Experimental study on reinforcement of existing bridge pile foundations using sheet pile wall

Etude expérimentale sur le renforcement des fondations de ponts existants en utilisant les écrans en palplanches

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ABSTRACT: Due to the riverbed soil excavation for the utilization in construction works for many years, the level of riverbed of the Mae Nam Ping River in Thailand has been considerably lowered, resulting in reduction of embedment lengths of piles of bridge foundations. Erosion was not a cause of the lowering of the riverbed. Reductions of bearing capacity due to the lowering of riverbed soil is the main cause of bridge pile foundation settlements or collapses at present. In order to prevent the damages of existing bridge pile foundations caused by the riverbed soil excavation, a reinforcement method using sheet piles called "Sheet Pile Wall (SPW) reinforcement" is proposed in this paper through a series of vertical load tests on a small-scale model pile foundation in dry sand ground at 1-g field.

RÉSUMÉ: Suite à l'excavation du lit de fleuve qui est réutilisé comme matériaux pour la construction pendant plusieurs années, le niveau du lit du fleuve Mae Nam Ping en Thailand devient de plus en plus bas. Par conséquent, la longueur d'ancrage des pieux de fondations des ponts sera diminuée. L'érosion n'est donc pas la cause majeure de l'abaissement du lit. La diminution de la capacité portante due à l'abaissement du lit est la principale origine qui provoque le tassement voire l'effondrement de fondations des piliers. Afin de prévenir les conséquences des ponts existants endommagés due à l'excavation du lit, une méthode de renforcement en utilisant les écrans en palplanches (SPW) est proposée dans le présent article à l'aide d'une série des essais de chargement vertical sur un modèle de fondation de pieux à petite échelle dans un sable sec dans un champs 1-g.

KEYWORDS: Reinforcement,` Existing bridge pile foundation, Riverbed soil excavation, Model load test.

1. INTRODUCTION

In the past decade, the Mae Nam Ping River crossing bridges in Chiang Mai and Lamphun, located in the northern area of Thailand (Figure 1), encountered pile foundation damages frequently.

Figure 1. Location of the Mae Nam Ping River in Chiang Mai and Lamphun, Thailand.

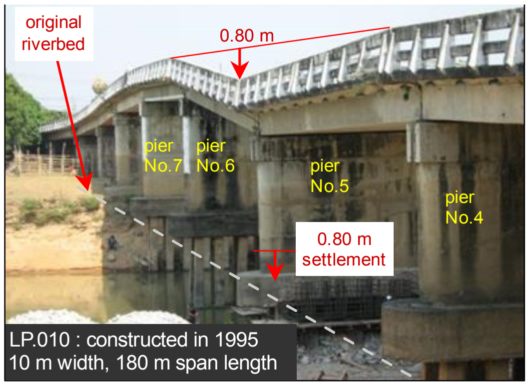

Figure 2. Differential settlement of the bridge LP.010 in Lamphun, Thailand.

Figure 3. An example case of undamaged bridge which has potential risk of damaging.

Figure 2 shows the first case of bridge foundation damage in 2006. One of pile foundations of the bridge LP.010 in Lamphun settled during a high flood season. The investigation and arrangement for the solution were performed for 2 years. The settled bridge LP.010 was repaired in 2008 by using new additional piles, extension of the footing, jacking up the bridge girders and extending the height of the settled bridge pier by 0.80 m to keep flat level of the bridge slabs.

The main cause of the bridge foundation damages mentioned above was the lowering of riverbed soil, in other words, the reduction of pile embedment length. Though the damaged bridges were repaired, most of undamaged bridge pile foundations along the river still have potential risks of damaging due to the riverbed soil excavation as shown in Figure 3. It should be noted here that excavation of the riverbed is prohibited by regulation at present.

In order to obtain an efficient countermeasure for the existing bridge pile foundations subjected to the problem of riverbed soil excavation, a fundamental experimental study was carried out in this research. Considering safety, economic and uncomplicated approach, a reinforcing method using sheet pile wall (SPW) called "SPW reinforcement" (SPW method, hereafter) is proposed.

Figure 4 illustrates the concept of SPW reinforcement method. The construction procedure of SPW reinforcement consists of 2 simple steps without new additional piles or any modifications of existing structures. Firstly, a permeable sheet pile wall is constructed surrounding the existing problematic bridge pile foundation. Finally, the empty space inside the SPW is filled with sand or other porous materials such as crushed concrete.

