Investigation of the effects of the girder on the seismic performance of the abutment foundation using FEM analyses

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1. INTRODUCTION

Past study has found that pile foundation can sustain serious damage like buckling under the axial load alone when the ground near the pile liquefied (Bhattacharya *et al*, 2004). Furthermore, about 700,000 of existing bridges in Japan were built on the liquefiable ground (Soil research institute doc No.4037, 2007). These result in the urgency to develop retrofitting method against the liquefaction damage, and it is important to accurately evaluate the seismic performance of the abutment foundation first.

In the past, the mechanism of abutment has been studied separately from its superstructure. In later year, some studies have considered the presence of the superstructure. However, there are still only few studies that include the superstructure to evaluate the abutment's seismic performance.

The purpose of the study is to understand the influence of bridge girder on the mechanism of the abutment foundation during earthquake through FEM analyses. The changes in abutment's foundation behavior will be observed through abutment's displacement, bending moment along the pile and displacement vector of model, under various values of the gap between the girder and the abutment.

2. METHODOLOGY

This study is conducted by performing the three-dimensional FEM analyses using the code DBLEAVES (Ye *et al.*, 2007). Figure 1 shows the analysis setup. The conditions of the model are based on the previous centrifuge model tests done by Loek *et al.* (2022). The ground used in analyses was silica sand No.7, and it is modeled by the Cyclic Mobility model (Zhang *et al*, 2007). Table 1 shows the parameters for the ground.

The backfill and non-liquefiable layer have a relative density D_r = 80%, while the liquefiable layer has D_r = 40%. Piles have square cross-section with the diameter of 0.4 m. Piles are modeled by the hybrid-element which consisted of vertical beam elements surrounded by the solid elements (Danno and Kimura, 2009). The interface between the ground and the back of abutment was modeled by joint element. Table 2 contains parameters for pile, abutment, and joint element. The girder is modeled by adopting the bi-linear spring element. The behavior of spring element mainly controlled by the parameters d, k_1, and k_2. d is gap between the girder and abutment in each case. k_1 and k_2 are spring constant in compression zone. $k_1 = k_2$ when the gap is 0 mm, and $k_1 = 0$ when there the gap is not zero. For k_2, it equals to 3×10^5 kN/m for all cases.

Nine cases were conducted to understand the effects of the gap d between the girder and abutment on seismic performance of piles that support abutment. Seismic wave with amplitude about three times of level I earthquake was used. (Japan Road Association, 2012).

3. RESULTS

3.1. Displacement of abutment

Figure 2 shows the displacement of abutment in each case. It is observed that the displacement stops increasing once it reaches the prescribed gap *d*. This suggests that the spring elements behave as intended, meaning that they can prevent the abutment from moving any further when displacement reach value *d* in each case. In addition, we can observe that the displacement can be reduced depending on the value of the gap *d*.

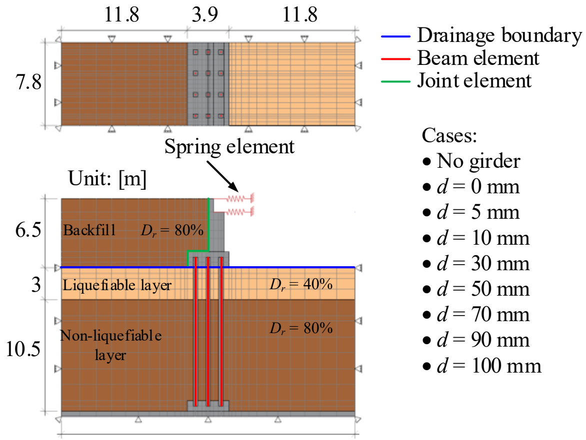

Figure 1. Analysis setup

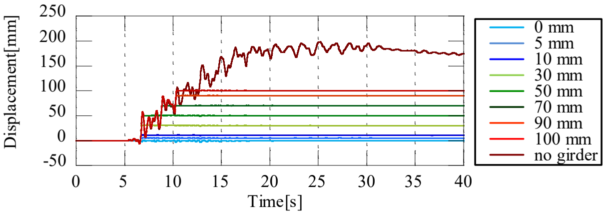

Figure 2. Displacement of abutment

Table 1. Silica sand – cyclic mobility parameters

Compression index, λ	0.01
Swelling index, κ	0.0064
Critical state parameters, M	1.3
Poisson's ration, ν	0.3
Parameter of structure, a	0.5
Parameter of overconsolidation, m	0.01
Parameter of anisotropy, b_r	1.5
Void ratio (p'= 98 kPa), $N = e_0$	0.87
Density [g/cm^3], ρ' (D_r = 80%)	0.486
Density [g/cm^3], ρ' (D_r = 40%)	0.341

Keywords: Abutment, FEM analysis, girder, liquefiable ground, pile, seismic.

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Table 2. Pile, abutment, and joint parameters

Young's modulus of pile's beam, E_b	6.15×10^7
Young's modulus of pile's solid, E_s	2.38×10^6
Young's modulus of abutment, E [kPa]	6.87×10^7
Shear stiffness of joints [kPa/m]	1.55×10^5
Normal stiffness of joints [kPa/m]	1.55×10^5
Cohesion [kPa]	5
Internal friction angle [deg]	28

3.2. Bending moment (BM)

Figure 3 shows the bending moment distribution of the back pile at 40s. Overall, when the gap d decreases, the bending moment at pile head reduced while the bending moment at the pile tip increases. However, it is observed that the case with the smallest bending moment is not the case when $d = 0$. It is when the gap is equal to 5 mm.

