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The impact of driven plate piles to cohesive slope behaviour

L'impact des pieux de plaques enfoncés sur le comportement des pentes cohérentes

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ABSTRACT: Plate pile technique involves driving vertically in the slope an array of angle bars, each of which is outfitted with a rectangular steel plate welded onto one of the bar legs to hold the sliding soil in position. However, as of writing, no investigation exists on its impact to rotational slope failure as it is typically used for translational colluvium slides, nor is the effect of altering the traditional shape of the plate. Hence, laboratory model tests were conducted on small-scale English China Clay slopes. Maximum sustained hydraulic ram loads at the crest were compared for unreinforced slope, and those reinforced with traditional plate piles and with plate piles outfitted with circular steel plates with the same surface area as the traditional one. All the reinforced models showed no rotational slip, instead, the loading plate punched into the slope. Under similar soil conditions, the failure load was increased by around 10% and 7% for rectangular and circular plate piles, respectively although the mode of failure shifted from being rotational slope failure for unreinforced slope to local punching shear failure for reinforced slope models, although these observations seemed to have been influenced to some extent by the boundaries set by the test box. Results suggest that plate piles can also improve a rotational slip. Nevertheless, using a circular plate pile with the aforementioned geometrical properties, did not increase the load failure further. This rather suggested the impact that the length of the steel plate above the sliding surface may have.

RÉSUMÉ : La technique des *plate pile* consiste à enfoncer verticalement dans la pente un ensemble de cornières, chacune étant équipée d'une plaque d'acier rectangulaire soudée sur l'une des jambes de la barre pour maintenir le sol glissant en position. Cependant, il n'existe actuellement aucune étude sur l'impact de cette technique sur la rupture de la pente en rotation, car elle est généralement utilisée pour les glissements de colluvions en translation ; il en va de même pour l'effet de la modification de la forme traditionnelle de la plaque. C'est pourquoi des essais sur modèles en laboratoire ont été réalisés sur des pentes d'argile de Chine anglaise à petite échelle. Les charges maximales soutenues du bélier hydraulique au niveau de la crête ont été comparées pour une pente non-renforcée, et celles renforcées avec:1) des pieux plats traditionnels et; 2) avec des pieux plats équipés de plaques d'acier circulaires ayant la même surface que le traditionnel. Tous les modèles renforcés n'ont montré aucun glissement en rotation, la plaque de chargement étant plutôt enfoncée dans la pente. Dans des conditions de sol similaires, les pieux plats ont amélioré la charge de rupture d'environ 10% et 7% pour les pieux plats rectangulaires et circulaires, respectivement. Les résultats suggèrent que les pieux plats peuvent également améliorer le glissement en rotation. Néanmoins, l'utilisation d'un pieu plat circulaire avec les propriétés géométriques susmentionnées n'a pas amélioré davantage le renforcement de la pente. Cela suggère plutôt l'impact que la longueur de la plaque d'acier au-dessus de la surface de glissement peut avoir.

KEYWORDS: slope stabilising piles, slope stabilisation, model tests, plate piles, driven plate piles

1 INTRODUCTION

Slope stabilization using piles has been in practice as early as the 1970s (Laurito, 2019). Over the couple of years that followed, several improvements had been done. In 2006, Short et al. (2006) introduced the plate pile technology. In this technique, a structural steel section, typically an angle bar, with a rectangular steel plate welded to one of the shaft legs, is driven vertically into the slope.

With this technique, however, there seems to be some knowledge gaps to fill in. For instance, this method has so far been studied by investigating its performance on translational sliding failure, such as those in colluvium slopes (Short et al, 2006; Short and Prashar, 2011). The plate pile technique has not been investigated, however, in its effectivity in rotational slope failure which occurs predominantly in cohesive slopes. Secondly, the plate welded to the steel section is typically rectangular-shaped. Apparently, there has not been any numerical and experimental study investigating the impact of altering the shape.

Hence, this research project primarily aims to investigate the impact of the driven plate piles in the context of rotational slope failure which predominantly occurs in cohesive slopes. It also aims to investigate the effect of changing the traditional shape of the steel plates being used.

Laboratory tests on small-scale model slopes using cohesive soil were conducted. The changes in the failure load, and mechanism of slope failure when these model slopes are reinforced with plate piles were investigated and reviewed. Moreover, the author further examined when circular steel plates are introduced as a new shape configuration for the steel plates that holds the soil in position.

