CENTRIFUGE MODEL TESTS ON BEARING CHARACTERISTICS OF A PILE SUPPORTED BY A THIN SAND LAYER

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1. INTRODUCTION

Pile foundations are often used in sites wherein a high resistance is required. This high resistance is mainly attributed to the transfer of the applied loads to the underlying bedrock or to a highly dense soil layer with a thickness sufficient to meet standards set by local codes. However, in some locations, the thickness of this highly dense soil layer may be below the aforementioned standards. Therefore, it is important to obtain a comprehensive understanding of the effects of the layer thickness on the bearing capacity of the pile and on the soil surrounding the pile tip.

Numerical analyses have been performed by Matsui & Oda (1991) to evaluate the effect of layer thickness on the bearing capacity. However, there is still limited study through experimental investigations, particularly regarding the effects on soil surrounding the pile tip.

The objective of the current study is to conduct centrifuge model tests on a pile supported by a dense sand layer. In particular, the effect of the thickness of this sand layer on the load-displacement curves and on the horizontal earth pressure in the soil surrounding the pile tip are obtained. Moreover, the failure of the soil is analyzed based on the obtained data.

2. METHODOLOGY

Given the objectives of the study, centrifuge model tests were conducted using the geotechnical centrifuge at the Disaster Prevention Research Institute (DPRI) at Kyoto University. A prototype to model ratio of N = 50 was used, with a centrifugal acceleration of 50g. The model pile was made of stainless steel with a diameter D of 20 mm and height of 210 mm. The dense sand layer supporting the pile was made of Silica Sand No. 5 with a relative density D_r = 90%, while the underlying loose layer was composed of Toyoura Sand with a relative density D_r = 20%.

Figure 1 shows the experimental set up and the cases performed in the study. Five different cases corresponding to five different thicknesses of the dense sand layer H were performed: 8D, 3D, 2D, 1D, and 0D. Three additional cases were performed with four (4) 3-MPa earth pressure gauges (EPG) located in the soil surrounding the pile tip to measure the horizontal earth pressure: 8D-EPG, 3D-EPG, and 1D-EPG. Figure 2 shows the position of the EPGs. One pair of the EPGs was placed 1D below the pile tip level, while the other pair at 2D. For each pair of EPGs, one is located 0.50D

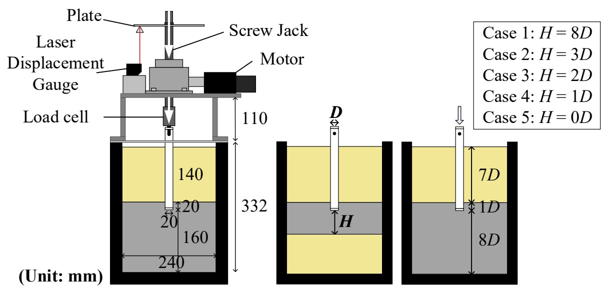

Figure 1. Experimental Cases

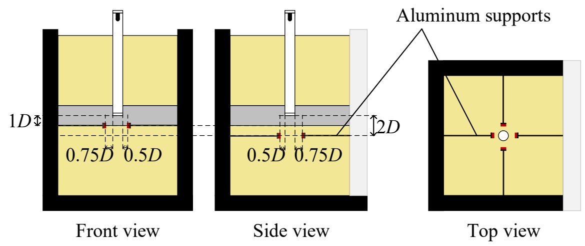

Figure 2. Position of earth pressure gauges (marked red)

from the edge of the pile, while the other at 0.75D. In addition to the stiffness of the soil itself, the EPGs were supported using aluminum bars attached to the walls of the soil chamber to obtain the reaction force of the soil by the pile loading. This support would restrict the EPGs from horizontal movement due to loading, since a radial local failure is expected in the soil around the pile tip.

The pile displacement was measured using a laser displacement gauge, while the pile head load was measured using a load cell. A screw jack was used to apply a constant loading rate of 0.6 mm/min up to a displacement of 1D.

3. RESULTS

3.1. Pile head load-displacement curves

Figure 3 shows the pile head load-displacement curves. It can be observed that the values of the curves increase with an increase in the thickness of the dense sand layer until a thickness of 3D (Case 2). When the thickness is further increased, no significant difference in the values can be observed, particularly at low displacements. This result is consistent with the results of the previous study[1] despite the difference in material used, which indicates that when the thickness of the layer is at least 3D, conventional design methods can be used provided that the layer is sufficiently dense.

Keywords: Pile; thin bearing layer; centrifuge model test; load-displacement curve; horizontal earth pressure
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3.2. Failure of soil surrounding pile tip

Figure 4 shows the change in the horizontal earth pressure in the soil surrounding the pile tip due to loading. Despite the possibility of movement in the EPGs during loading, there exist clear tendencies among the obtained curves. Thus, the relative values are analyzed. The curves obtained from EPGs located nearer (1*D* below) to the pile tip can generally be divided into three stages: (1) an initial increase, (2) a transitional stage, and (3) a decrease in the values. In particular, a clear transition point exists between stages (1) and (2), which occurs at approximately the same pile displacement as the yield point in the load-displacement curves.