Figure 4 shows the bending moment distribution of back pile when $d = 0$, 5, 10, and 30 mm. It is observed that the bending moment increase when the d is larger or equal to 30mm, and bending moment decrease when d equal to 5 and 10mm. This suggests that the bending moment can be further reduced when the gap is larger than 0 but smaller or equal to 10mm.

To better understand the change in bending moment, seismic wave with the intensity of 1.5 and 2.0 time of input wave are applied to the case d =0, 5, and 10mm, as shown in Figure 5. Overall, as the intensity of the input wave increase, the difference in bending moment along the pile become smaller.

3.3. Displacement vector of model

Figure 6 shows the magnitude of displacement vector of the model at the end of excitation (40s) in case there is no girder, $d = 0$, 10, 50, 70 and 100 mm. As the gap increases, the displacement of abutment and backfill become larger. At the same time, the displacement of ground in front of abutment become smaller.

4. CONCLUSIONS

Dynamic three-dimensional FEM analyses were conducted to observe the effects of the girder on the seismic performance of the abutment foundation in the liquefiable layer. The findings suggest that, in the conditions where the liquefiable layer is not excessively thick, the presence of the girder can reduce the abutment's displacement and pile's bending moment depending on the value of the gap between the girder and abutment. Among all the cases, the smallest bending moment is observed when there is small gap (5 to 10 mm) between the girder and abutment. For the model's displacement vector, larger displacement is observed when the gap increases. In contrast, the positive effects of girder are expected to be reversed when the liquefiable layer is excessively large. This is because thicker liquefiable layer induces larger pile's horizontal displacement, and the constraint created by the girder at pile head will make the displacement at the middle of pile even larger.

REFERENCES

Bhattacharya, S., Madabhushi, S. P. G. & Bolton, M. D.: An alternative mechanism of pile failure in liquefiable deposits during earthquakes, *Géotechnique*, Vol 54, No. 3, pp. 203-213, 2004.

土研資料第 4037 号:「橋梁基礎形式の選定手法調査」、2007.

Ye, B., Ye, G. L., Zhang, F. and Yashima, A.: Experiment and numerical simulation of repeated liquefaction-consolidation of sand, *Soils and Foundations*, Vol.47, No.3, pp.547-558, 2007.

Zhang, F., Ye, B., Noda, T., Nakano, M. and Nakai, K.: Explanation of cyclic mobility of soils: Approach by stress-induced anisotropy, *Soils and Foundations*, Vol.47, No.4, pp.635-648, 2007

Loek, S., Sawamura, Y., Kido, R. and Kimura, M.: Effects of the girder on the seismic performance of the abutment foundation by centrifuge experiments, *57th Annual Meeting of the Japanese Conference on Geotechnical Engineering,* 2022. (in press)

Danno, K. and Kimura, M.: Evaluation of long-term displacements of pile foundation using coupled FEM and centrifuge model test, *Soils and Foundations*, Vol.49, No.6, pp.941-958, 2009.

Japan Road Association: Specification for Highway Bridge, Part V (Seismic Design), 2012.

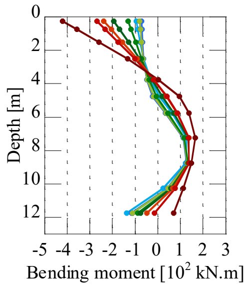


Figure 3: BM at 40s of all cases

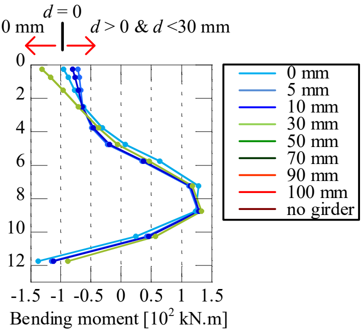
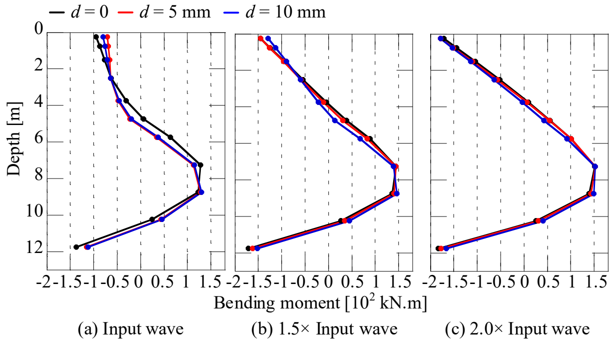


Figure 4: BM at 40s, d =0, 5, 10 & 30 mm



(a) Input wave (b) 1.5× Input wave (c) 2.0× Input wave

Figure 5. BM in case d =0, 5, 10 mm when input wave intensity increases

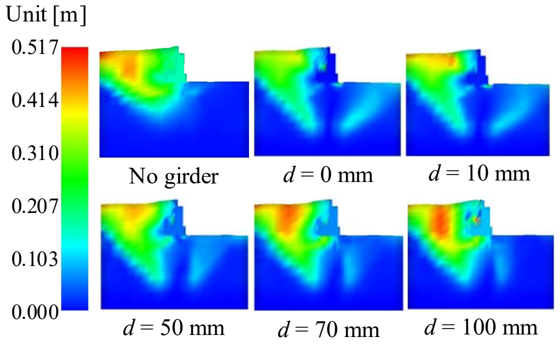


Figure 6. Displacement vector of model at 40s