The effect of sheet pile length on the capacity of sheet pile foundation

Influence de la longueur des palplanches sur la capacité des fondations en palplanches

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ABSTRACT

This research is to study the effect of sheet pile length on the capacity of sheet pile foundation. The sheet pile foundation is a shallow footing that is skirted by sheet piles around the periphery. From the previous study, it was indicated that sheet pile can dramatically improve the vertical, horizontal and moment capacities of the existing shallow foundation. This study was performed in the laboratory by using 1g physical modeling test. The new equipment was newly designed and developed in order to study the sheet pile foundation's behavior resting on sand under vertical loading test. The local sand in the Northeastern area was selected in this study. The ground models in the same conditions were prepared in the container tank by the pluviation. The effect of sheet pile length to the capacity of existing shallow footing can be evaluated by the results of load-settlement relationship. The reference case performed with shallow footing was also tested for comparison purpose. The results show the effectiveness of sheet pile to increase the capacity of shallow foundation. An appropriate sheet pile length was also found from this study. Pictures taken during the loading steps in cooperation with image processing technique can be used to identify the mode of failure and can be used to calculate the soil movement and displacement vector below the foundation.

RÉSUMÉ

La présente recherche a pour objet l'étude de l'influence de la longueur des palplanches sur la capacité de fondations en palplanches. Une fondation en palplanches est une fondation superficielle qui est entourée de palplanches à sa périphérie. L'étude précédente avait montré que les palplanches pouvaient énormément améliorer les capacités verticale, horizontale et de renversement de la fondation superficielle existante. L'étude a été menée en laboratoire à l'aide de la modélisation physique à 1g. Le nouvel équipement a été conçu et développé pour étudier le comportement de la fondation en palplanches reposant sur du sable et soumis à des essais de chargement vertical. Le sable local de la région du Nord-Est a été sélectionné pour cette étude. Les modèles de sol ont été préparés dans les mêmes conditions par pluviation dans la cuve. L'influence de la longueur des palplanches sur la capacité de la fondation superficielle existante peut être évaluée par l'examen de la courbe charge-tassement mesurée. La fondation superficielle a également été testée, afin de servir de référence pour la comparaison. Les résultats montrent l'efficacité des palplanches pour la capacité de la fondation superficielle. Une longueur de palplanches appropriée a également été trouvée par cette étude. Des photographies prises durant les paliers de chargement, associées à une technique de traitement d'images, peuvent être utilisées afin d'identifier le mode de rupture et peuvent être utilisées pour calculer les mouvements du sol sous la fondation.

Keywords : sheet pile foundation, periphery, modeling test, pluviation, shallow footing

1 INTRODUCTION

The use of skirted or caisson foundation is becoming common in geotechnical applications especially for offshore structures (Watson and Randolph, 1998). The foundation creates a confined nucleus with its lateral prevention. This results in increased bearing capacity and reduced settlements. The application of skirted and caisson foundations can be used in various soil conditions ranging from soft clay to dense sand. As an alternative design to the conventional shallow foundation, Tokyo Institute of Technology and the Railway Technical Research Institute of Japan proposed the usage of sheet pile foundation (Punrattanasin et al., 2002) to enhance the performance of the existing foundation and to solve the inappropriate spread footing design by applying the design concept of skirted foundation. In the construction of the sheet pile foundation, sheet piles are driven vertically with sufficient length and are connected around spread footing whereas the caisson foundation uses the concrete as a skirted system. Figure 1 shows the schematic drawing and the overview of the proposed sheet pile foundation. The construction of sheet pile foundation to increase the performance of shallow footing has considerable potential as a cost-effective option over using pile in some soil conditions. The primary load from structure is transferred to the subsoil by the shallow foundation and the sheet pile system is mainly an auxiliary to reduce settlement as well as tilting and increase the pull out capacity.

