sewer pipeline, manhole, uplift, centrifuge model test

1 INTRODUCTION

The Tokyo Metropolitan Government has developed and implemented the *float-less method* (CTRCO, 2012, Nishiwaki, 2014) since 2005 as a way to prevent manhole uplifts resulting from soil liquefaction (Tanaka and Terasako, 2018).

To date, in regard to the seismic behavior of this method, the uplift suppression effect on a stand-alone manhole has been confirmed through a centrifuge model test (Matsuda et al., 2005). However, in reality, manholes are connected to pipes, and the effect of such connections has not been considered (Suzuki, 2015).

In this study, centrifugal model tests were conducted by connecting pipes and manholes to reproduce the ground deformation from the occurrence of earthquakes to liquefaction in time history, and the ground deformation effects on the pipelines and manholes were clarified. The purpose is to collect fundamental data for investigation of seismic countermeasure method.

2 CENTRIFUGE MODEL TESTS

Centrifuge model tests were conducted in 30g of centrifugal force field. The centrifuge used in this study was manufactured in-house by Nippon Koei Co., Ltd. and is a beam-type device with an effective radius of 2.6 m. For the input wave, a waveform recorded by the Kobe Marine Observatory (NS component) of the 1995 Great Hanshin earthquake was used, and the amplitude was adjusted such that the target maximum input acceleration will be 6.82 m/s^2.

Toyoura sand and Silica sand #3 were used in the tests. The main properties of these sands are summarized in Table 1. Toyoura sand was used for the liquefaction layer and Silica sand #3 was used for the foundation layer. The model ground (depth of 6.7 m in prototype scale, relative density of 54%) was prepared in a rigid soil container (1000 × 400 × 250 mm) by an air pluviation method. Table 2 shows the dimensions of the model manholes and pipelines used in the tests. As prototypes, manholes with 1390 mm in outer diameter and pipelines with an inner diameter of 700 mm are adopted.

Table 3 shows the experimental cases, and Figs. 1, 2, and 3 present the outline of each experiment. The fluid used to saturate the model was a methylcellulose solution (metolose) fluid with kinematic viscosity of 30 mm^2/s. The ground saturation method was performed in

7g of centrifugal force field, controlled by a piezometer until the prescribed saturation was reached.

Table 1. Physical properties of test materials.

Physical properties	Toyoura sand	Silica sand #3
Maximum grain size, $D_{\max}$ (mm)	0.425	2
Mean grain size, D_{50} (mm)	0.169	1.46
Uniformity coefficient, U_c	1.43	1.47
Coefficient of curvature, U_c'	0.966	0.975
Minimum dry density, $\rho_{d\min}$ (g/cm^3)	1.368	1.483
Maximum dry density, $\rho_{d\max}$ (g/cm^3)	1.663	1.685
Density of soil particles, ρ_s (g/cm^3)	2.649	2.635

Table 2. Dimensions of the models.

Dimensions	Manhole		Sewer pipes	
	Prototype	Model (1/30)	Prototype	Model (1/30)
Diameter	1390 mm (outer)	46.3 mm (outer)	700 mm (inner)	23.3 mm (inner)
Height	2300 mm	76.7 mm	-	-
Weight	3475 kg	128.7g	899 kg	33.3 g
Length	-	-	2430 mm 1200 mm	81 mm 40 mm

Table 3. Test cases.

Test Cases	Modeling details
Case1	Manholes with and without float-less method
Case2	Jointless pipelines are connected to a manhole without float-less method
Case3	Bell-and-spigot jointed pipes between manholes without float-less method

Silica sand No. 3 layer with a thickness of 10 mm and a model asphalt layer (prototype equivalent thickness assuming a roadway: 300 mm) were placed on top of the liquefaction layer to achieve the same overburden pressure as the prototype road pavement. The average unit volume weight of this pavement section is γ_t= 15.671 kN/m^3.

Case1 was conducted on a float-less method manhole (hereinafter referred to as Flm-MH, left) and a manhole without float-less method (hereinafter referred to as Non-Flm-MH, right) as shown in Fig. 1. In the Flm-MH, 12 excess pore water pressure dissipation devices were installed using the float-less method (see Fig. 4). It can dissipate excess pore water pressure generated during earthquakes by the holes with dissipation devices on the wall and prevent the manhole to be uplifted.

Case2 in Fig. 2 was conducted to confirm the uplift and deformation behavior of jointless pipelines connected to a Non-Flm-MH. The interface between the pipe and the manhole was rigidly connected.

