The Capacity of Improved Pile Foundation with various sheet pile lengths on Sand under Vertical and Horizontal Loading

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Abstract

Improved pile foundation which can be defined as a pile foundation with sheet piles surrounding pile cap is expected to have better performance against seismic loading than the pile foundations. In this study, a series of 1g physical modeling tests were conducted on sand. The model foundations were subjected vertical and horizontal loading on purpose of studying the effect of sheet pile lengths on the capacity of improved pile foundation. The concept of swipe test was adopted to find out the horizontal capacity and shape of failure surface in V-H load space. The effect of sheet pile length to the capacity of existing pile foundation can be evaluated by the results of load-settlement relationship. The loads and settlements were recorded by using load cells and linearly variable differential transducers (LVDTs). The results present the effective tendency that the horizontal capacities of sheet piles combined with pile foundation can withstand more than those of the pile foundation. Moreover, the results show that the longer the sheet piles, the greater horizontal capacity of the foundations.

1 Introduction

Due to the high application to various soil conditions and various types and sizes of superstructures, pile foundation is usually priority choice to satisfy both safety and economy in case of weak soil and great bearing loading requirement. At present, unexpected conditions and forces such as dynamic loads or horizontal forces from earthquake can be frequently found. These forces can make troubles and damages to existing pile foundation. The necessity of earthquake resistant reinforcement to pile foundation has risen. Nguyen and Punrattanasin (2010) adopted the design concept of sheet pile foundation which was defined as a shallow foundation with sheet piles attached around the footing (Punrattanasin et al, 2002, Nishioka et al, 2009) to reduce existing pile foundation problems. Installing sheet piles around the pile foundation called improved pile foundation is one of remedial measures in the geotechnical point of view. Takemura et al. (2009), Nguyen and Punrattanasin (2010, 2011) indicated that sheet piles significantly enhance the capacities of pile foundation in terms of vertical, horizontal an moment. In order to study the influence of sheet pile length on the horizontal capacity of pile foundation, a series of 1 g physical model testing was continuously carried out on sand under combined vertical and horizontal loadings. All tests were completed with the same initial condition so that the experimental results can then be properly compared and discussed. From the results of this study, an appropriate sheet pile length was also revealed.

2 Experimental Works

This paper reports the results of a series of 1g loading tests of pile foundation model with variety of sheet pile length on sand under the combined vertical-horizontal loading. The purpose of these tests was to investigate sheet pile length's effect on the horizontal capacity of pile foundations. In order to properly compare and discuses the

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experimental results, all the tests were completed with the same initial condition.

2.1 Model Foundations

The model foundations include four identical steel piles (200mm in length and 14mm in diameter), a steel pile cap (70mm x 70mm x 30mm) and four 1mm-thick steel sheet piles with variety of lengths. The distance from the center to center of piles in the group is 3d or 42mm (d is the pile diameter). The four piles are screwed into the pile cap which has a groove at center of its top surface, as shown in Figure 1, for applying vertical load. The sheet piles of which length is measured from the bottom of pile cap are also connected to the pile cap by screws. A succession of sheet pile lengths (Ls) of 10mm, 20mm, 30mm and 40mm or Ls/ L ratios of 0.05, 0.1, 0.15 and 0.2 were used in this study (L: length of pile). The variety of sheet piles is shown in Figure 2. In addition, both sides of sheet pile surface are not glued with sand or any material, so the roughness of the sheet pile is assumed to be smooth.

Beside the models of pile foundation with sheet piles at the four sides of pile cap (PFFS), the pile foundation model (PF) was used in this research with the aim of comparison. Both of them (shown in Figure 3) under combined vertical and horizontal loads were embedded in the same sand and initial condition.

