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Study On The Increament Of Shear Resistance Of Soft Soil Due To Vertical Piles Reinforcement Based On Modeling In Laboratory

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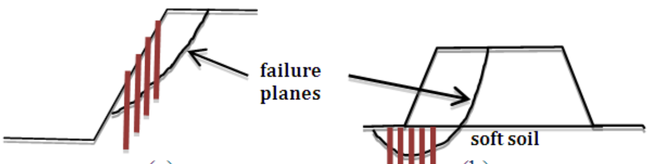
Abstract.
Currently, there are many methods of soil reinforcement have been used on soft soil to increase the shear strength of the soil. Detail informations, interaction between soft soil and vertical piles in laboratory works were needed to complete it. This research was conducted by physical model of laboratory scale using practise behaviour approach. The approach is modifying direct shear test with large box. The large box is used to avoid friction effect between vertical piles and vertical plane of the box. The shear strength test was applied by several variations, namely; ratio of pile insertion, spacing of piles group, piles number, and piles diameter.
The results showed that shear resistance of soil is increase by increasing of length piles below the sliding surfaces and spasing piles of 3D to 5D. Shear resistance of soil decreases for piles spacing of 5D to 8D. The use of more piles as resistance against sliding would decrease the lateral capacity of each individual pile, similar to that of efficiency factor used in group of piles under axial loading. Maximum shear resistance was reached by pile spacing of 5D. Piles diameter also affect the shear resistance of soil, larger diameter increase it than lower diameter.

Key words: pile-soil interaction, soil reinforcement with piles, slope stability, ground improvement, laboratory modeling.

INTRODUCTION.

The efforts to increase the shear strength of soft soil can be done using soil reinforcement method. The reinforcement method is aimed to increase the strength of the soil to support the loads acting on it. Currently, the varieties of the method are available supported with adequate technology. The method is well-developed as well.
One of the effective soil reinforcement methods to soil embankments and slope stability are by using vertical piles reinforcement that acts like pile system. The use of pile as soil barrier had been done in the past since it may give efficient solution, since pile can be done easily without equilibrium disturbing (DeBeer and Wallays, 1970; Ito dkk, 1981). A pile was used as stability reinforcement for the very soft soil in Sweden eventhough at that time, the use of drill pile with 1, 5m diameter was popular used in Europe and America to increase the landslide stability on the stiff clay (Bulley. 1965)
The pile has been effectively used as alternative method of road embankment reinforcement. On the road embankment, the pile is used as a stiff material that is functioned to increase soil stability. The presence of the pile under the road embankment may increase bearing capacity and decrease the settlement. It is because the pile can result resistance the shear failure. As the reinforcement of the slope, a pile is functioned effectively as a dowel that can cut sliding area of surface. So that a pile can give additional shear strength on the slope that may against the shear stress of the slope sliding happened. The additional shear strength that is produced by the pile can increase the safety factor of the slope stability.
Several studies about the solving of the failure of the road and the slope stability on the field (Mochtar, 2011) shows that the pile has been proved that it is able to increase the shear strength of soil. Mochtar (2011) also states that if the overall stability is more decisive in the sheet pile stability, therefore, the closer assumption towards the actual condition in the field is the pile construction assumption. A pile has more capability rather than the sheet pile in solving overall stability. The reason is based on the capability of the pile that is capable to cut the sliding plane on the landslide area. The pile can be staked to pass the sliding plane without producing an excessive flexibility as happened to the sheet pile.
This research is done to answer the problem of how soil behavioral interactions with the pile in the increase of shear strength of soft soil. Therefore, the main objective of this study is to develop the theory of the soft soil shear strength as the result of the existence of the pile.
In Indonesia, this system of soil reinforcement had been used widely in the past in the form of wooden and concrete mini piles with diameter 7. 5 cm to 25 cm, driven vertically or slightly inclined on natural slopes that have been suspected to

be in danger of sliding; or the piles were driven into the relatively soft soil under highway embankments, to increase the stability of the embankment as given in Figure 1.



(a) (b)

Figure 1: Typical soil reinforcement with piles acting as resistance against sliding. (a). Piles acting as dowels against lateral sliding on natural slope. (b). Piles acting as resistance against lateral sliding in soft soil under embankment.