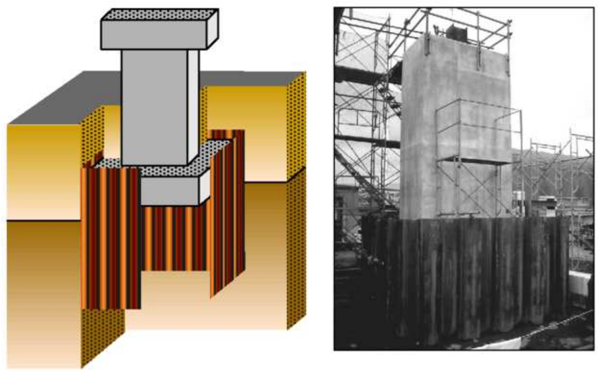

Figure 1. The schematic drawing and the overview of the sheet pile foundation (after Nishioka et al., 2007).

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The researches on sheet pile foundation are now being studied by many research groups in the laboratory and in the field. Figure 2 from the study of Punrattanasin et al. by performing centrifuge tests (2003a and 2003b) shows the comparison between the capacity of shallow and sheet pile foundation in *V-H-M* load space. This 3D picture clearly demonstrates the beneficial effect of the sheet pile in increasing the vertical, horizontal and moment capacities of the shallow footing. Figure 3 shows the full scale loading test performing with shallow and sheet pile foundations with actual scale. The load-settlement results of horizontal loading test in Fig. 4 also indicated the higher horizontal capacity of sheet pile foundation over the shallow footing. The incremental capacity is from the stronger foundation system.

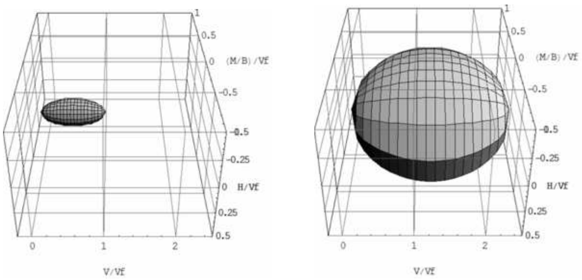


Figure 2. *V-H-M* capacity of shallow and sheet pile foundations from centrifuge tests (after Punrattanasin et al., 2003a and 2003b).

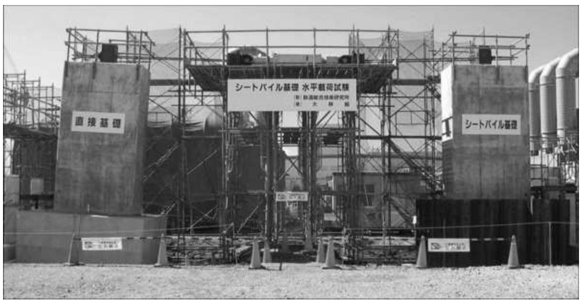


Figure 3. The full scale horizontal loading test on sheet pile foundation (after Nishioka et al., 2007).

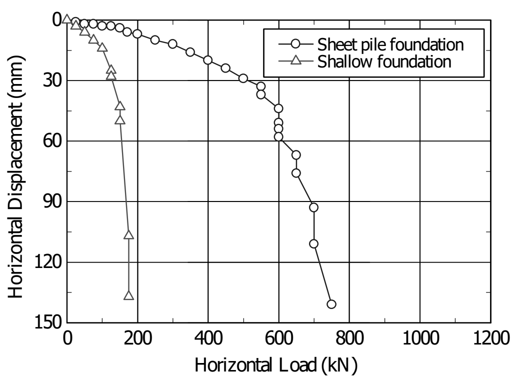


Figure 4. The horizontal capacity of shallow and sheet pile foundations from full scale horizontal loading test (after Nishioka et al., 2007).

The combination of sheet pile system and shallow foundation results in economical advantages, if the sheet pile foundation is designed properly. The aim of this study is continue to investigate the length effect of sheet pile on the performance of sheet pile foundation. Understanding the new foundation behavior and the foundation capacity will make an engineer more confidence in design and construction processes.

2 EXPERIMENT CONDITIONS

This paper presents the extensive results from 1g physical modeling test of model foundations on sand under purely vertical loading. The objective of test is to observe the performance of the sheet pile foundation under various sheet pile lengths. All tests were done and conducted with a same initial condition so that the experimental results can then be properly compared and discussed.