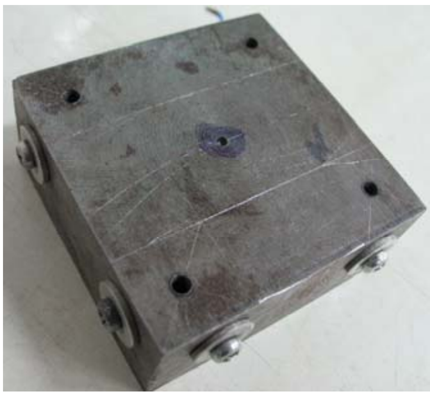


Figure 1 Pile cap with center groove

Figure 2 Variety of sheet pile lengths

Figure 3 Two types of model foundations: PF and PFFS

2.2 Soil Sample

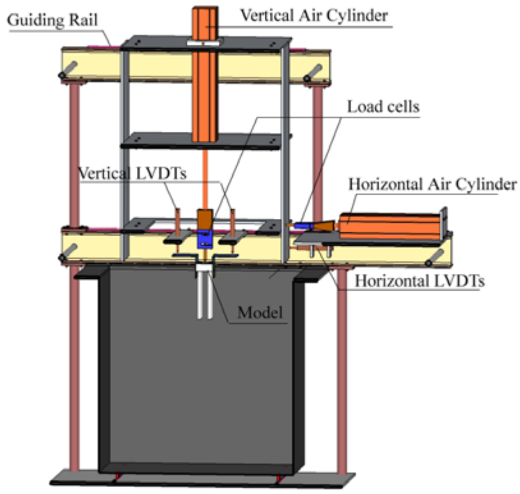
Dry sand, the Puttaisong sand which is easily found in the Northeast of Thailand, used in this research is uniformly graded sand, sorted by particle sizes. The sand was poured from a hopper into the soil container, a steel box with inner dimensions of 80cmx40cmx80cm in length, width and depth, respectively. Its size is large enough with no apparent influences of boundary effects (Al-Mhaidib, 2006). In order to create the same initial condition for all the tests, the height between the bottom of the hopper and deposited sand surface was chosen to be 50 mm and periodically adjusted to the rise of the sand surface to maintain the constant height until the sand was fully poured into the container. In other words, the uniform sand, of which relative density is constant, could be achieved through this way. In addition, pouring the sand until the container became full means that there was no apparent influence from effects caused by the bottom of the container (Al-Mhaidib, 2006). Table 1 summarizes the properties of the sand.

Table 1 Physical properties of experimental sand

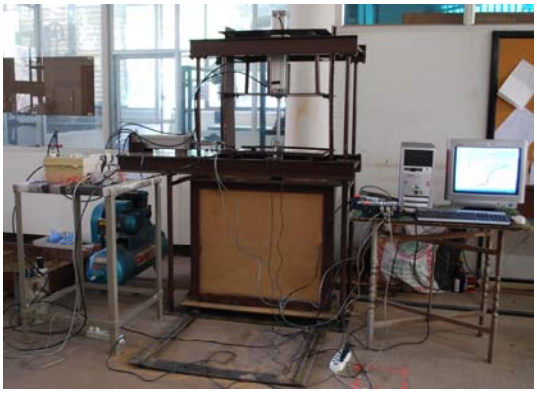
Type	Sand
Unit weight (kN/m^3)	14.39
D60 (mm)	0.395
D30 (mm)	0.360
D10 (mm)	0.240
Uniformity coefficient, C_u	1.646
Coefficient of graduation, C_c	1.367

2.3 Loading System

The test program in this study was performed at Department of Civil Engineering, Khon Kean University, Thailand, by using a new combined loading apparatus designed and constructed by Nguyen and Punrattanasin (2011). The outstanding point of this apparatus is that it can be highly applicable for any combination of vertical, horizontal and moment loadings and displacement paths can be generated and applied to model foundations with precise force, position and direction. There are four main parts in the loading apparatus: loading system, measuring system, control system and data acquisition system. Besides, the loading apparatus includes a soil container which is linearly and smoothly movable out of the loading system by means of its four wheels moving on two rails in order to easily prepare the soil before testing. Two air cylinders were respectively used for apply vertical and horizontal loads on the foundation. The loads and the displacements of the model of foundation were measured via load cells and linearly variable differential transducers (LVDTs). Portable data logger was used to record the data from load cells and LVDTs through a computer. Due to the small size of the pile cap, two arms attached to the surface of the pile cap via screws were used to measure the vertical settlement of the foundation. Figure 4 respectively shows the 3D schematic drawing and general view of the combined loading system



