Behavior of Road Embankment Using Hybrid Pile Supported System under Dynamic Loading

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Introduction

The Kumamoto earthquakes occurred in Kumamoto Prefecture in 2016 and caused considerable loss of life and structural damage. A new deformation countermeasure technique of hybrid pile supported system is developed to stabilize the highway embankment. The vertical piles increase the stability of embankment slopes and foundation. A slanted pile was screwed to each vertical pile, to transfer load to the surrounding soil through the friction between slanted pile and soil. The hybrid pile supported system was evaluated through a series of 1g shaking table tests [1]. In this study, the effectiveness of the proposed geo-technique is evaluated using the dynamic effective stress FEM analysis.

Numerical Method

Fig. 1 shows the 2D finite element model for hybrid pile supported system. The parameters of each soil layer are shown in **Table 1**. The element of the embankment is treated as dry element. The slanted pile is modeled as linear elastic beam element. The hybrid beam element for vertical pile, consist of the conventional beam element and elastic solid element, is used to represent the pile volume [2]. The joint elements are added along all interfaces between the soil and structures, to share identical displacements in the horizontal direction. The bottom of the model is set to the rigid; all lateral boundaries are set to fixed only in X- or Y- direction as a container wall. The lateral and bottom boundaries are assumed to be impermeable, whereas the top of loose sand layer is a permeable boundary. In order to ensure the numerical stability, a time integration increment is considered as 0.001s. The input motion is shown in **Fig. 2**.

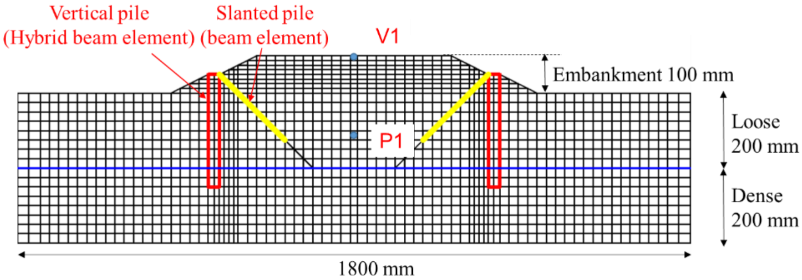

Fig. 1 Finite element model of the entire model

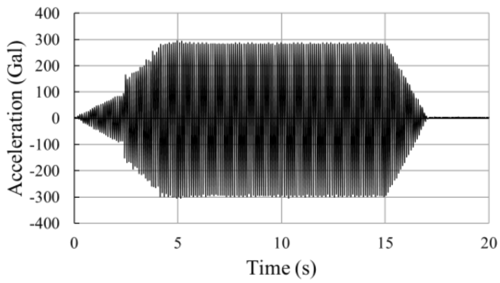

Fig. 2 The input acceleration

Table 1 Material parameters of the constitutive model

Name of soil profile	Unit	Toyoura sand Dr = 60%	Toyoura sand Dr = 90%	Embankment
Density	$\rho(t \cdot m^{-3})$	1.88	2.00	1.88
Coefficient of permeability	$k\ (cm \cdot s^{-1})$	0.01	0.01	0.01
Initial void ratio	e_0	0.738	0.659	0.738
Compression index	λ	0.02	0.0004	0.02
Swelling index	κ	0.0005	0.00008	0.0005
Failure stress ratio	M_f^*	1.300	1.466	1.300
Phase transformation stress ratio	M_m^*	0.980	0.765	0.980
Initial shear modulus ratio	G_0/σ_m^*	2343	1133	2343
Dilatancy parameter	D_0^*	0.5	0.12	0.5
	n	5.0	4.0	5.0
Hardening parameter	B_0^*	6550	54000	6550
	B_1^*	65.5	5400	65.5
Reference strain parameter	γ_r^{P*}	0.002	0.03	0.002
	γ_r^{E*}	0.008	0.36	0.008