2.1 *Model foundation*

Rectangular models of the sheet pile foundation were used in the experimental investigation. This study, all models are in the plane strain condition where as all previous studies both in 1g and centrifuge tests were in the axial symmetry condition. The reason of choosing the plane strain condition is that in the transparent container the behavior of ground under the foundation can be extensively studied. The model foundation used is divided into two parts; the shallow footing and the skirted or sheet pile system. The rectangular shallow-strip foundation models are made by steel with a width, *B* of 50 mm. The length and thickness of model foundations are 400 mm and 50 mm, respectively. The model of sheet pile system is made by the stainless steel with a constant thickness of 1 mm. Sheet pile lengths measured from the bottom of shallow foundation, *L* of 25, 50, 75 and 100 mm or *L/B* ratios of 0.5, 1.0, 1.5 and 2.0 were used in this study. In this study the both sides of sheet pile surface is not glued with sand or any material. Therefore, the roughness of the sheet pile is assumed to be smooth. Figure 5 shows the sheet pile foundation models.

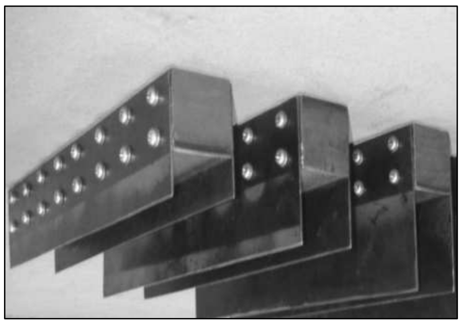


Figure 5. Models of sheet pile foundation.

2.2 *Loading system*

All tests in this study were performed at Khon Kaen University, Thailand. Experimental testing has been conducted by using a transparent container so that the behavior of soil and soil movement beneath the model foundation can be visually observed. A rectangular container with a dimension of 400, 800 and 800 mm for width, length and height, respectively, was used to contain the soil sample. The loading apparatus used to apply the vertical load consists of four parts; a system of jacks, a control system, a system of transducers and a data acquisition system. A key feature of this loading system is that any applied vertical loads can be generated and applied to model footings with high precise force and position. The movement of the footing was measured by a system of two LVDTs and by an image processing technique. The overview of the apparatus and loading system was shown in Fig 6.

2.3 *Soil sample and sample preparation*

The soil used for all tests was dry Putthaisong sand. This local sand is found in abundance in the Northeastern part of Thailand. The physical properties of the sand are given in Table 1. The reproduce of soil strata was prepared by pluviation. The height of the hopper above the deposited sand surface was periodically adjusted with the rise of sand surface to keep the height constant. The uniform sand with a constant relative density could then be achieved. A target relative density, *Dr* of 70.0% was used for comparison purpose throughout all experimental programs.

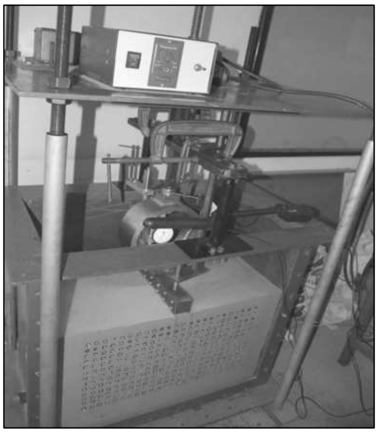


Figure 6. Transparent container and a loading system.

Table 1. Physical properties of Putthaisong sand.

Type	Putthaisong sand
Specific gravity, G_s	2.65
D_{60} (mm)	0.25
D_{10} (mm)	0.18
Coefficient of uniformity, C_u	1.50
Coefficient of curvature, C_c	0.95

3 DETAILS OF THE TESTS

The 1g test programs consist of five vertical loading tests. All tests are grouped and detailed in Table 2. The primary focus of the study is on the vertical capacity of sheet pile foundation on sand at different sheet pile lengths. An appropriate sheet pile length can be found by considering the sheet pile capacity and the construction cost.

Table 2. Conditions of the vertical loading test.