A method for reinforcing an existing pile foundation by means of sheet pile wall, called In-cap Method, has been proposed by Fukuda et al. (2005). The In-cap method surrounds the existing foundation footing to a required depth, solidifies the soil inside of the sheet piles for improvement of the bearing capacity of the footing and integrates the improved footing with the existing foundation. The SPW reinforcement method proposed in this paper has similar feature to the In-cap Method, however, a big difference between the two methods is that no soil (ground) exists around the sheet pile wall in the SPW reinforcement method. The shape of the proposed SWP reinforcement method is similar to that of a coffer dam. A feature of the SPW method is to use permeable sheet pile wall in order to minimise the interference of river stream.

In this study, series of vertical load tests on small-sized model pile foundations at 1-g field were carried out to demonstrate the validity of the SPW method and to investigate the mechanism of the SPW method, because the actual damages of the bridge foundations in Thailand were caused by large settlements with little horizontal displacement.

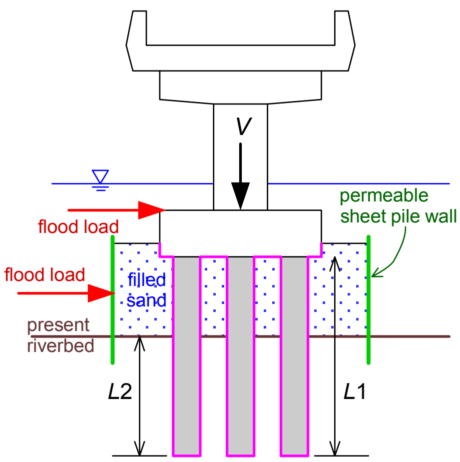

Figure 4. A concept of Sheet Pile Wall (SPW) reinforcement method.

2. OUTLINE OF THE EXPERIMENTS

2.1 *Model foundation*

Figure 5 shows the configurations and dimensions of the 4-pile pile foundation model. Geometrical and mechanical properties of the model pile and the pile cap are listed in Tables 1 and 2.

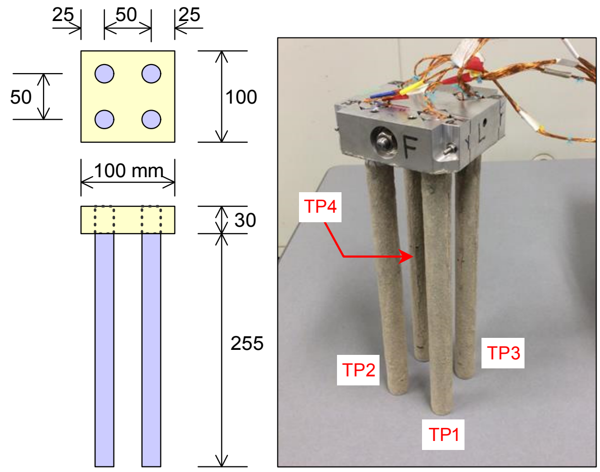

Figure 5. Configurations of the 4-pile pile foundation.

Table 1. Geometrical and mechanical properties of the model pile.

Properties	Value
Outer diameter, D (mm)	20
Wall thickness, t (mm)	1.1
Effective length from raft base, L (mm)	255
Young's modulus, E_p (N/mm^2)	70267
Poisson's ratio, ν	0.31

Table 2. Physical and mechanical properties of the model pile cap used in 4-pile pile foundation.

Item	Value
Width, B (mm)	100
Length, L (mm)	100
Thickness, t (mm)	30
Pile spacing, s (mm)	50
Normalised pile spacing, s/D	2.5
Density, ρ (t/m^3)	2.79
Young's modulus, E (MPa)	73000
Poisson's ratio, ν	0.33

2.2 *Model sheet pile walls (SPW)*

A PVC (polyvinyl chloride) pipe having 140 mm inner diameter with 135 mm length as shown in Figure 6 and Table 3 was used as model SPW in the reinforcement stage of load tests. Strain gauges were instrumented on the outer surface of SPW to measure vertical (axial) and horizontal (hoop) strains during the load tests.

Table 3. Properties of the model SPW.

