Effect of Lateral Soil Movement of Unstable Slope on Socketed Piles

Tschickardt T. G., Lee C.Y.

Abstract— **The stability of a slope is an important issue to prevent landslides, which in many cases results in extensive property damage and even in loss of human lives. The severity of a slide can be a major factor that disturbs the sustainable development in a country. A quintessential problem is the ensuring of slope stability. One of many measurements is the application of using stabilization piles, because it is an efficient and effective solution since the installation of piles improves the equilibrium of the slope. The objective of this study is to investigate the effect of lateral soil movement of unstable slope on socketed piles. A total of 41 tests with free and fixed head socketed model piles have been conducted to investigate the pile resistance subjected to lateral soil movements. The experimental model pile tests were conducted in the laboratory with a large shear box apparatus. The conducted model pile tests had variable parameters such as the pile characteristics (rigid or flexible model piles), the pile spacing, the number of row of piles and also the pile group configuration such as 'zigzag' or parallel pile arrangement. The higher stiffness of the rigid piles is responsible for higher resistance to lateral soil movement than of flexible piles, but the low stiffness of the flexible piles will cause pile deflections. It was found that the group interaction and arching effect would increase with decreasing pile group spacing. The use of rigid and flexible piles in one pile group configuration considered as a hybrid pile group arrangement. This hybrid pile group arrangement may develops higher resistance for lateral soil movement and pile deflection.**

Index Terms— **Lateral soil movement, unstable slope, stabilization piles, soil resistance**

I. INTRODUCTION

The stability of a slope is important to prevent landslides, which in many cases results in extensive property damage and even in loss of human lives. The severity of a landslide is a major factor that disturbs the sustainable development in a country. It is important to understand the regions with high risk for potential landslides and to predict slope disaster based on geotechnical and geological engineering for a sustainable development (Murakami et. al, 2014).

Ensuring the stability in both, natural and man-made slopes continues to be a quintessential problem in geotechnical engineering. The balance of the slope stability is determined by shear stress and shear strength, but a slope also has to withstand the undergo movement of soil. An existing stable slope may lose its stability as a result of various factors, such as climatic events and natural erosion, lead to soil movement and become dangerous to the surrounding area. The priority is to prevent potential slides when choosing a new construction site or existing ones and to apply appropriate measurements to stabilize the slope. One of many measurements is the application of using stabilization piles (Chen and Martin, 2002). Stabilization piles are an efficient and effective solution since the installation of piles will increase the stability of the slope (Abbas et Al, 2010). The analysis of a pile reinforced slope requires that the sliding soil mass and the reaction of the piles to be known. In earlier researches, these issues were analyzed and addressed as pile/slope system (Hassiotis et al, 1997).

Kourkoulis et al (2012) indicated the problem of piles subjected to lateral soil movement of an unstable slope as shown in Figure 1. If the lateral movement of soil increases over the limit of the slope stability, the pile is subjected to the sliding mass and the reinforcing pile will be affected by bending moment and has to bear the lateral soil movement otherwise the slope will fail. Pile reinforced slope stability depends on factors such as: fixity conditions of pile head and base, pile length above sliding surface, pile diameter, pile stiffness, pile group configuration, pile spacing and soil properties. The understanding of those important factors is quite essential to stabilize an unstable slope with minimum piles and to achieve a cost effective solution.

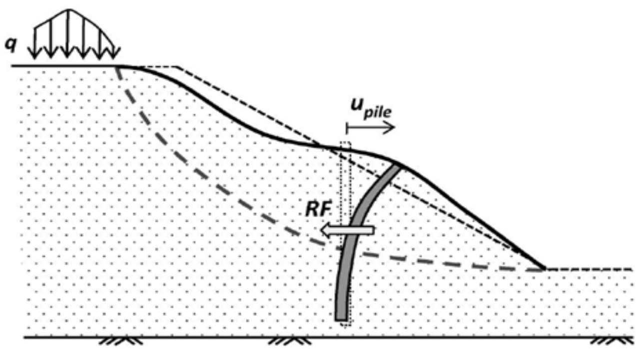

Figure 1: Pile Behaviour on unstable Slope (Kourkoulis et al, 2012)