However, due to time restrictions, this paper shall not examine other shapes of steel plates, as well as the impact that the shape may have on other parameters such as pile spacing, arrangement in the slope, slope angle, etc.

2 LITERATURE REVIEW

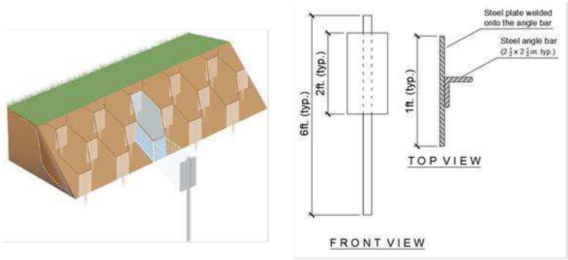
2.1. *The plate pile stabilization technique*

In 2006, Short et al. (2006) introduced the plate pile technique—an improved version of installed piles in the slope. In this method, the pile outfitted with a rectangular steel plate at one end, called as 'plate piles' are driven vertically into a potentially unstable slope using tracked excavators with a hydraulic hammer attachment. Plate piles are then installed in an offset grid, taking full advantage of the soil arching effect between adjacent piles as shown in Figure *1* (Geopier, 2019; Short et al., 2006). The steel plate attached to the steel section provides the surface that holds the unstable soil, and by load transfer mechanism, the pile transfers the destabilising force to the stable soil beneath the slip surface (Short et al., 2006; Smith et al., 2016).

2.2 *Stabilising mechanism of slope-stabilising piles*

Ellis and O'Brien (2012) explained that free-head piles installed in rows in a slope dowel potential shear planes by providing shearing resistance. This shearing resistance comes from the load transfer mechanism wherein the pile transfers the load from the unstable soil mass into the stable soil below the slip plane. Such a phenomenon then comes from the soil arching mechanism that forms within the pile interval.

This arching mechanism occurs when there exists a soil condition where a yielding part of a soil mass adjoin a less-yielding or restrained material, wherein a transfer mechanism or stress redistribution of soil pressure from the yielding zone to non-yielding zone occurs (Chen and Martin, 2002).



(a) (b)

Figure 1. The plate pile technique: (a) typical grid pattern arrangement of the plate piles installed in a slope (Smith et al., 2016), and (b) typical dimensions for plate pile, figure adopted from Short et al. (2006).

2.3 *Factors influencing the slope-stabilising mechanism*

The analysis on the characteristics of equations proposed by Ito and Matsui (1975) revealed that for a given spacing, the lateral force acting per metre length of pile increases linearly as the diameter of the pile increases. The impact of the diameter potentially suggests the effect of the contact area at the pile-soil interface that resists the sliding soil. Because, as the diameter of the pile increases, the bearing area that is available to resists soil movement must also increase. Which seems to be a logical agreement with the concept of 'arching foothold' in the comparative analysis of Liang and Zeng (2002) between the effects of circular-shaped and square-shaped piles on soil arching. They elucidated that the square-shaped piles provided more solid soil arching foothold or surface, which facilitated more arching-induced load transfer than circular ones. Hence, a greater 5% of stability was manifested by square piles.

In addition, surface roughness, and pile length above the slip surface increase the slope stability as revealed in the studies of Ito et al. (1981) and Chen and Martin (2002).

With these findings in the literature, it is apparent that the stability of pile-reinforced slopes changes as the condition of the pile-soil interface is changed. In connection, it is likely that there might be a change in slope stability if the shape of the plates being used for the plate pile technique is altered, as changing the plate's shape will inevitably modify the pile-soil interface.

3 METHODOLOGY

3.1 *Overview of the experimental methodology*

The experimental methodology was generally divided into two. The first part was the characterisation tests for the English China Clay (ECC) to identify its properties to guide the model tests—the water content to be used for the slope, the compaction effort in building the slope, and the corresponding soil strength under these earthwork parameters.

The second part involved three small-scale model tests simulating slopes which were loaded to failure. The unreinforced slope, (*i.e.*, Model Test 1) would be the control test. It would then be compared with Model Test 2 (*i.e.*, slope reinforced with rectangular plate piles), which in turn, be compared with a third model test (*i.e.*, slope reinforced with circular plate piles).