Item	Value
Outer diameter, D_o (mm)	151
Inner diameter, D_i (mm)	140
Height, H (mm)	135
Wall thickness, t (mm)	5.5
Density, ρ (t/m^3)	1.415

Young's modulus, E (MPa)	2100
Poisson's ratio, ν	0.31

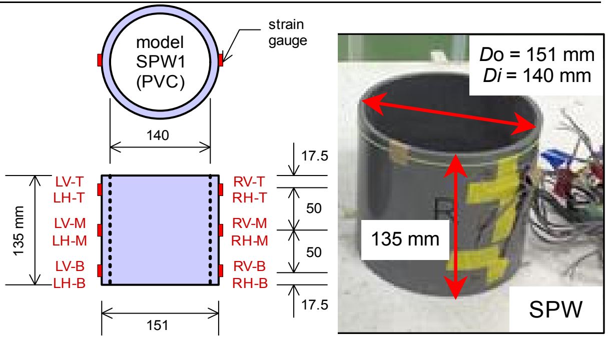

Figure 6. Configurations of the model SPW.

2.3 *Model ground*

The soil used for model ground in this study is a dry silica sand having the properties as shown in Table 4. The model ground with a relative density, D_r, of about 82% (ρ_d = 1.533 t/m^3) was prepared in a soil box having dimensions of 566 mm in diameter and 580 mm in depth.

Table 4. Properties of the sand used for model ground.

Property	Value
Density of soil particle, ρ_s (t/m^3)	2.668
Maximum dry density, ρ_{dmax} (t/m^3)	1.604
Minimum dry density, ρ_{dmin} (t/m^3)	1.269
Maximum void ratio, e_{max}	1.103
Minimum void ratio, e_{min}	0.663

3. EXPERIMENTAL RESULTS

VLTs on the 4-pile pile foundation were carried out at the initial condition and in each stage of the pile embedment length reduction and the SPW reinforcement, as shown in Figure 7 (reduction stage) and Figure 8 (reinforcement stage). In the reinforcement stage, SPW1 was located very close to the model foundation, as shown in Figure 9. It is desirable to minimise the size of the SPW so that the SPW structure does not interfere river stream as much as possible when the SPW reinforcement is applied to an actual bridge foundation.

Figure 10 shows load-settlement curves at the initial stage No.1 and in the embedment reduction steps No. 2 to No. 4. Note here that settlement was zeroed at the start of loading in each step for comparison. It is seen that vertical resistances and initial stiffness of the pile foundation decreased with the reduction of pile embedment length from No. 2 to No. 4. It is also seen that the load-settlement curves in the reduction steps No. 2 and No. 3 exhibit a plunging behaviour and the response in step No. 4 exhibits a softening behaviour, while the response at the initial stage No. 1 shows a progressive failure behaviour.

Figure 11 shows load-settlement curves in the reinforcement steps No.5 to No.7, comparing with the results at the final embedment reduction step No.4 and the initial stage No. 1. It is seen that the vertical resistance and stiffness of the 4-pile pile foundation increased from step No. 4 to step No. 7 with increasing pile embedment length using the SPW reinforcement. In particular, the vertical resistance at the final reinforcement step No. 7 was much greater than that of the initial stage No. 1.

Figures 12 and 13 show the loads carried by the 4 piles and the raft at the initial stage (step No. 1) and at step No. 7 (the final reinforcement), respectively. It is seen from the comparison of both figures that the vertical resistances of both the raft and the 4 piles increased by approximately double, comparing step No. 7 with step No. 1, showing a considerable effect of the SPW reinforcement.

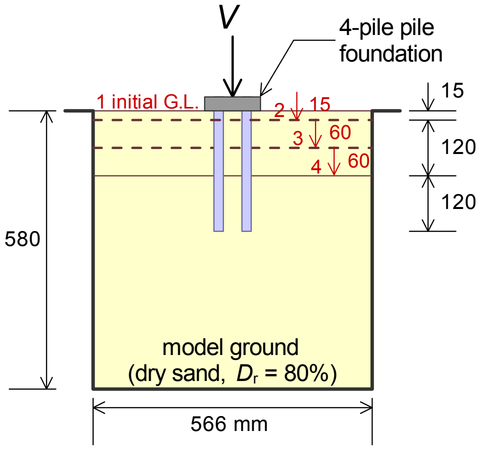

Figure 7. Test conditions of VLTs at the initial stage and in the embedment reduction stage.