(a) 3D cross section schematic drawing



(b) General view

Figure 4 The combined loading apparatus

2.4 Details of the Tests

A concept of swipe test was first introduced by Tan (1990) was applied to investigate the horizontal capacity and the shape of failure surface in V-H load space. In order to apply the swipe test concept, each model was tested separately in three times. For the first time, the model was applied to vertical load until Vstart= 60%Vmax then horizontal load started applying. The other tests were conducted in the same way with Vstart=75%Vmax and Vstart=90%Vmax, respectively. (Vstart: the specified vertical load, Vmax: the ultimate vertical capacity of foundations).

Table 2 Test Conditions

Type of Loading	Type of Foundation	Name of Test	Number of Tests	Notes
Vertical Loading Test	Pile Foundation	PF	1	i=1: Ls/L=0.05 j=1:Vstart=60%Vmax i=2: Ls/L=0.10 j=2:Vstart=75%Vmax i=3: Ls/L=0.15 j=3:Vstart=90%Vmax i=4: Ls/L=0.20
	Improved Pile Foundation (PFFS)	PFFSi (i=1-4)	4	
Vertical-Horizontal Loading Test	Pile Foundation	H-PF0-j (j=1-3)	3	
	Improved Pile Foundation (PFFS)	H-PFFSi-j (i=1-4; j=1-3)	12	

To determine the ultimate vertical capacity of all the foundations, they were also carried out under purely vertical load. A series of 20 loading tests, grouped and detailed in Table 2, were conducted and reported in this paper. Two kinds of foundations were used in this research. They are pile foundation (PF) and pile foundation with four sheet pile (PFFS). In terms of PFFS, a succession of sheet pile lengths (Ls) of 1cm, 2cm, 3cm and 4cm or Ls/ L ratios of 0.05, 0.1, 0.15 and 0.2 were used in turn (L: length of pile).

3 Experimental Results

In order to properly compare and discuses the experimental results, all the tests were completed with the same sand and initial condition.

3.1 Vertical Loading

Vertical load – settlement relationships of the foundations were plotted in Figure 5 to determine their ultimate capacity (Vmax). The ultimate bearing capacity of the foundation is defined at the peak value in the vertical load–settlement curve. In case, the peak load occurs at very large settlement, according to Punrattanasin et al. (2009), the loading corresponding to the settlement of 0.1B=7mm is considered as the ultimate bearing capacity. It should be noted that the driving capacity of pile foundation is around 130N as the touchdown happens. From Figure 5, the ultimate capacities of the foundations (including driving capacity) at settlement of 0.1B= 7mm are 284N, 315N, 340N, 370N and 415N in cases of Ls/L=0, 0.05, 0.1, 0.15 and 0.2, respectively.