Case3 was conducted to confirm the uplift and deformation behavior of pipelines with joints connected to Non-Flm-MHs. The pipeline specifications are shown in Fig. 3. The total pipeline length is 607 mm (prototype 18.21 m) with inner diameter of 23.3 mm

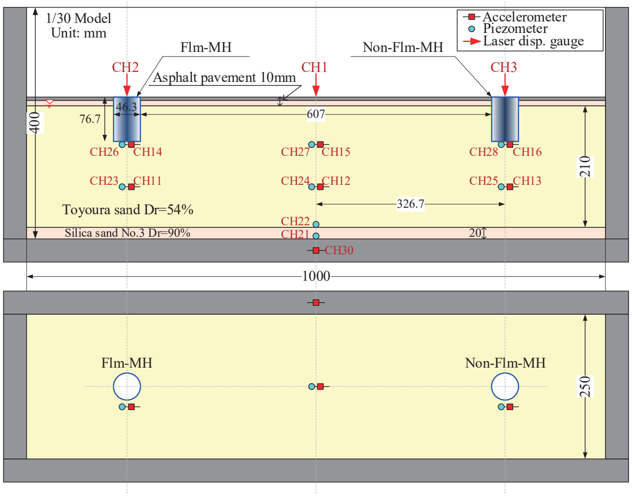


Fig. 1. Outline of centrifuge (Case1).

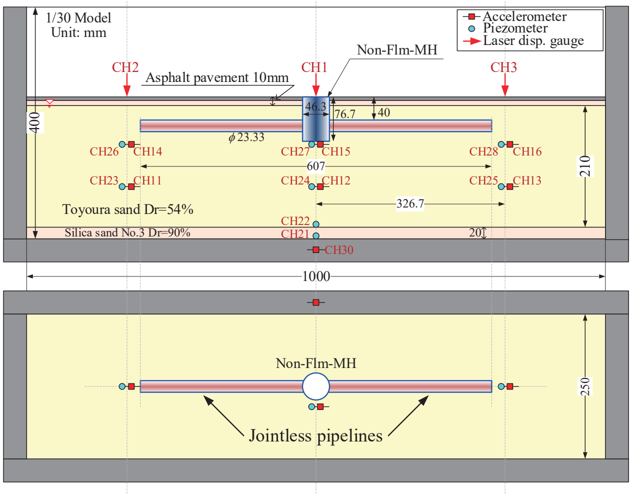


Fig. 2. Outline of centrifuge (Case2).

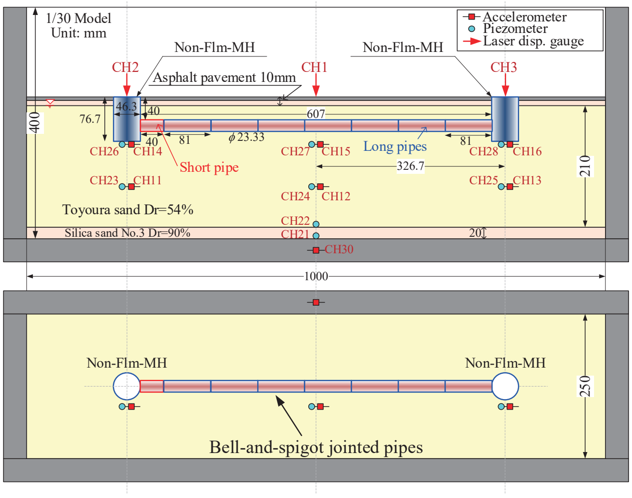


Fig. 3. Outline of centrifuge (Case3).

(prototype 700 mm) consists of one short pipe and seven long pipes. The pipe joint was connected with a thin coating of silicone agent applied to the pipe connection for the sole purpose of water sealing. Furthermore, the interface between the pipe and the manhole was rigidly connected.

Fig. 5 shows the model preparation situation of each test cases.

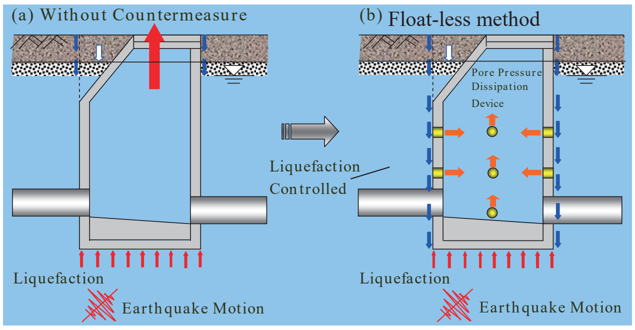
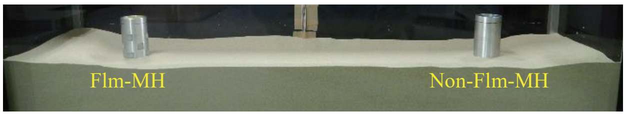


Fig. 4. Principle of the float-less method.