A fourth model tests with a mean moisture approximately the same as that of Model Test 3 was added as the average values of water content and vane shear strength for Model Test 3 turned out relatively inconsistent with the first two model tests. Model Test 4, reinforced with rectangular plate piles was then compared with Model Test 3 so that the impact of altering the shape of plates of the plate piles could be investigated, and the objectives of the research still met.

3.2 *Materials*

3.2.1 *English China Clay (ECC)*
In practice, the plate pile technology mitigates rainfall-induced translational landslides occurring in cohesive soils, such as colluvium slides and is considered as not very efficient and applicable to cohesionless soils, such as very loose to loose sands (Short et al., 2005; Smith et al., 2006 and Geopier, 2019). Hence, ECC was selected, aside from other reasons such as its availability in the laboratory, good plasticity, and non-swelling property. *Puraflo 50*, a commercially available relatively pure kaolinite clay, from supplier WBB Devon Clays, Ltd., was utilised. From the characterisation tests conducted, a Plastic Limit (PL) of 27% and a Liquid Limit (LL) of 60% were identified.

3.2.2 *Plate Pile Material*
In the field, the pile shaft being used is either a steel angle or S-shape section, and typically of black steel (Smith et al., 2016), hence the material selected for the plate piles was black mild steel, of Steel Grade S275JR, which is commercially available from a local supplier (Camp Steel, 2019).

3.2 *Characterisation tests*

Characterisation tests to determine the properties of ECC include standard tests Plastic Limit and Liquid Limit Test and Standard Proctor Test in accordance to BS EN ISO 17892-12:2018 (British Standard Institute, 2018) and BS 1377-4: 1990 (British Standard Institute, 1990), respectively. Hand shear vane tests according to BS 1377-9: 1990 (British Standard Institute, 1990) were conducted on samples from the standard proctor test to aid in the selection of moisture content of the soil in the model tests such that the soil of the model slopes would be of low to medium strength, and of soft to firm consistency.

3.3 *Model tests*

Comparability of results among the model tests is a crucial factor to consider. With this, the slope reinforcement, and the shape of the plate for the plate piles were held as the controlled variables. Other factors such as the slope geometry, layout and spacing of plate piles, etc. were held as constants. Moisture content on the other hand was ideally intended to be an experimental constant. Hence, monitoring tests (*i.e.,* moisture content tests and hand shear vane tests) at every 100mm depth interval of the model slope were conducted per model test.

3.3.1 *Laboratory setup*
Wooden box of internal plan dimensions of 1000mmx500mm by 500mm of height was fabricated to facilitate the model tests. To minimise the possible loss of moisture, polythelene sheets were used to cover the insides of the box. Sides of the box were marked to facilitate the cutting of the slope. The final set up per model test is as illustrated in **Error! Reference source not found.**. Details of the model geometry were coordinated with the numerical modelling study of Ng (2019) to assure that the failure circle of the unreinforced slope is within the boundaries of the test box. Furthermore, the slope angle 40^o was deemed acceptable as it agrees with the slope angle with which the plate pile technology is applicable, *i.e.*, 17^o to 45^o (Geopier, 2019).

The small-scale plate piles were then vertically driven in the slope using hand-held hammer. The setup was then left overnight prior to loading to failure. During loading, a wooden plate (150mm x 200mm) was positioned on the crest, the small-scale model was then placed under the hydraulic ram to load the slope to failure.

3.3.2 *Plate pile dimensions and arrangement*

Traditionally, the plates of plate piles were optimised at a width-to-length ratio of 1:2, i.e., 1ft x 2ft (Short et al., 2006; Short et al., 2011; Smith et al., 2006). With this, a steel flat bar of 50mm width was selected as it is commercially and readily available. Summary of details is presented in Table 1.

The spacing chosen is within the range of maximum ratios that the literature provides for the soil arching between piles to exist (Kourkoulis et al., 2011; Liang and Zeng, 2002; Smethrust and Powrie, 2007). Furthermore, two rows of plate piles were arranged in a staggered grid arrangement at the lower half end of the slope as demonstrated in **Error! Reference source not found.** for maximum effectivity (Ausilio et al., 2000; Poulos and Davis, 1980; Chen and Martin, 2002; Kourkoulis et al., 2011)

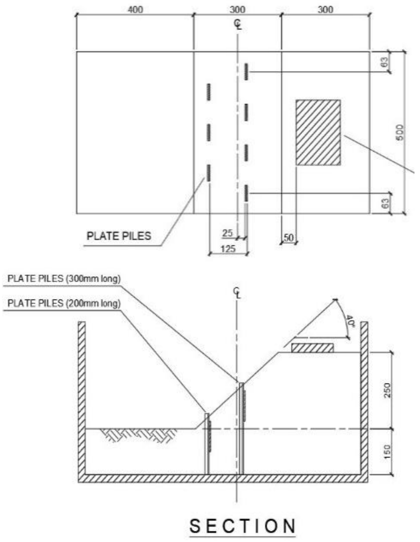


Figure 2. Laboratory setup for the model test. Note: units are in mm.