II. TEST EQUIPMENT

Testing Steel Vessel

The testing vessel was modified from a large direct shear box to study the response of model pile behavior subjected to lateral soil movement. It was made from steel sheet of about 3mm thickness, having internal dimensions of 500mm high, 500mm long and 500mm wide, as shown in Figures 2 and 3. Two vertical steel plates were placed across the 500mm width inside the vessel. The steel plates were hinged at mid-height with the lower parts of the steel plates fixed to the bottom of

Tschickardt, T. G., Civil Engineering Department, Universiti Tenaga Nasional, Malaysia.
Lee, C.Y., Civil Engineering Department, Universiti Tenaga Nasional, Malaysia.

the vessel while the upper parts were free to rotate around the hinges. This would allow the soil in the lower part of the vessel to be stationary while that in the upper part of the vessel was subjected to lateral movement as the upper plates rotated about their hinges. A motor-controlled piston was attached to upper part of the steel plate to push it to rotate about its hinge and subsequently caused the upper part of the soil subjected to a triangular profile of lateral movement; with the maximum and zero displacements at soil surface and level of hinges of the two steel plates, respectively. A load cell of 10kN capacity was incorporated in the loading system to measure the force required to move the upper soil layer. Linear displacement transducers were used to measure the applied soil movement and the pile deflection.

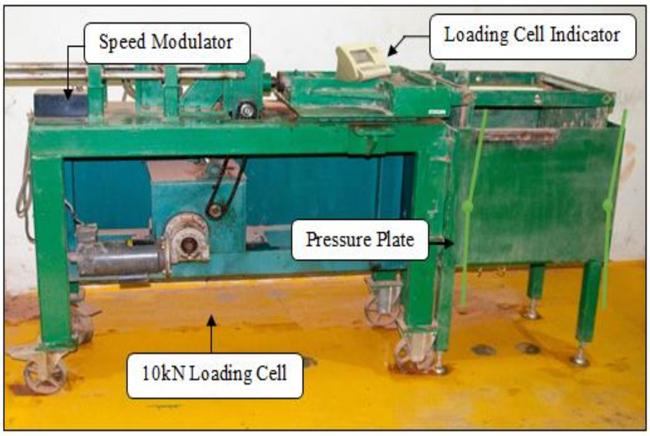

Figure 2: Modified Model Pile Testing Vessel

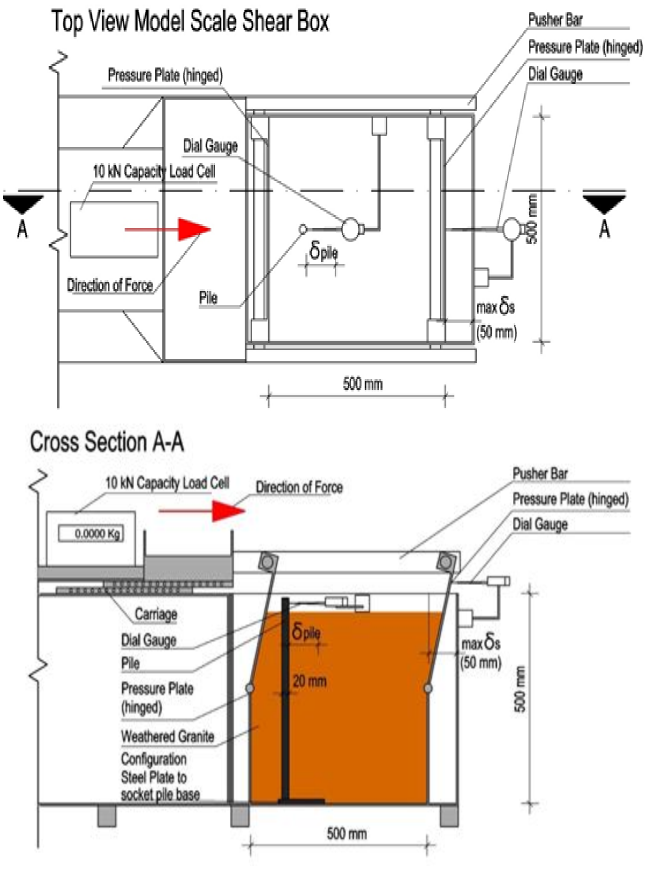

Figure 3: Modified Model Pile Testing Vessel Schematic Diagram

Model Piles

Figure 4 shows the model flexible and rigid piles with length of 460mm and 20mm diameter.