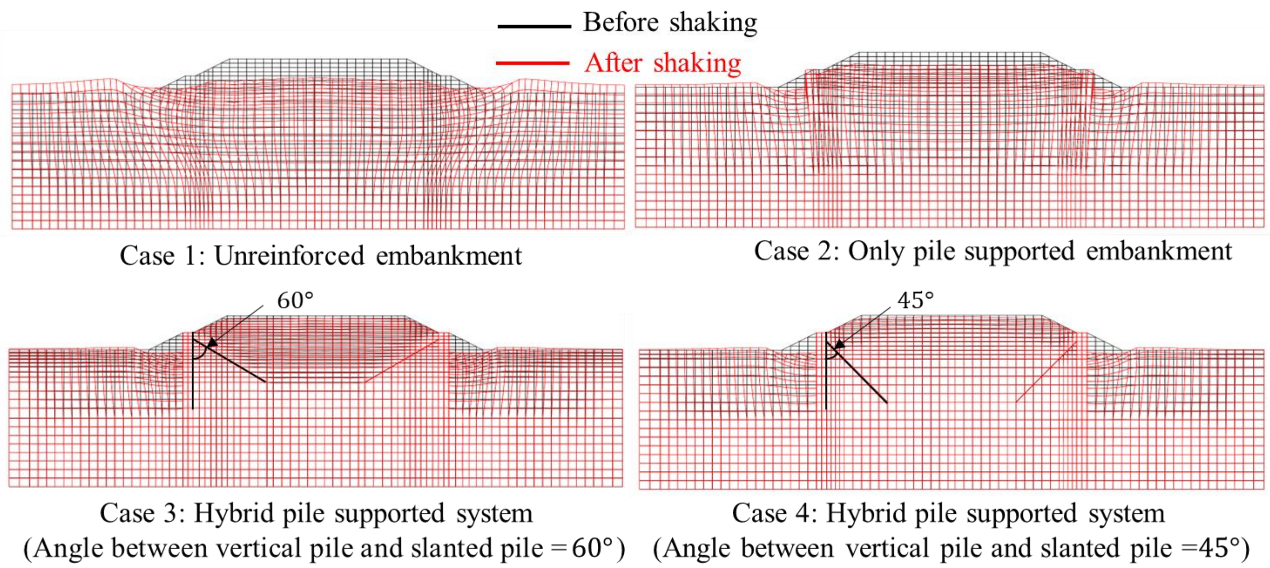

Fig. 3 Deformed configuration after the earthquake

Simulation Results

Fig. 4 shows the time histories of excess pore water pressure ratio (Ru) in the loose layer. The P1 is located at the depth of 150 mm under the middle of highway embankment. The Ru of Case 1 and Case 2 reach 1.0 at about 3 seconds and keeps constant until the end of the shaking. Comparing with Case 1 and Case 2, the Ru of Case 3 reaches 0.2 at 3 seconds, and increase slightly thereafter, and finally becomes 0.95 at the end of the analysis. The peak of excess pore water pressure in the Case 4 is around 0.3 during the shaking. **Fig. 3** shows the final configuration of deformation of 4 cases. Comparing the amounts of settlement in **Fig. 5**, the huge settlements occurred in the middle of highway embankment in Case 1 and Case 2. In contrast, the settlements of Case 3 and Case 4 have significant reduction.

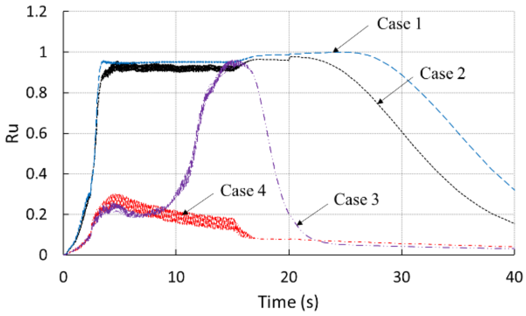

Fig. 4 The time histories of Ru at P1

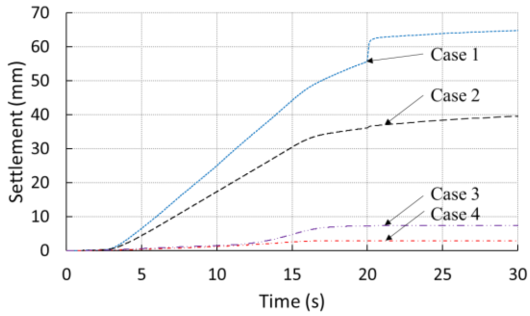

Fig. 5 The time histories of settlement at V1

Summary

1. The highway embankment without reinforcement has a huge settlement because of liquefaction.
2. The embankment with only vertical piles can restrict the horizontal and vertical deformation only to a certain extent and cannot prevent the liquefaction.
3. The hybrid pile supported system can prevent the development of excess pore water pressure and reduce the settlement effectively. However, the angle between the vertical pile and slanted pile and the length of the slanted pile need to be evaluated in the future.

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