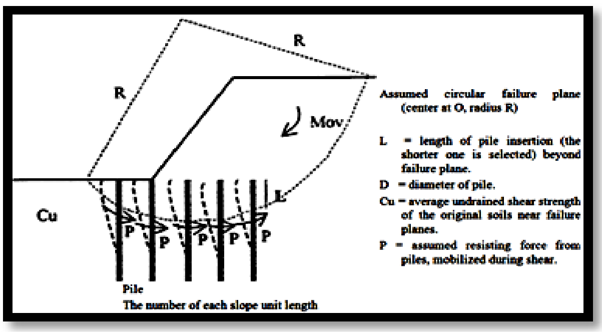
A laboratory study using model piles were conducted on soft soils (Rusdiansyah et. al., 2015) to investigate the increase of shear strength of the soft soils due to the existence of group of piles in the soils. The group of piles will add more resistance against lateral sliding of the soft soils, so that the effects of many variations of the piles and the soils can be investigated. The variations involved in this study were: space distance between the piles, length of the pile embedment, diameter of the piles, number of piles used, relative stiffness of the piles, and the relative stiffness of the soils themselves.

REFERENCIAL STUDY

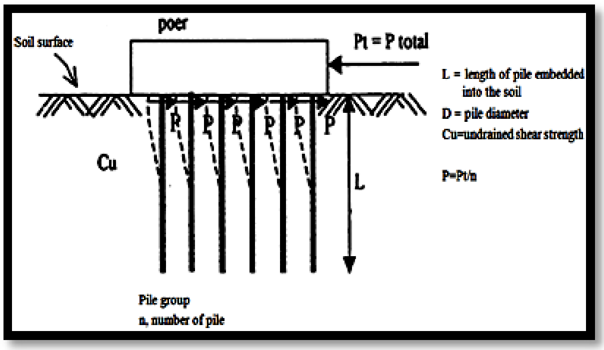
Theoretical background

Piles can be assumed to act as dowels when sliding occurs in the soil, so that the piles will produce additional resistance to the sliding plane to increase general stability of the soils against failure. Mochtar (2000) had developed a theory about the additional resistance to soil shear strength against sliding due to insertion of piles into the soils. This theory was based on the theory of piles against lateral force given in NAVFAC DM-7 (1971).

In this theory, the lateral resistance capacity of a pile in soil are governed by: stiffness and flexural moment resistance of the pile, length of pile penetration into the soil, shear resistance of the soil, and the number of piles per length of slope. The assumptions by Mochtar (2000) as given in Figure 2. a. is comparable with the assumption of group of piles against lateral force by NAFVAC DM-7 (1971) given in Figure 2. b.



(a)



(b)

Figure 2: Assumption used by Mochtar (2000) to find resistance of piles against lateral sliding; (a). Actual piles to act as dowel resistance against lateral sliding under embankment or on slopes. Resisting forces P are working along the failure plane. (b). Original assumption given by NAFVAC DM-7 (1971)

In his theory, Mochtar (2000) proposed the formula to obtain the number of piles needed to improve Safety Factor against sliding, and it was based on the ability of 1 (one) pile to resist against lateral force P. This pile resisting capacity against lateral force was also a function of the pile moment flexural resistance, Mp, pile coefficient Fm, and relative stiffness T, as follows:

$P_{max\ (analytical)\ of\ 1\ pile}$ = Maximum Lateral Resisting Force of 1 pile
= $\mathbf{(Mp_{max\ 1\ pile})/(Fm \times T)}$............. (1)

in which:

$\mathbf{Mp_{max\ 1\ pile}}$ = maximum flexural moment the pile can withstand;

Fm = coefficient of moment due to lateral load P (from NAFVAC DM-7);

$P_{max\ (analytical)}$ = maximum lateral load the (individual) pile can mobilized;

$T = [(EI_{\ of\ piles})/(f_{\ of\ soil})]^{0.2}$
= relative stiffness factor of piles compared to the soil strength (as given in NAFVAC DM-7, 1971).