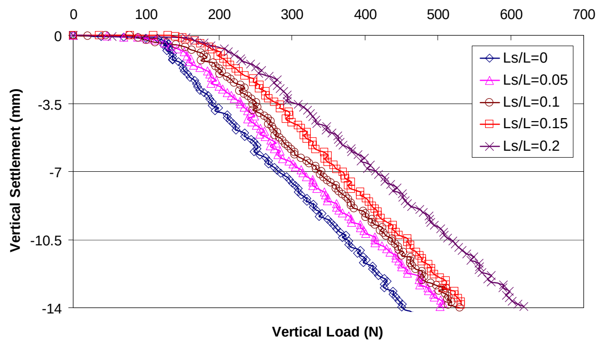


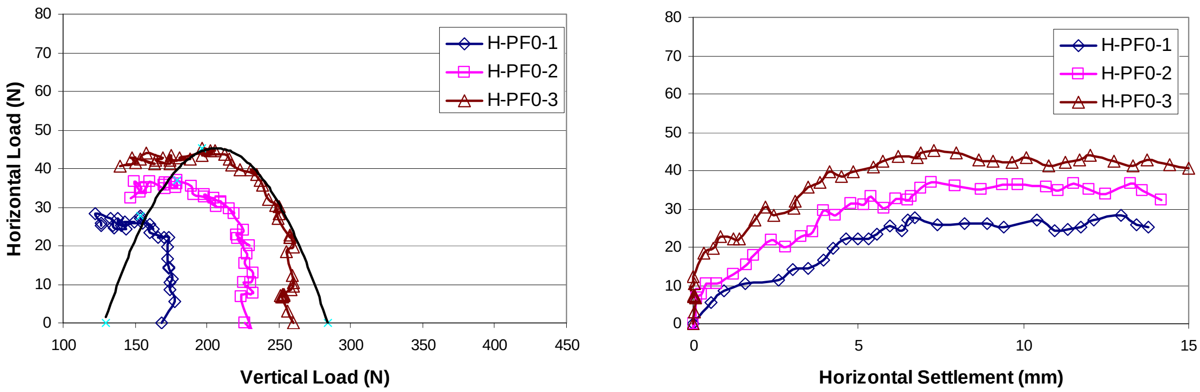
Figure 5 The vertical load – settlement relationship of the foundations

3.2 Horizontal Loading

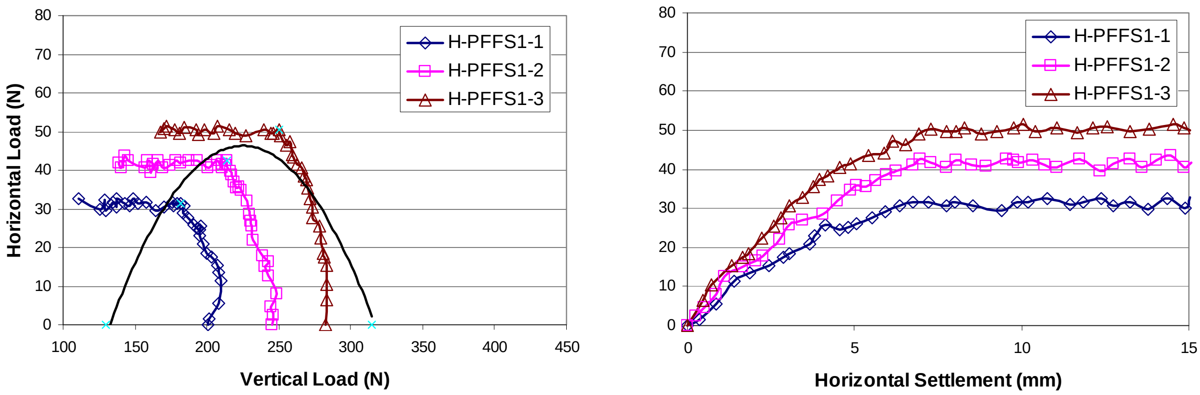
A concept of swipe test was first introduced by Tan (1990) to investigate the horizontal capacity and the shape of failure surface in V-H load space for conical footing on sand. The procedures of swipe test are as follows. Firstly, a vertical displacement is applied until the foundation reaches a specified load or displacement. At this stage, the vertical displacement is fixed (zero incremental vertical displacement) and then the foundation is driven horizontally. The concept was then adopted and modified to identify the horizontal capacity of many types of footings. For example, the maximum horizontal capacities on sand are: Hmax=12%Vmax for the shallow foundation (Gottardi and Butterfield, 1993), Hmax=0.13Vmax for shallow foundation (Punrattanasin et al., 2004) and Hmax=0.132Vmax for sheet pile foundation (Punrattanasin, 2008). In addition, Punrattanasin et al. (2004) indicated that failure surface of horizontal capacity of square shallow foundation is parabolic shape.

A series of model foundations with a succession of sheet pile lengths mentioned above were experimented on sand to investigate sheet piles lengths' effect on horizontal capacity of the foundations. Fifteen horizontal swipe tests (detailed in Table 2) were performed to evaluate how the sheet pile length affect on the horizontal capacity of foundations in V-H load spaces. Besides, it should be noticed that, the driving capacity of pile foundation (130N) was considered as a new zero value for generating the failure surface. Figures 6 presents the results of the horizontal swipe tests for foundations at various sheet pile lengths.