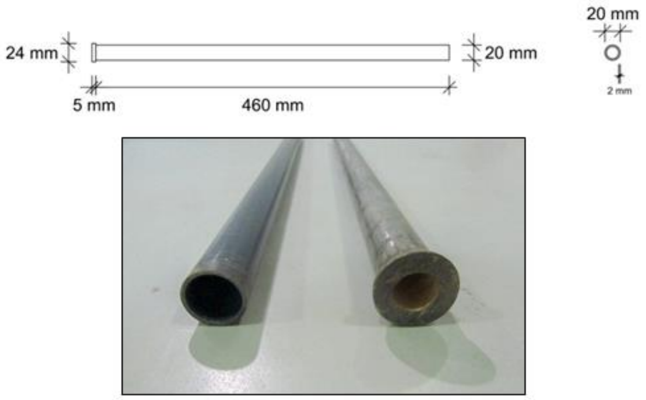

Figure 4: Detail of Model Pile and Fabricated Top Steel Plate

Steel Plates for Model Piles

A top steel plate was fabricated to guide the installation of model piles accurately in their required positions. The top steel plate is shown in Figure 5 and it has the dimension of

600mm by 130mm with five rows of drilled holes. Each row consists of 23 drilled holes at spacing of about 20mm. The drilled hole has a size of 20.05mm to ensure a smooth installation of the model piles in their required positions. The 23 drilled holes in the steel plate may provide sufficient variation of pile configuration. A similar bottom steel plate was used to provide the socketed boundary condition at the pile base.

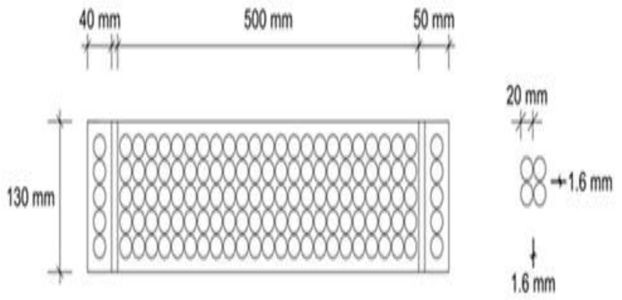

Figure 5: Detail of Fabricated Top Steel Plate

III. EXPERIMENTAL PROCEDURES

Weathered granite soil is widely found in Malaysia and it was used in the experimental study. The model piles were installed into the drilled holes of the bottom steel plate to ensure the fixity condition at the base of the pile for the required pile group configuration (Figure 6a). Then the dry weathered granite soil was rained into the testing vessel. The weathered granite soil was compacted gently in several layers to achieve an average dry density of 60% - 70% (Figure 6b). A loading rate of 0.85 mm/min was used in all the model pile tests. Linear displacement transducers were used to measure the soil and pile head displacements.

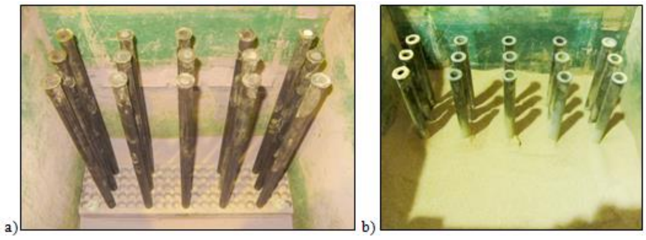

Figure 6: Typical Arrangement of Model Steel Piles

IV. EXPERIMENTAL RESULTS

A series of tests was performed mostly on the free head socketed model piles. However a few fixed head socketed model pile tests were also carried out (Figure 7).