(a) Case1

(b) Case2

(c) Case3

Fig. 5. Model preparation and setup.

3 TEST RESULTS

The experimental results are shown below.

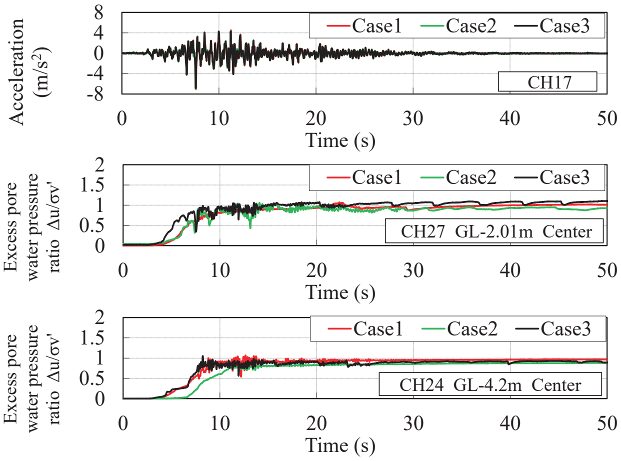


Fig. 6. Acceleration and excess pore water pressure ratio.

Fig. 6 shows the response acceleration obtained from the foundation and the excess pore water pressure ratio from each experimental case. The maximum response acceleration of the base in Case1, Case2 and Case3 was 7.06, 7.01, and 6.82 m/s^2, respectively. The excess pore water pressure ratio ($\Delta u/\sigma_v'$) is the value obtained by dividing the excess pore water pressure Δu generated in the ground by the effective overburden pressure σ_v'. Based on $\Delta u/\sigma_v' \geq 1$, as shown in Fig. 6, it can be considered that the entire ground was completely liquefied.

Fig. 7 shows the relationship between the elapsed time and the vertical displacement value obtained from the laser displacement gauge measured during shaking. A comparison of the vertical displacement of manholes and ground for all cases is shown in the figure. The residual displacements shown in Fig. 7 are summarized in Table 4.

In Case1, the vertical displacement of the Non-Flm-MH was +47.2 cm (uplift), whereas that of the Flm-MH was -6.6 cm (settlement), showing the effectiveness of the float-less method. In Case2, the vertical displacement of the Non-Flm-MH is +2.5 cm, which is less than the Non-Flm-MH in Case1. It would be the effect of the jointless pipeline connected to the manhole, which inhibits the manhole from uplift behavior. In Case3, the vertical displacements of manholes sited at each end of the pipeline are +17.8 cm and +14.3 cm, respectively. As they are smaller than the Non-Flm-MH in Case1, it is suggested that the pipeline prevented the manholes from uplifting.

However, the amount of uplift of Non-Flm-MHs in Case3 is larger than that in Case2. It is assumed the following mechanisms: (1) Both manholes were uplifted due to the earthquake. (2) Both ends of the pipes were lifted and the joint near center was bent as shown in Fig. 8. (3) Because of the joint deformed, the restraining force applied to the manholes being raised was less than that of Case2.

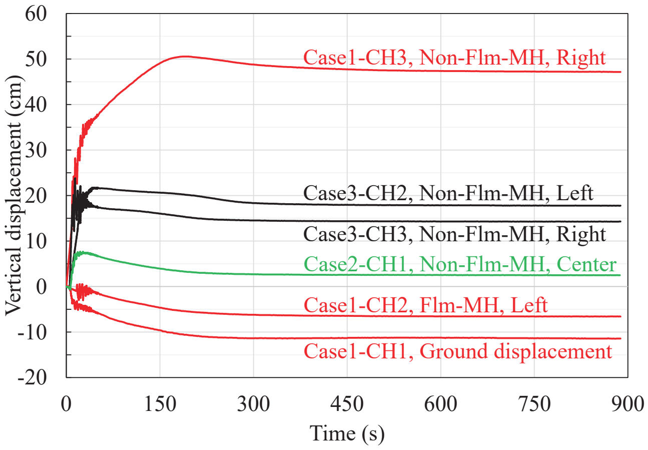


Fig. 7. Vertical displacement.

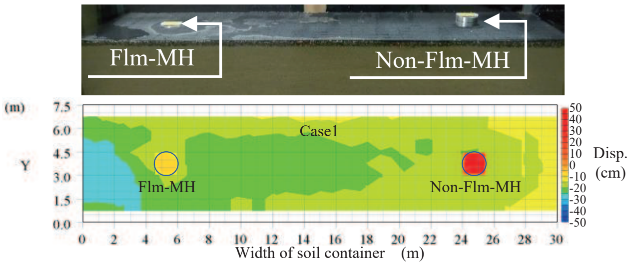
Table 4. Residual vertical displacement.