Type of foundation	*L/B*	Test No.
Shallow foundation (reference case)	0	1
Rectangular- strip sheet pile foundation	0.5	2
Rectangular-strip sheet pile foundation	1.0	3
Rectangular- strip sheet pile foundation	1.5	4
Rectangular-strip sheet pile foundation	2.0	5

4 TEST RESULTS

To investigate the ultimate bearing capacity of sheet pile foundations, the test with shallow footing has also been conducted for comparison purpose. The purposes of the vertical loading test were to establish the vertical load-vertical settlement relationship within the vertical capacity of the footings and to evaluate the improvement capacity received from the sheet pile system. The ultimate vertical bearing capacity of the foundation in this study is defined at the peak load in the vertical load-vertical settlement plot. In case where the large settlement occurred, peak load was not selected. Instead the load at a settlement of 0.1*B* (5mm) was chosen. Since the loading system is displacement-controlled, the load and displacement can be continued and measured after the peak load. Figure 7 illustrates the observed vertical load-vertical settlement relationships of a shallow footing and sheet pile foundations. An ultimate vertical bearing capacity of 150.2 N was found for the shallow footing. For sheet pile foundation the vertical capacities at a vertical settlement of 5.0 mm (0.1*B* settlement) of 571.0 N, 604.1 N, 670.0 N and 825.0 N were indicated from the cases of *L/B* = 0.5, 1.0, 1.5 and 2.0, respectively. The results from Fig. 7 clearly demonstrate that sheet pile foundation can dramatically increase the vertical capacity of shallow footing on sand. The longer sheet pile length provides the higher vertical capacity. The improved capacity can be attributed from (1) the end bearing of square footing, (2) the transfer of load to the skin friction of sheet piles, and (3) the confinement effect of soil inside the footing.

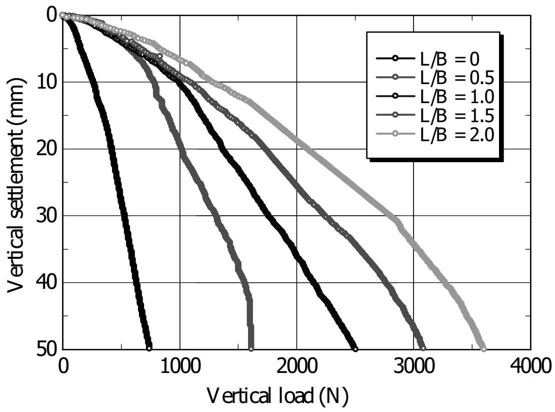


Figure 7. The vertical load- settlement relationship of foundations.

Table 3 summarizes the vertical capacity of footings at various settlements. Since the tests are displacement-controlled, the load and displacement can be continued and measured after ultimate load or at a very high settlement. All tests in this study were performed and conducted up to a maximum settlement of 50 mm before terminating the test. From the tests, it was found that the sheet pile foundation in Test No.5 (*L/B* = 2) provides the highest capacity but it was not suitable to install in sand due to the long length of sheet pile. Figure 8 illustrates the model footing after test. It can be seen that the geometry of sheet pile model especially at the end portion was displaced outward from its origin due to the high stress field encountered inside the footing system during loading. At settlements of 5, 10, 25 and 50 mm, an average capacity of sheet pile foundation (*L/B* = 1.5) is higher than that of the shallow one by about 420%.

Table 3. The vertical capacity of shallow and sheet pile foundations at various settlements.

L/B	Vertical load at various settlements (N)			
	5 mm	10 mm	25 mm	50 mm
0	150.2	260.4	470.8	751.4
0.5	571.0	781.0	1172.1	1612.9
1.0	604.1	995.0	1577.9	2506.5
1.5	670.0	1081.9	1983.6	3095.6
2.0	825.0	1273.3	2449.5	3604.2

To find an appropriated sheet pile length for the construction, the data of vertical capacity and the cost of construction were plotted against the sheet pile length. Figure 9 indicates that a sheet pile length of 50 mm (*L/B* = 1) is suitable for installation based on both the construction cost and the foundation capacity. The advantage of using a transparent container is that the behavior and movement of soils beneath the foundation can be visually observed. In cooperation with an image processing technique, pictures during the test can be captured and recorded. Figures 10(a) and 10(b) show the response of ground after testing. Using pictures taken at the beginning and the end of the test, the displacement vector can then be generated. Figures 11 and 12 show the displacement vectors from the Test No. 1 and No.4, respectively. It is clearly shown from the pictures that after testing the soils below the shallow foundation were moved to the left and right sides and the displacement vectors were occurred up to the depth of 100 mm measured from the ground surface. For this case, the failure surface in the soil was extended to the ground surface. For the case of sheet pile foundation, the displacement vectors of the soils were also moved to the left and right sides but the displacement vectors can be occurred up to the depth of 200 mm below the soil surface. The failure surface can also be observed at the ground surface but the size of failure surface outcrop is smaller than that of the case of shallow foundation. This is due to the beneficial effect of the sheet pile foundation. Mode of failure for two cases can be identified as general shear failure.