Table 1. Summary of plate pile dimensions and spacing. ***Note**: units in mm.*

	Rectangular Plate Pile	Circular Plate Pile	Remarks
Plate's dimension	50x100x3 thk	ϕ80x3 thk	Both plates are of approximately same surface area
Pile shaft	13x13x3 thk Angle Bar		
Spacing	125 horizontally both ways		Spacing at 2.5*width of the plate of rectangular plate pile

3.3.3 *Earthworks of the model slope*

In total, 295 kgs (i.e., 11.80 bags) of dry Puraflo 50 ECC, with 5% of wastage allowance was used. The dry ECC was mixed with water in batches using an 82-kg-capacity soil mixer. The amount of added water in the mixer was calculated based on the selected water content at 33%. Moisture content was selected primarily based on workability of the moist soil, and corresponding vane strength as will be explained in Section 4.1.

Moist soil was then compacted at 100mm-thick lifts using the modified proctor hammer dropped at 750 blows per layer applied on a wooden plate 250mm x 250mm placed on soil surface to evenly distribute the total number of blows per lift. This provided approximately 50% of the standard energy of the standard proctor test. 50% was selected as the compaction effort didn't have a significant influence on the trend of behaviour of the shear strength of the ECC from 50% to 100% of compaction effort as shown in Figure 4.

To address the issues with compaction of fine-grained fills, and compaction-induced surface as explained by Nowak and Gilbert (2015), big lumps of soil are broken down into small bits using hand shovel prior to compaction and surface of a compacted layer is scarified.

3.3.4 *Monitoring tests*

The moisture content during the earthworks is monitored per lift as the moisture content of fine-grained fills complicates their behaviour (Nowak and Gilbert, 2015). Three samples per layer of compaction were obtained for water content measurement while four to six points per layer were selected for the hand shear vane test.

3.3.5 *Remixing the soil sample*

Microwave oven heating method according to ASTM D4643-17 (ASTM International, 2017) was used to obtain the current water content prior to soil remixing. Simple hand calculation using fundamental relationships between dry and bulk unit weight of soil, and the moisture content was used to obtain the amount of water that would be added.

4 RESULTS AND DISCUSSION

4.1 *Results of characterisation tests on ECC*

The result of hand shear vane tests on ECC with varying moisture content primarily signifies the essential role of moisture content on the shear strength of the ECC, which in turn is crucial factor to slope stability. For instance, as illustrated in Figure 4, around 10 KPa decrease of shear strength per unit increase in the moisture content is evident especially on the steeper portion of the curves.

These initial findings seem to agree with the literature. Parsons (1992) similarly found a decrease in the undrained shear strength with the increasing water content for a glacial till as a cohesive fill material. Although, he correlated an inversely proportional relationship at a greater rate of change between these two earthwork parameters.

More importantly, these findings implicate the crucial role of establishing approximately constant moisture content for all the model tests to ensure comparability of results. Because, as the water content significantly affects the shear strength of the soil, it will certainly affect the slope stability as pointed out by Ito and Matsui (1975) in their equation of lateral force acting on slope stabilising piles installed in a cohesive slope.

In addition, Figure 4 shows that at 33%, the undrained shear strength is around 45KPa to 50 KPa. This strength value was anticipated to provide soft to firm consistency and low to medium strength when referred to the table provided by Nowak and Gilbert (2015).

4.2 *Results of the monitoring tests on earthworks for the model slope*

In general, the results of the monitoring tests per layer of the model slopes are within the acceptable range of variability as per their average values shown in
Figure 3. Although, some readings of the vane shear strength vs. depth seem to have relatively higher degree of spread from the mean (i.e., as much as ±5KPa) as seen from the error bars of the graph for Model Test 1, their mean values however appear to be not significantly different from other values taken at different depths. Aside from that, the corresponding water content readings seem to be relatively similar to each other as seen from their average values, with consideration to their error bars.