On the other hand, the curves obtained from the EPGs farther (2*D* below) from the pile tip do not exhibit the same tendencies. The values increase throughout loading, with initially similar values for all three cases, which later on diverges. The tendencies observed from both pairs of EPGs suggests that the yielding of the pile-soil system is apparent in the soil located 1*D* below the pile tip, wherein a plastic behavior can be observed. The yielding of the soil, however, does not reach the depth of the second pair of EPGs, wherein the soil is observed to behave elastically. Moreover, the rearrangement of the soil throughout loading, particularly in the cases of a larger layer thickness, is hypothesized to be correlated with the change in the slopes of the curves in the lower pair of EPGs. This may be due to the increasing amount of dense sand with a larger layer thickness, which has a tendency to dilate when sheared.

Generally larger change in horizontal earth pressure values were observed for a thicker layer. The larger values are hypothesized to be correlated with lower displacement values due to the higher confining pressure, which would restrict soil movement. This hypothesis was confirmed with the findings of a displacement field analysis by Suezawa et al. (2019) on similar cases. Thus, the decrease in the width of the bulb-shaped high-displacement zone, which surrounds the highly compressed wedge beneath the pile tip, can be attributed to the higher confining pressure observed in a thicker layer. This higher confining pressure may be further correlated with the dilatancy of the highly dense sand. Figure 5 shows the estimated zone of high displacement for all three cases, considering the zone of plastic radial shear failure located at the lateral boundaries of the described bulb.

Consequently, the generally lower values obtained for a thin sand layer may be correlated with the rapid expansion of the bulb, which would thereby penetrate the underlying layer at lower pile displacements. This is further correlated with the lower capacity values obtained for a thinner layer.

4. CONCLUSIONS

Centrifuge model tests were conducted on a pile foundation supported by a dense sand layer with varying thicknesses. It is concluded that the values of the load-displacement curves increase with the thickness up to 3*D*, where *D* is the pile diameter. Conventional design methods can therefore be applied to cases wherein the

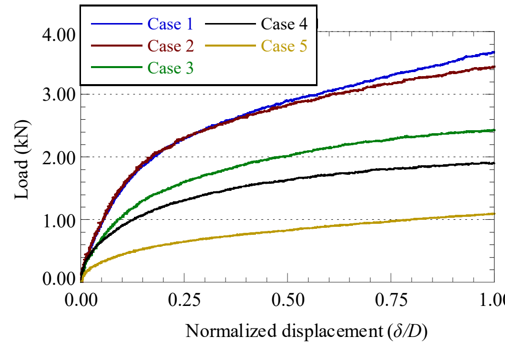

Figure 3. Load-displacement curves

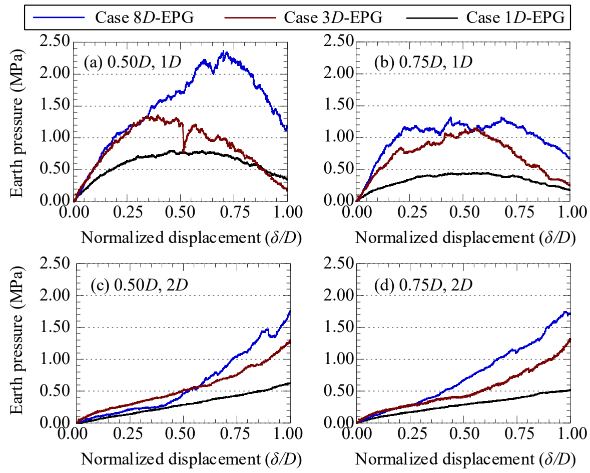

Figure 4. Change in horizontal earth pressure

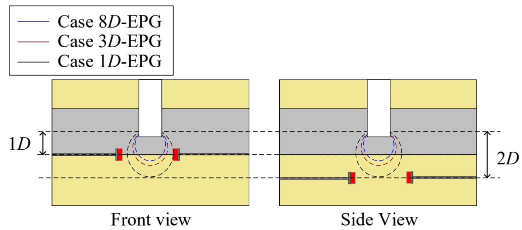

Figure 5. Estimated zone of high displacement

layer thickness is larger than 3*D*. Moreover, observations on the change in the horizontal earth pressure due to loading suggest that the yielding of the soil occurs up to a depth between 1*D* and 2*D* below the pile tip. Below this, the soil behaves elastically throughout loading. The generally lower confining pressure values obtained for a thinner layer is correlated with a larger zone of high soil displacement, resulting in the penetration of the underlying soil at a lower pile displacement and consequently, lower capacity values.

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