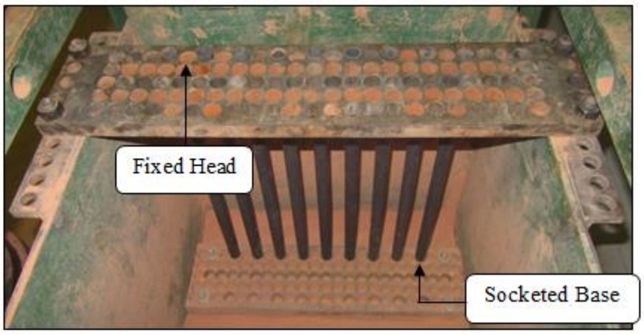

Figure 7: Fixed Head Piles with Socketed Base

Figure 8 shows the normalized soil pressure (P/P_{S-R}) and normalized pile deflection (δ_{Pile}/d) versus normalized pile spacing (D_2/D_1) for one row of piles arrangement, where P= maximum lateral soil pressure on pile group, P_{S-R}= maximum lateral soil pressure on single rigid pile, δ_{pile}= pile head deflection, d=pile diameter, D_1= pile spacing and D_2= clear interval between piles. The rigid piles exhibit higher soil pressure than flexible piles but the soil pressures on both rigid and flexible piles decrease with increasing pile spacing. The pile head deflection increases with pile spacing.

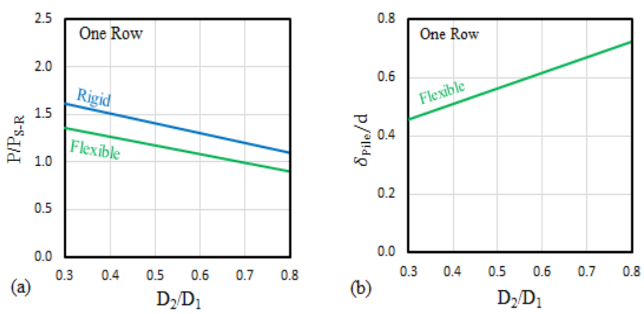

Figure 8: Normalized Soil Load and Normalized Pile Deflection for One Row Arrangement

Figures 9a and 9c show the normalized soil pressure for two row of parallel and zigzag arrangements. The zigzag arrangement consists of more than one row of piles with an offset at alternate row of piles. The hybrid arrangement consists both rigid and flexible piles. The leading row is consisted of rigid piles and the trailing row is consisted of flexible piles at same spacing.

The aim of these pile arrangements was to investigate the effect of pile spacing on load transfer mechanism on both rigid and flexible piles. The load carried by two rows of parallel pile arrangement is about 17% higher than that of one row of pile arrangement. As expected, the rigid pile capacity is about 21% and 10% higher than flexible and hybrid pile arrangements, respectively. However the zigzag arrangement exhibit about 6% higher pile load capacity than that of parallel arrangement. The pile resistance developed by hybrid arrangement lies in between those measured for rigid and flexible pile configurations. The pile resistance of the three different pile arrangements decreases with increasing pile spacing.

Figures 9b and 9d show the normalized pile head deflection for two rows parallel and zigzag arrangements. It was found that the parallel arrangement develop larger pile deflection than that for the zigzag arrangement. The deflections of two different pile arrangements increase with increasing pile spacing. The leading row of the hybrid pile arrangement consists of rigid piles and hence induced less pile deflection.