The above Equation (1) was further developed by Arya and Mochtar (2002) to include also the correction factors involving different variety of soils (Cu), different depth of soil penetrations (L/D), different diameters of piles (D), and different numbers of piles. This study was obtained from laboratory modeling using very small samples with diameter of wooden piles used about 1. 0 to 2. 0 mm, and the result was given in Equation (2) as follow:

$P_{max\ (analytical)\ of\ 1\ pile} = \boldsymbol{Fk} \times \mathbf{(M_{pmax\ 1\ pile})/(Fm\ xT)}$…. (2),

in which:

$$Fk = 2,643.\left[\frac{0,89+0,12L/D}{2,69}\right]\left[\frac{0,855Cu^{-0,392}}{2,865}\right]$$

The laboratory modeling and testing were conducted using the principles of Direct Shear test as shown in Figure 3. With the insertions of model piles in the soil samples, the increase of soil resistant against shearing forces could be measured.

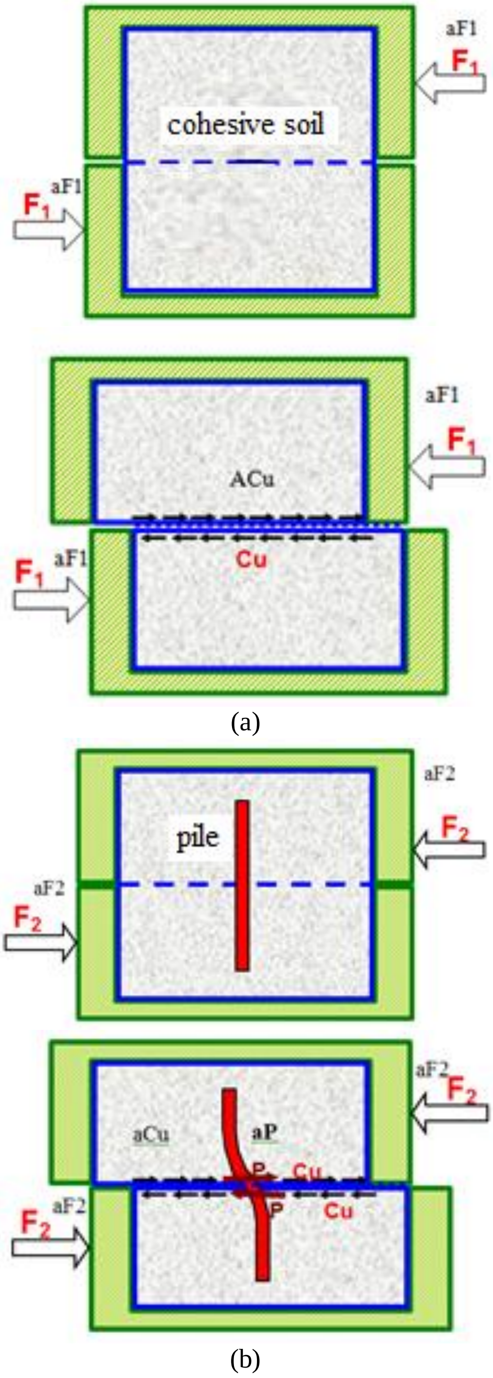


Figure 3: Assumption used for the increase of soil resistance due to insertion of model pile (Mochtar, 2000; Arya and Mochtar, 2002) (a). Condition without insertion of model pile. (b). Condition with model pile inserted.

From Figure 3 (a), condition without model pile in cohesive soil ($\phi \approx 0$), when sheared to failure; soil undrained shear strength= Cu; F1 = Cu x A; A = area of soil being sheared

Soil shear strength, $\tau = Cu + \sigma n \tan \phi \rightarrow \tau = Cu$

From Figure 3(b), condition when model pile was inserted, the piles were acting as a dowel.

When sheared to failure; F2 =(Cu x A) + P; P = assumed maximum resisting force from 1 (one) model pile.

If **n** number of model piles were inserted, F2 = (Cu x A) + (n x P).

The study in laboratory using model piles by Arya and Mochtar (2002) was still considered inadequate, since relatively very small samples were involved. Some other parameters were thought to be significantly important but not yet investigated, such as pile distances, pile arrangement, and pile inclination. Besides, it was much more difficult to make more homogenous model piles in their stiffness properties when using smaller model piles. Stiffness properties of relatively very small model piles were found to vary considerably from one pile to another. Therefore, further studies using bigger model and more homogenous model pile stiffness and involving as many as possible important parameters are still required.