Figure 3. Graph of the variation of moisture contents and vane shear

strengths across the depth of each model slopes. Error bars plotted represent the standard deviation.

Besides, consistency and homogeneity of the soil material can be checked as well by the determining the moisture content should the readings from the hand shear vane becomes uncertain. Especially that the hand shear vane can be susceptible to human error as explained by Das (2005).

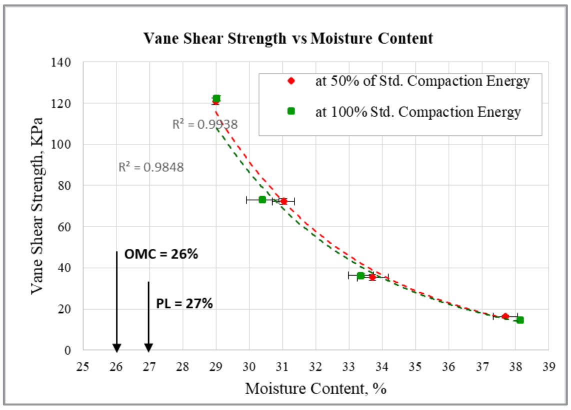


Figure 4. Vane shear strength vs. moisture content of moist ECC. Error bars indicate standard deviations of measured values. Note: LL is at 60%; R2 = correlation value.

4.3 *Results of the model tests*

4.3.1 *Overview of the results*

In general, the observed improvement in terms of the mode of failure between the unreinforced slope (i.e., Model Test 1) and the reinforced ones (i.e., Model Tests 2, 3 and 4) was noticeable and consistent. As demonstrated in

Figure 5, no sign of a total rotational slip was visible from neither the slope face nor on the surface of the toe of Model Tests 2, 3, and 4. Instead, it seemed that the rotational slip failure was restrained, hence a local punching failure of the loading plate occurred at the crest.

In contrast, prominent tension cracks on top of the crest which progressed to seemingly rotational slip which cut right through the surface of the slope was observed on Model Test 1. Notwithstanding, it seems that from the direction and orientation of the tension cracks on top of the crest of Model Test 1, the size and extent of the failing soil mass seems to exceed the extent of the boundaries of the test box, which means that the boundary conditions seemed to take effect.

Nonetheless, the observed improvement in the behaviour of the slope failure between reinforced and unreinforced model slopes suggests that reinforcement of the slope was taking effect. It may also imply that the pile-soil interaction mechanism mobilised the development of lateral force to the piles, which in turn, provided the reaction force that helped in the stabilisation of the slope (Ito and Matsui, 1975; Ito et. al., 1981). For instance, it can be seen from the summary of the results as tabulated in **Error! Reference source not found.** that the failure load carried by Model Test 1 was larger by around 10% relative to Model Test 2. Although this percentage of increase in the failure load may not be considered as very significant, it is worth mentioning, nonetheless, that the behaviour of slope failure was improved.

Likewise, in the field test by Short et al. (2006) on a translational type of slope failure, translational slide of the slope was totally not observed after plate piles were installed. They further elucidated, in a computer simulation analysis that followed, that in general, around 20% increase in the factor of safety could be achieved.

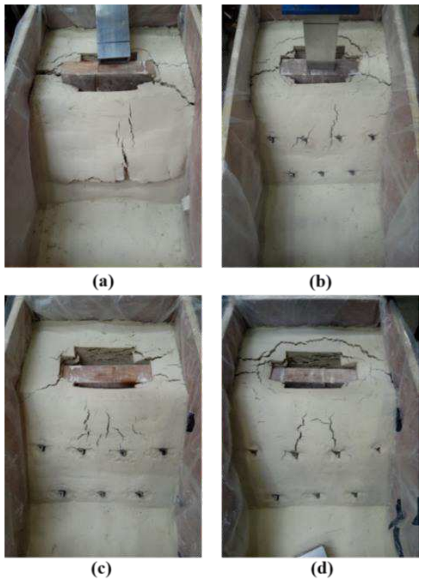


Figure 5. Photographs of the model slopes after loading to failure: (a) Model Test 1, (b) Model Test 2, (c) Model Test 3, and (d) Model Test 4