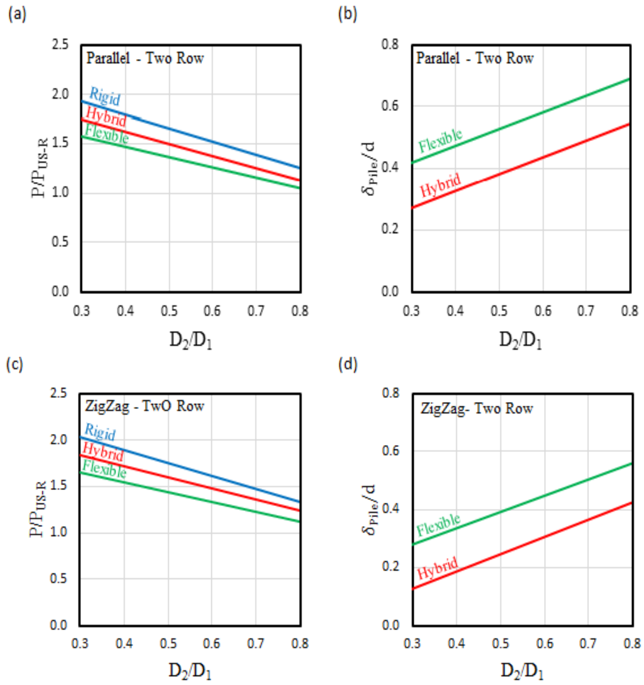

Figure 9: Normalized Soil Pressure and Normalized Pile Deflection for Two Row Parallel and zigzag Arrangement

Figures 10a and 10c show the normalized soil pressure for three rows parallel and zigzag arrangements. The zigzag arrangement consists of a leading row of rigid piles and two offset rows of trailing flexible piles. The measured results indicate again that the pile resistance increases with increasing number of piles and decreases with pile spacing. Figures 10b and 10d show the normalized pile head deflection for three rows parallel and zigzag arrangements. It was found that the parallel arrangements develop larger pile deflection than that for the zigzag arrangement. The deflections of the flexible and hybrid pile arrangements increase with increasing pile spacing.

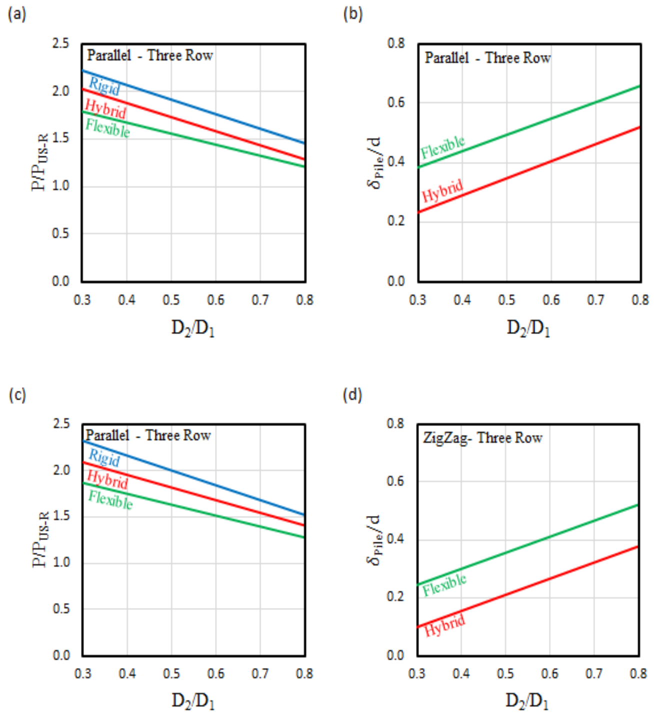

Figure 10: Normalized Soil Pressure and Normalized Pile Deflection for Three Row Parallel and zigzag Arrangement

V. Conclusion

A series of model tests has been conducted in this study to investigate the effect of lateral soil movement of unstable slope on socketed piles. From the model pile test results, it was found that the loads acting on the model piles increase as the relative soil movement increases. However, the pile loads appear to reach a maximum value and remain constant when the soil movement reaches about two times pile diameter. This implies that any additional soil movement has no more effect on the pile load transfer mechanism. The loads acting on the model piles increase with increasing pile rigidity but decrease with increasing pile spacing. Each pile in a group exhibits like a single pile behaviour without any arching effect when pile spacing is greater than 3 times pile diameter. The measured loads acting on the model piles in the zigzag arrangement are about 6% higher than loads in parallel arrangement. This indicates that multi soil arching effects for a zigzag arrangement of piles provide piles more restraint to soil movement. The parallel pile arrangement develops larger pile deflections than those for the zigzag arrangement.

Acknowledgement

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