Parameters influencing the improvement of Safety Factors of natural slopes reinforced with piles as resistance against lateral movement.

There are some parameters that may influence the interaction of the slope-pile in the field. Those parameters are: 1) the effect of the length and the depth of the piles, 2) the effect of the ground type, 3) the effect of the diameter and stiffness of the piles, 4) the effect of the position of the piles, 5) the effect of the amount of the piles, 6) the effect of the space of the piles, 7) the effect of the group piles configuration towards the direction of shear force that works.

Lately some researchers have conducted an analysis of most of these parameters by using numerical simulations (finite element, finite difference, etc.) and limit equilibrium analysis method. Here are outlined some of the results of the study the researchers on the subject, including Ashour and Ardalan (2012) has studied the analysis of slope stabilization with a pole (in this case can be referred to as pile) based on the equilibrium model of soil-pile.

In the study analysis, Ashour and Ardalan (2012) used the programming language assistance PSSLOPE which is a combination of Fortran languages and visual basic. Soil parameters used are assumption data of types of good quality clay soil, sandy soil and rock.

The results show that the depth of piles on slopes reinforced pile system which are strengthen by the piles should be embedded on stable ground below the surface of the sliding area. This is because it can minimize the deformation that occurs on piles. If the type of soil that is above the sliding area surface of the soil classified unfavorable, it will generate more pressure on the piles.

Ashour and Ardalan (2012) also stated that the spacing pile, the larger the pile's diameter used the more increases the safety factor (SF). However, the ratio between the length of the pile above the surface of landslides and small pile's diameter can be zoomed precisely by the larger pile's diameter SF used. Furthermore the study indicates that the location of the piles right at the center of slope (between the leg side slope and top / head of the slope) can produce the maximum SF. Meanwhile, related to the pile's spacing, that the increased piles spacing will lower safety factor (SF) of slope stability.

Kourkoulis et al (2011) have done modeling analysis pile-slopes using finite element method and software XTRACT assistance. Assuming the type of soil used is soil with silty sand type and soft rock.

The results of the analysis states that the piles embedded in under the sliding surface, the smaller the deformation that will occur on the piles' head. Deformation on the piles' head will shrink if the piles are embedded on the type of hard soil. Piles' small spacing can increase the retaining shear force, minimize the bending moment, and minimize deformation in the piles' head.

The study results Kourkoulis et al (2011) also showed that if the soil layer has a thin thickness then the piles will behave like rigid and resemble the behavior of retaining wall or kaisson foundation, so that the effect of piles group will have no effect. Conversely, when the thickness of the soil layer is large, then the piles will behave flexibly and effects of group piles became influential.

RESEARCH APPLICATION

Material Used

In this study, the type of clay used is clay with a soft consistency level taken from around the ITS campus (the Surabaya Institute of Technology, in Surabaya, Indonesia). In Table 1 are The physical and mechanical characteristics of the soil. Table 1 shows that the types of soft clay that is used in this study by classification USCS method classified as having a high degree of plasticity (CH). Meanwhile, according to AASHTO classification methods classified as A-7 (Clay Soil). Mini piles models used in this study are made of Meranti wood (wood class II). Piles model are made in the form of a cylindrical rod with a diameter of 3mm, 4, 5mm and 6mm, and the length of the rod is adapted to the needs of variety of treatment in this research.

The wood was specially selected to have mostly homogenous properties and water content in the wood were averagely about 14. 87% and with average unit weight of wood was about 0. 55 gr/cm3. From tensile stress tests performed on the mini wooden piles, the modulus of elasticity was found to have an average value of E = 21812. 39 kg/cm^2, which is typical for wooden pile. The maximum tensile strength of the wooden piles was averagely of $\sigma_{\mathbf{tensile}}$ = 780. 518 kg/cm^2.

Table 1: Physical and mechanical characteristics of the undisturbed soil used the model soil-pile interaction.