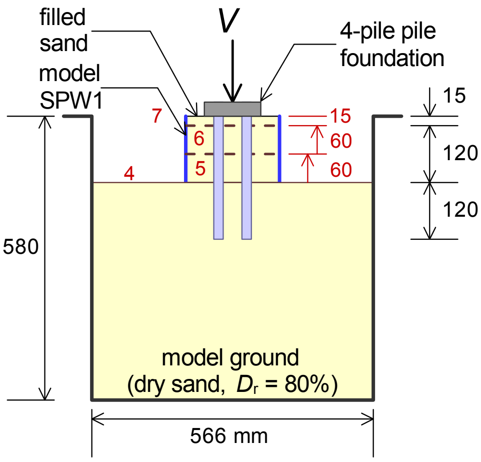

Figure 8. Test conditions of VLTs in the reinforcement stage.

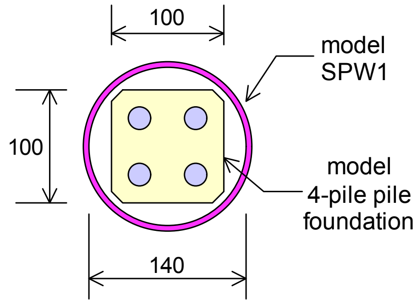

Figure 9. Top view dimensions of SPW reinforcement in VLTs on 4-pile pile foundation.

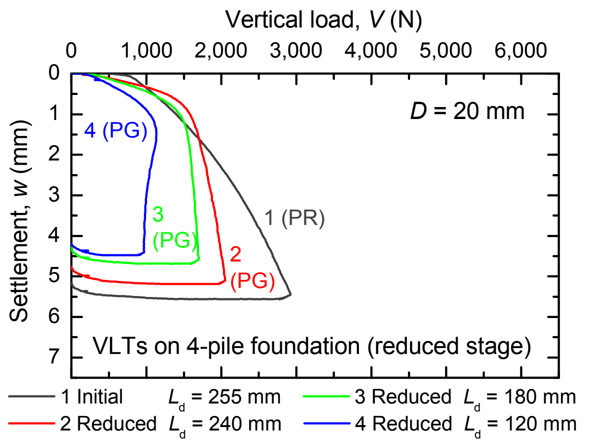

Figure 10. Load-settlement curves of the foundation at the initial stage and in the stage of pile embedment reduction.

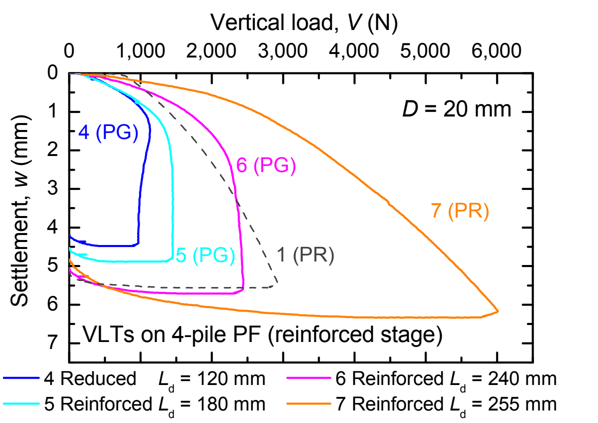

Figure 11. Load-settlement curves in the reinforcement stage.

Figure 14 show changes of distributions of hoop strains of the SPW with increasing normalised settlement of the foundation, w/D, where w is the settlement and D is the pile diameter, respectively, during load test at the final reinforcement step No. 7. Note that compression strain is taken as positive and tension strain is taken as negative. It is seen that the maximum values of hoop strain were generated around the SPW base. Absolute magnitudes of the hoop strains were larger than those of the axial strains at each w/D. This means that the soil inside the SPW is subjected to large horizontal stresses by the existence of SPW. Hence, it is reasonable that the foundation, especially the raft component, at step No. 7 has the larger resistance than that of the initial stage. Although the direct estimation of the horizontal stresses of the soil inside the SPW from the measured hoop strains of the SPW is difficult, the results of Figures 14 indicate that larger vertical and horizontal stresses are generated in the soil inside the SPW at step No. 7.