It is clearly shown from Figure 6 that the horizontal loads increase moderately until reaching the peak at horizontal settlement of about 7mm and then slightly decrease. Conversely, the vertical loads fall slightly until the peak then rapidly drop down to failure. The Figure 6 reveals that the ultimate horizontal capacities of PFFS are 45N, 48N, 50N, 53N and 60N in case of Ls/L=0, 0.05, 0.1, 0.15 and 0.2, respectively. As expected, the longer sheet pile provides the greater horizontal capacity.

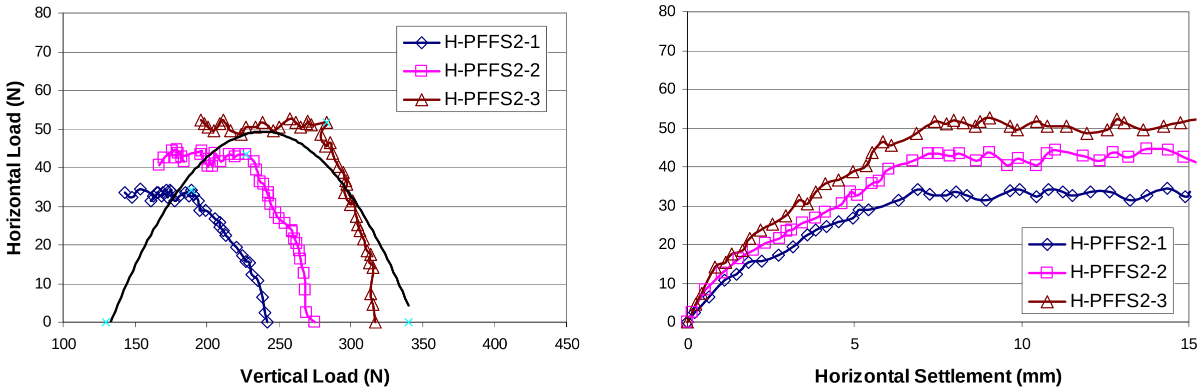


(a) $L_s/L=0$

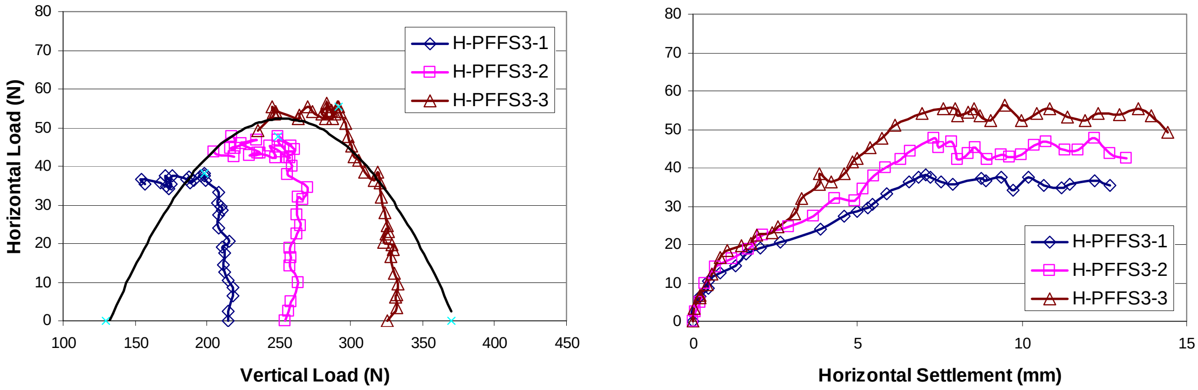


(b) Ls/L=0.05

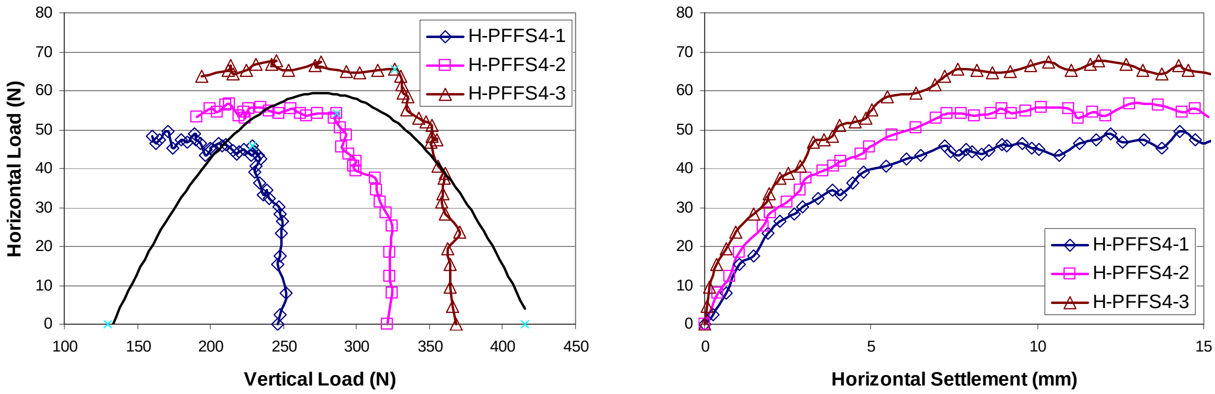
Figure 6 Horizontal swipe tests of PFFS with various sheet pile lengths



(c) Ls/L=0.10



(d) Ls/L=0.15



(e) Ls/L=0.20

Figure 6 (Cont) Horizontal swipe tests of PFFS with various sheet pile lengths

Table 3 summarizes the value and the relationship between ultimate vertical and horizontal capacities of the foundations. It shows that the average ratios of maximum horizontal capacity to ultimate vertical capacity of the improved pile foundation is 15% (or Hmax=0.15Vmax). From the data of Table 3, in terms of horizontal capacity, PFFS are 6%, 11%, 17% and 33% greater than PF in case of Ls/L =0.05, 0.1, 0.15 and 0.2, respectively. It is indicated that sheet piles significantly improve the horizontal capacity of foundation when Ls=4cm.