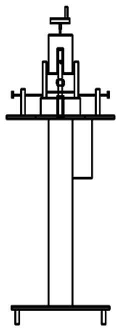
No.	Parameters(*)	Values
1	Unit weight, γt	1, 424 gr/cm3
2	Water content, Wc	92, 21%
3	Void ratio, e	2, 567
4	Degree of saturatio Sr	100%
5	Specific Gravity, Gs	2, 643
6	Liquid Limit, LL	64, 90%
7	Plastic Limit, PL	30, 33%
8	Plasticity Index, PI	34, 57%
9	Percent Clay fraction	75, 44%
10	Percent of Silt fraction	17, 32%
11	Percent of Sand fraction	7, 24%
12	Undrained, Cohesion, Cu	0, 190 kg/cm2

(*) Note: the depth of soil sample and depth of water table was in-1, 2m

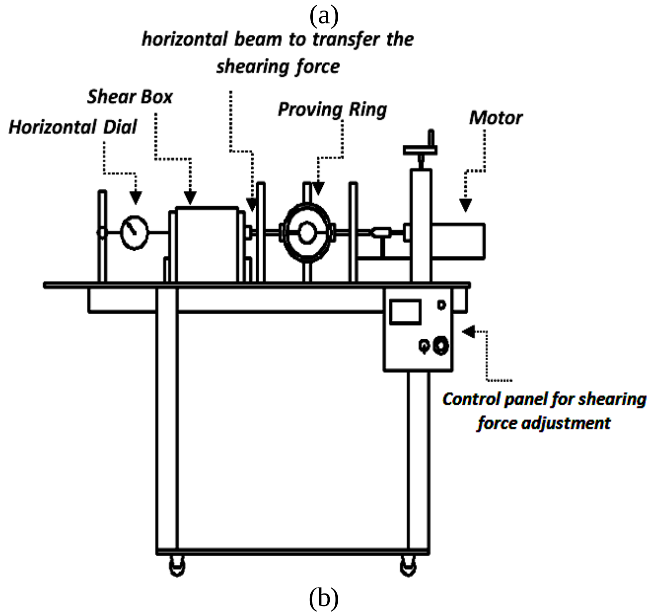
Equipment.

The equipment used for testing was a modification of a Direct Shear test, in which the shearing box was modified to become larger to be able to contain the whole testing apparatus of model piles and soils. However, no loading and dial gage were needed in vertical direction, because shear loading was performed in horizontal direction only.

In the following Figure 4, the shearing apparatus is shown. The main components of this shearing apparatus are: (one) proving-ring with capacity to 500 kgf., horizontal beam to apply the shearing force, (one) dial gage to be able to measure up to 50 mm horizontal translation, one unit of motor to apply the horizontal force required, and two large shearing boxes with the sizes of 20 cm x 15 cm x 12 cm and 20 cm x 15 cm x 18 cm, in which the model piles and soils were assembled.



(a)



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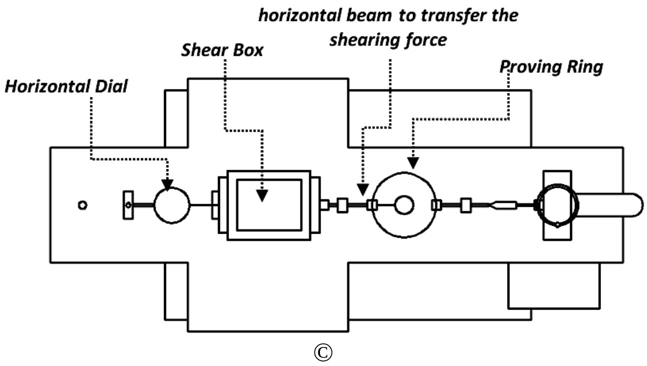


Figure 4. Apparatus for shearing test (modification of the Direct Shear test) (a) side view, (b) frontal view, (c) seen from above.

Testing Procedures

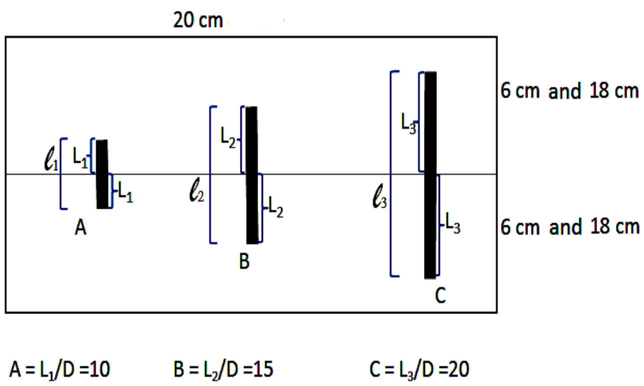
The undisturbed soils were taken directly from the field using special soil sampler, which had a form similar with the shearing box. The soils were then extruded from the sampler and then set up inside the shearing box, to become the model soils. On each model soil, the model piles were inserted using hand and using a special frame apparatus to help in assuring the position and the verticality of the model piles.