Table 2. Summary of results for the four laboratory model tests

Test Data	Model Test 1	Model Test 2	Model Test 3	Model Test 4
Moisture Content (%)	31.8 ± 0.2	32.3 ± 0.4	33.3 ± 0.4	33.1 ± 0.2
Vane Shear Strength (KPa)	55.5 ± 2.6	54.8 ± 1.4	45.7 ± 1.0	45.20±1.0
Failure load (KN)	17.5	19.2	13.3	14.2
Mode of failure	Rotational Slip	Punching/local failure at the crest		

4.3.1.1 *Impact of boundary conditions*

Going back to the context of rotational slope failure, improvement in the behaviour of slope failure is expected when piles are installed. This is evident from analytical studies of Poulos (1995) and Ausilio (2000) wherein a row of piles induced a relatively larger critical slip circle. Furthermore, a laboratory study by Zhang and Wang (2017) found out a shift in the behaviour of progression of the critical slip surface based on the location of the pile in a slope scale model, suggesting the idea that slip circle tends to follow the path of least resistance.

In connection, it is probable that as with the case of Model Tests 2, 3 and 4, the reinforced slope tends to fail by generating a larger slip circle. However, the straining of the soil fabric was further resisted by the sides of the box in addition to the reinforcement coming from the plate piles, thereby resulting into the loading plate punching into the crest. Similarly, Smith (2006) pointed out the impact of boundary conditions set by a stiff material underlying a cohesive embankment. He explained the limiting effect of the stiff material to the depth of the slip circle to which it could have extended and the shift in its location and range in horizontal direction.

Therefore, it is likely that the improvement in the slope failure behaviour was a shared effect by both the pile-soil interaction mechanism and the limit set by the boundary conditions. In order to eliminate the effect of the boundary conditions, the size and extent of the sliding volume has to be within the boundaries set by the geometry of the box. In order to do so, a Finite Element Modelling can be done first to identify the geometry and extent of the failing soil mass, from which the dimension of the whole slope and the test box can be properly obtained.

4.3.2 *Results of Model Test 1 vs Model Test 2*

The summary of results presented in Table 4.1 were plotted with error bars representing ± 2 Standard Error of the Mean (SEM) as shown in **Error! Reference source not found.**. SEM was selected to represent the error bars of the data obtained per model test as it measures the precision of the mean of data from a single experiment (*i.e.*, a model slope test) from the true mean. Furthermore, in terms of statistical analysis of sets of data, SEM determines their level of comparability— that in order to say that data from two experiments are similar to each other, their SEM error bars should overlap and their overlapping regions should include the mean values of each other (Durran, 2005; Piers, 2016).

With respect to their moisture contents, what can be clearly seen in **Error! Reference source not found.** (a) is that although there is an overlap of SEM error bars between Model Tests 1 and 2, the overlapping region, however does not include the mean values. This implies that there might be a similarity between their moisture contents, although to a little degree (Piers, 2016). Notwithstanding, moisture content values is not the sole basis for comparing the similarity of the soil conditions between model tests. Because, as per **Error! Reference source not found.** (b), the strength values of Model Tests 1 and 2 are approximately similar to each other as evident from their overlapping SEM error bars covering the averages of their vane shear strengths.

Despite the slightly contrasting views on the degree of similarity of soil conditions, it can still be anticipated that an increase in the improvement of sustained load from Model Test 1 would have been achieved had the averages of moisture contents been more proximate to each other. Say as with Model Test 1, if the moisture content would be slightly wetter, approaching closer to that of Model Test 2, the soil structure would be weaker, possibly sustaining a lower load on top of the crest hence possibly increasing the present 10% gap in the sustained loads between Model Tests 1 and 2.

4.3.3 *Results of Model Test 3 vs Model Test 4*

Considering the evident similarity of soil conditions for Model Tests 3 and 4 as seen from their overlapping SEM error bars in **Error! Reference source not found.** (a) and (b), it can then be inferred from their values of sustained load on top of the slope crest as indicated in **Error! Reference source not found.** that the rectangular plate piles potentially provided a greater degree of reinforcement compared to circular plate piles by around 7%, although such disparity between the two types of plate piles is not that significant. Furthermore, with regard to the mode of failure of the slope, the results for both of these model tests seem to be consistent with Model Test 2 upholding consistent results for reinforced model slopes in general.