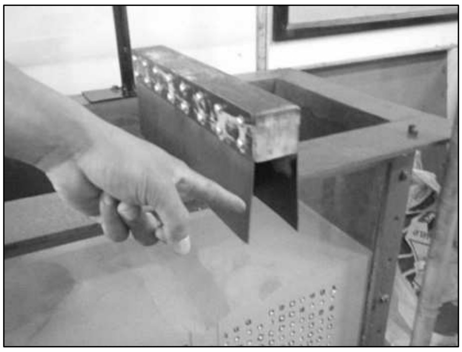


Figure 8. The model after test (Test No.5).

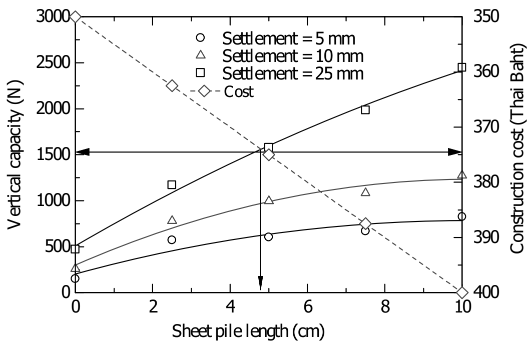
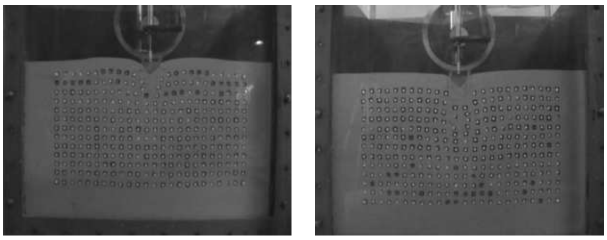


Figure 9. The cost-effective and foundation capacity relationship.



(a) Shallow foundation (b) Sheet pile foundation (L/B = 1)

Figure 10. The ground response after loading tests.

5 CONCLUSIONS

A series of 1g physical modeling test has been conducted with the aim of observing the performance of sheet pile foundation on sand under vertical loading. The sheet pile foundation is now being considered as a method to improve the capacity of existing foundation. The effect of sheet pile length to the capacity of sheet pile foundation can be evaluated from the results of load-settlement relationship. The test results indicate

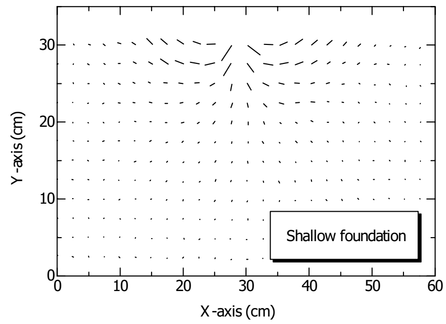


Figure 11. Displacement vector of ground under shallow foundation.

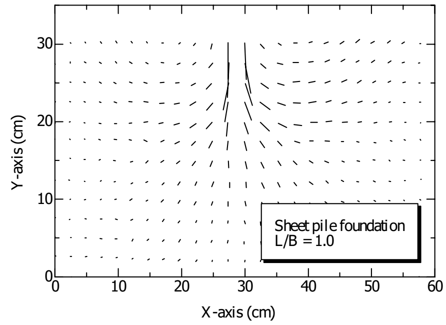


Figure 12. Displacement vector of ground under sheet pile foundation.

that sheet pile foundation can substantially increase the vertical capacity of shallow footing on sand. An appropriate sheet pile length of L/B = 1 was found from this study based on the results of the construction cost and the foundation capacity. Pictures taken at the beginning and the end of test in cooperation with image processing technique can be used to identify the mode of failure and can be used to calculate the displacement vector below the foundation.

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