Test Cases	Manhole Left (cm)	Manhole Center (cm)	Manhole Right (cm)	Ground Center (cm)
Case1	-6.6	-	+47.2	-11.4
Case2	-	+2.5	-	-
Case3	+17.8	-	+14.3	-

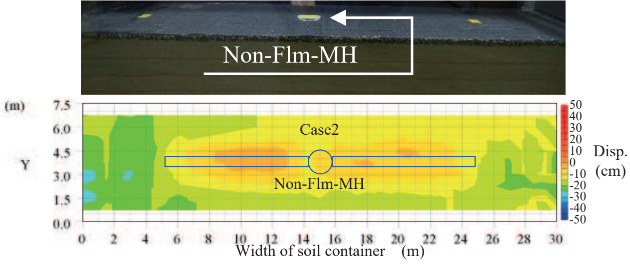
Fig. 8. Deformation of sewer pipes after shaking test (Case3).

Fig. 9 shows the deformation photographs and a visualization of the vertical displacement distribution based on the measured surface height after the experiment.

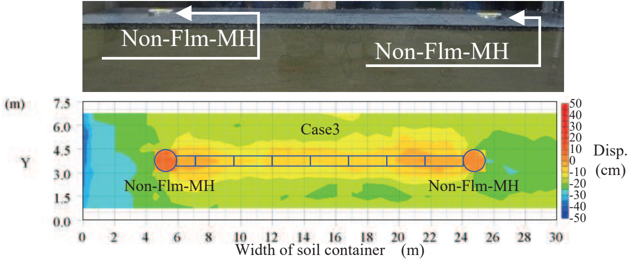
In Case1, the Non-Flm-MH uplifted significantly, whereas the Flm-MH uplifted less. In Case2, the Non-Flm-MH and the pipeline uplifted together, however, the amount of uplift was minimal. The ground distribution above the pipeline is uplifted (Fig. 9(b)). In Case3, both Non-Flm-MHs uplifted, which lifted the connected pipeline and uplifted the ground distribution above the pipeline (Fig. 9(c)).



(a) Case1



(b) Case2



(c) Case3

Fig. 9. Deformation photographs and vertical displacement distribution after tests.

4 CONCLUSIONS

The results derived from this study are as follows:

(1) The effect of the float-less method on the suppression of uplift was confirmed based on the result of Case1.

(2) When the manhole was joined at the center of the pipeline in Case2, the manhole uplift was less than that of the manhole without the float-less method in Case1, and the uplift was found to be 2.5 cm. It shows the uplift suppression effect on the manhole by the manhole-connected pipelines.

(3) The amount of manhole uplift in Case3 is about seven times larger than in Case2. One reason is considered to be due to the difference in the presence or absence of pipe joints. In case3, it is assumed that the pipe joints bent caused by the uplift of manholes. As result, the amount of uplift of manhole in Case3 was larger than that of Case2. The length of the pipelines connected to a manhole is also considered to have an effect on the amount of uplift and should be considered as an issue for future study.

(4) The manhole uplift owing to ground liquefaction was the greatest with the manholes without the float-less method, followed by the manhole jointed at both ends of the pipeline. The manhole jointed at the center of the pipeline showed the least amount of uplift.

(5) The effect of the pipelines connected to the manholes on the uplift of manholes was confirmed. For future study, it is needed to identify the problems that may be caused by the effect of the manhole-connected pipelines that prevent manhole uplifts and investigate the countermeasures against them.

REFERENCES

Construction Technology Review and Certification Organization (CTRCO) 2012. *Float-less Method, Liquefaction-Induced Manhole Uplift Suppression Technology*, Tokyo: Japan Institute of Wastewater Engineering and Technology.

Matsuda, K., Nishiwaki, M. and Li, L. 2005. Research on Countermeasures to Prevent Manhole Floatation due to Liquefaction during Earthquakes, *Proceedings of the 42nd Japan Annual Technical Conference on Sewerage*, 205–207. Tokyo: Japan Sewage Works Association.

Nishiwaki, M. 2014. Non-excavation method to prevent manhole floating due to liquefaction–"Floatless Method", *Procedure of the 25th Trenchless Technology Conference*: 127–134. Tokyo: Japan Society for Trenchless Technology.

Suzuki, T. 2015. A Method for Advancing Anti-Uplifting Measures of Existing Sewage ManHoles, *Proceedings of the Annual Conference of the Institute of Social Safety Science* 36: 63–64. Tokyo: Institute of Social Safety Science.

Tanaka, C. and Terasako, K. 2018. Seismic Retrofitting Measures for Sewerage Structures in Tokyo, *Annual Report on Technical Research & Development* 42: 298–305. Tokyo: Bureau of Sewerage, Tokyo Metropolitan Government.