Table 3 The relationship between ultimate vertical and horizontal capacity of the foundations

Ls/L	Improved Pile Foundation (PFFS)		
	Vertical Capacity (N)	Horizontal Capacity (N)	Hmax/Vmax
0	284	45	0.158
0.05	315	48	0.152
0.10	340	50	0.147
0.15	370	53	0.143
0.20	415	60	0.146

Figure 7 presents trends of the relationship between the bearing capacities of PFFS and the sheet pile length.

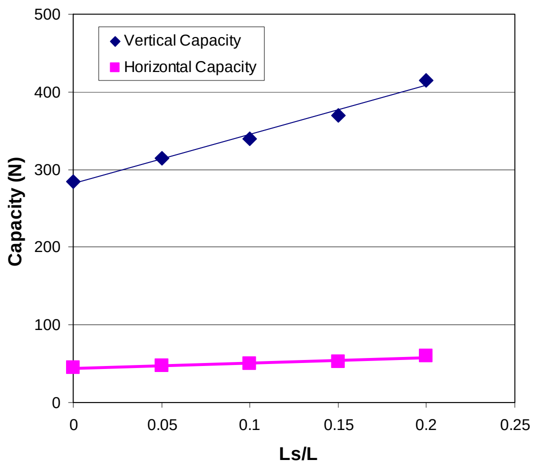


Figure 7 The capacity of improved foundations with different sheet pile lengths

4 Conclusion

A series of 1g physical modeling tests was conducted to evaluate the influence of sheet pile lengths on the pile foundation capacities under combined vertical (V) and horizontal (H) loads on sand by using a new combined loading apparatus. The experimental program was designed to find out the vertical and horizontal capacities of the foundations. The concept of swipe test was adopted to determine the horizontal capacity and shape of yield surface in V-H space. The results clearly demonstrate that attaching four sheet piles around the pile foundations provides significant improvements in capacities both vertical and horizontal. The capacities dramatically increase when the ratio Ls/L reaches 0.2. In deed, the greater percentages of capacities compared with pile foundation are 46% and 33% in terms of vertical and horizontal respectively.

5 Acknowledgments

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