Figure 15 shows a conceptual expression of stress transfer from the raft base to the soil inside the SPW. A part of the vertical load on the foundation is supported by the raft. The vertical load supported by the raft base is transferred to the soil inside the SPW. The horizontal stresses as well as vertical stress in the soil are increased by the increase in the raft base stresses due to the existence of the SPW. Hence, it seems to be reasonable that the raft resistance after the construction of the SPW becomes larger than that at the initial condition. It is inferred from the experimental results that efficiency of the SPW reinforcement is governed by size (distance) relative to the existing foundation, and stiffness of the SPW as well as stiffness of the soil inside the SPW.

4 CONCLUSIONS

Main findings from the experiments are:

(1) A significant reduction of the pile foundation resistance is caused by the loss of the vertical resistance of the raft due to a small amount of the soil excavation beneath the raft.

(2) After that, the foundation resistance decreases with increasing the depth of the soil excavation.

(3) The model foundation reinforced by the SPW method exhibits higher resistance than that at the initial condition.

(4) An important mechanism of the SPW reinforcement method is that the filled soil inside the SPW are effectively confined by the stress transfer from the raft base and the SPW.

5 REFERENCES

Fukuda, H., Kato, K., Aoyagi, M., Inagawa, H, and Shioi, Y. 2005. Application of reinforcing methods for existing pile foundation on soft ground (In-cap Method), Public Works Research Institute: The 23rd US - Japan Bridge Engineering Workshop.

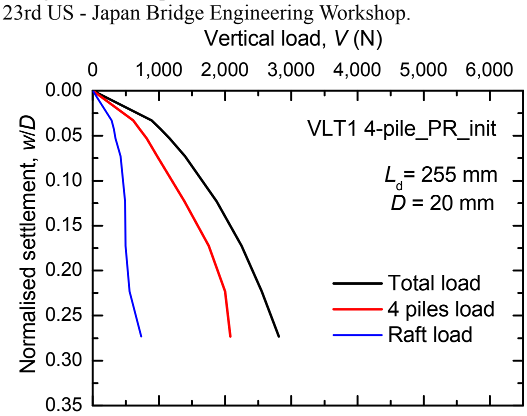

Figure 12. Loads carried by the piles and the raft at the initial stage.

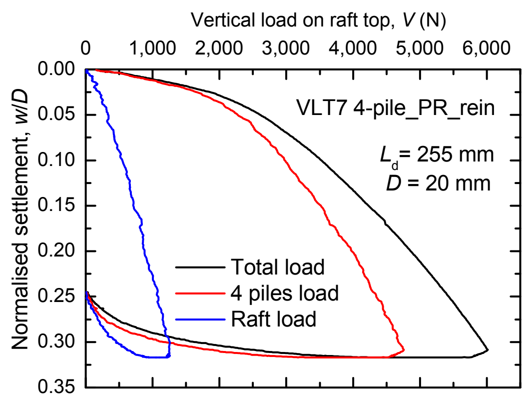

Figure 13. Loads carried by the piles and the raft at the final reinforcement No. 7.

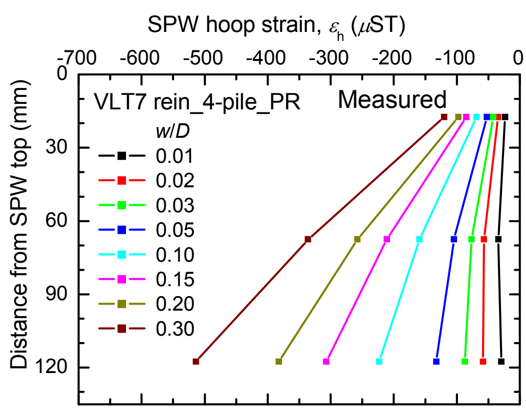

Figure 14. SPW hoop strain distributions in the final reinforcement stage of VLTs on 4-pile pile foundation.

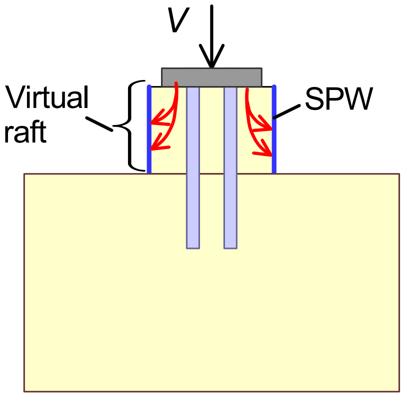

Figure 15. Conceptual expression of stress transfer from the raft to the soil inside the SPW.