The motor had to be switched on to move the horizontal beam to shear the apparatus with a relatively constant shearing speed. The speed can be adjusted between 0. 1 mm/minute to 2 mm/minute. The amount of force applied on the horizontal beam was equal to the total shearing force, and these forces were measured by means of reading the proving ring. The horizontal force in this measurement were designated as P_{lab} and they were recorded simultaneously with the horizontal displacement of the shearing box.

During testing the model soils and piles, the following variables were attempted, which were:

1. Variations of L/D ratio, (depth of pile insertion, L, to pile diameter, D) in which L/D = 5, 10, and 15.
2. Variations of space between model piles, S; in which S = 3D, 5D, and 8D.
3. Variations of model pile diameters, D; in which D = 0. 3 cm, 0. 45 cm. and 0. 6 cm.

More complete explanation can be given in Figure 5 to 7



- For D = 0,3 cm	then	L_3/D = 20	L_3 = 6 cm	l_3 = 12 cm
		L_2/D = 15	L_2 = 4,5 cm	l_2 = 9 cm
		L_1/D = 10	L_1 = 3 cm	l_1 = 6 cm
- For D = 0,45 cm	then	L_3/D = 20	L_3 = 9 cm	l_3 = 18 cm
		L_2/D = 15	L_2 = 6,75 cm	l_2 = 13,5 cm
		L_1/D = 10	L_1 = 4,5 cm	l_1 = 9 cm
- For D = 0,6 cm	then	L_3/D = 20	L_3 = 12 cm	l_3 = 24 cm
		L_2/D = 15	L_2 = 9 cm	l_2 = 18 cm
		L_1/D = 10	L_1 = 6 cm	l_1 = 12 cm

Figure 5: Illustration for the variations of the length of pile insertion.

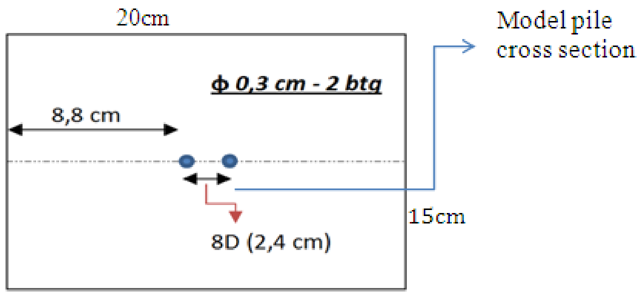


Figure 6: Illustrated example of the position of 2 model piles with spacing between piles = 8D (seen from above)