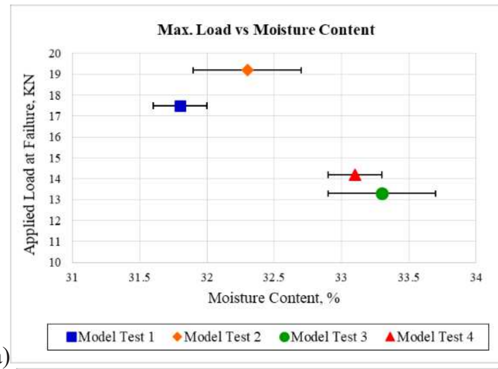
The relatively greater degree of stability which rectangular plate piles potentially provide than that of circular plate piles seems to be in agreement in the literature. As found out by Ito et al. (1981), the slope stability increases whereas the pile stability decreases with the increasing length above the sliding plane of a slope, which stems from the increased lateral force acting on the pile, and thereby increased lateral reaction force as the pile length above the sliding surface is increased.

In connection, as with the case of rectangular steel plates having the same surface area as the circular plates welded on one of the legs of the angle bar (*i.e.*, pile shaft), the length of the rectangular plates is greater than that of the diameter of the circular plates at 100mm and 80mm, respectively. Therefore, it can be suggested that with the same surface area, a circular steel plate does not stabilise the sliding soil as much as a rectangular steel plate.

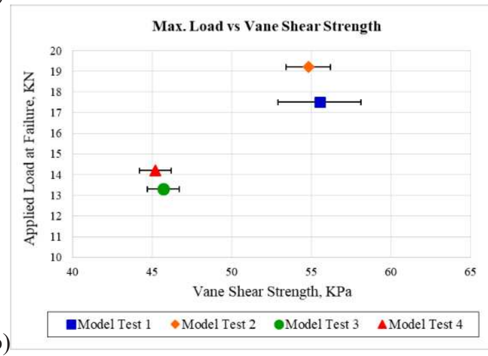
4.3.4 *Impact of disparity in moisture content values*

As with Model Tests 2 and 3, which were originally planned for investigating the impact of altering the plate's shape, a drop of 9.10 KPa in their average vane strengths was obtained for a wetter mean moisture content by 1% achieved for Model Test 3. Whereas Model Test 1 and 4, provided a lowering of 10.30KPa by an increase in moisture of 1.30%. These values seem to be approximately around the same value of the rate of decrease in the shear strength versus the moisture content as initially discussed in Section 4.1, Figure 4.

These finding reiterates the idea of the impact of moisture content to the undrained shear strength of the soil, and by extension to the slope stability. For instance, the failure loads obtained for Model Test 2 vs. Model Test 4, suggested that under the same condition of reinforcement, a significant decrease in the failure load occurred (i.e., around 26%) within 1% decrease of average moisture content of model slope.



(a)



(b)

Figure 6. (a) Failure loads plotted against average moisture contents and (b) average vane shear strengths of the four model tests

5 CONCLUSION

Four different small-scale model tests on cohesive slope were carried out in the laboratory. Originally, three different model tests were planned. However, due to development of relatively dissimilar soil strength characteristics achieved in the third model test, a fourth model test was added. After the characterisation tests on the moist English China Clay (ECC), and the series of model tests conducted, and their evaluation and analysis, the following conclusions were drawn:

1) Installation of plate piles can also improve the slope failure of a cohesive slope in terms of failure behaviour such that the total rotational failure seemed to have been restrained although the extent of the boundary conditions set by the test box seemed to have an influence.
2) In the context of failure load, a circular plate of the same surface area as the rectangular plate did not improve the level of reinforcement provided by the rectangular plate piles. However, this suggests a substantial insight on the impact that the length of the plates above the sliding surface may have on slope stability.
3) For a cohesive slope reinforced by the plate piles, the moisture content plays a pivotal role in the slope stability as

it decreases the undrained shear strength of the soil, which is crucial in the development of lateral force acting on the pile.

Knowing these, several improvements are opportune to further this research:

1) The moisture content of ECC should be increased, so as to promote the ease of loading the slope to failure and to decrease the size and extent of the failing mass such that it will be within the boundaries of the test box
2) To determine and set the parameters, such as the slope geometry, size of the box, moisture content, etc., which are pertinent to decrease the size and extent of the failing mass such that boundaries set by test box will not affect the straining of the soil, Finite Modelling can be utilised first.
3) Further investigation on the impact of the steel plate's length above the sliding surface on the slope stability, say through model tests on rectangular plate piles with varying lengths of plates may be done.
4) Due to time restrictions and the volume of the soil required for this research project, one trial per model test was carried out. It is therefore recommended to conduct more trials per model test to refine the results obtained.

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