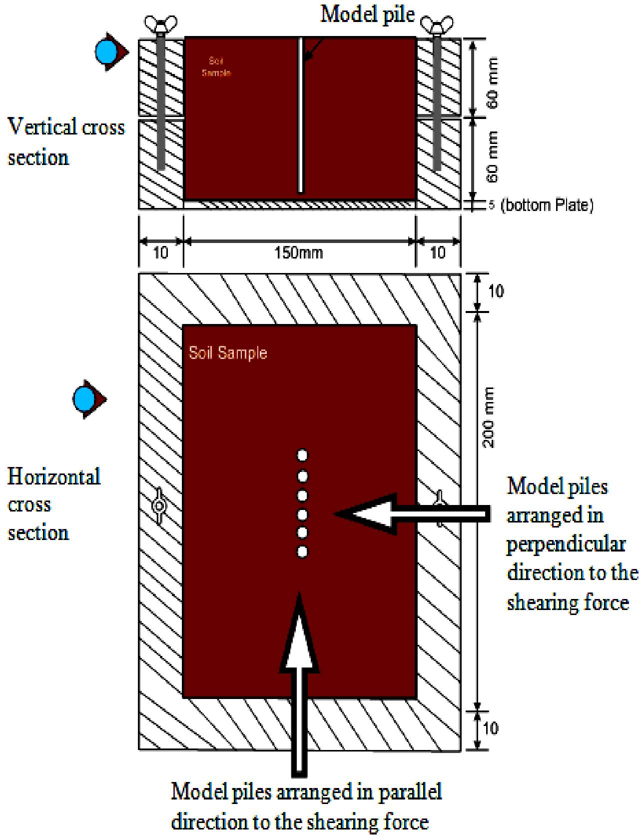


Figure 7: Illustrated position of model soils and piles inside the shear box relative to the direction of shearing

RESULTS AND DISCUSSION

The influence of the ratio of pile insertion, L/D, to the increase of shearing resistance.

In Figure 8 shows the curve that describes the relationship various ratios of pile insertions L/D (i. e. L/D = 5, 10, 15, and 20; in which D is pile diameter) with the increase of shearing resistance of the model pile-soil interaction. The shearing resistance of pile were represented by the ratios of $P_{lab}/P_{analitical}$. In this test, $P_{analytical}$ is the horizontal force which can be held by one model piles based on the analytical calculations using the formula given by Mochtar (2000) in Equation 1, for the given model pile. While P_{lab} is a horizontal force that can be held by one model piles based on the results of testing in the laboratory. The ratios of pile spacing, S, were also varied for S = 3D, S = 5D, and S = 8D. It was apparent that all the correlations tended to be linear, in which the space ratio S = 5D (or S/D = 5) was found to give the highest results, while the ratio S=8D (or S/D = 8) was to yield the lowest results.

Based on the curves described in Figure 8 shows that the shear strength of soft soil (ratio $P_{lab}/P_{analytical}$) has increased along with the increasing length of piles embedded under shear plane. It is caused by the larger value of the ratio of insertion which means that the long piles embedded under shear plane is deeper. With the increasing length piles embedded in the soil, the greater the working area local resistance or lateral reactions that occur in the piles that inhibit landslides. So the addition of shear strength resulted by piles becomes larger. At the same on the ratio value in the curve indicates that the piles that use 5D space result ratio Plab/Panalytical larger than the piles space of 3D and 8D.

The same result has also been demonstrated in studies Ashour and Ardalan (2012), as well as Kourkoulis, et al (2011). Ashour and Ardalan (2012) in his study mentioned that the depth of pile on slopes reinforced piles system should be embedded on stable soil below the surface of the sliding plane. This is because it can minimize the deformation that occurs in pile. In addition, according to Kourkoulis, et al (2011) states that the pile embedded in under the sliding surface, the smaller the deformation that will occur on pile head.

If from all the results in Figure 8, one could recalculate again the ratio of any P_{lab} with the measured P_{lab} at insertion ratio L/D = 15, from the same pile spacing ratio S/D; and all the results of $(P_{lab\ for\ L/D\ \neq 15})/(P_{lab\ at\ L/D\ =\ 15})$ can be plotted against the pile insertion ratio. The result could be simply represented by one linear line as given in in Figure 9.

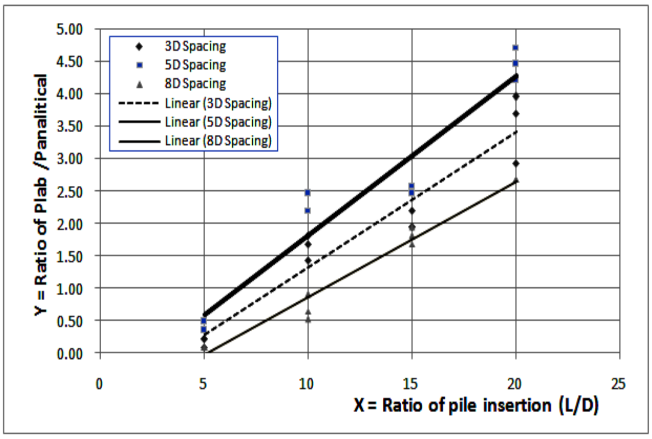


Figure 8: The relationship between pile insertion ratios with $P_{lab}/P_{analitical}$ for various spacing between model piles S = 3D, S = 5D, and S = 8D.

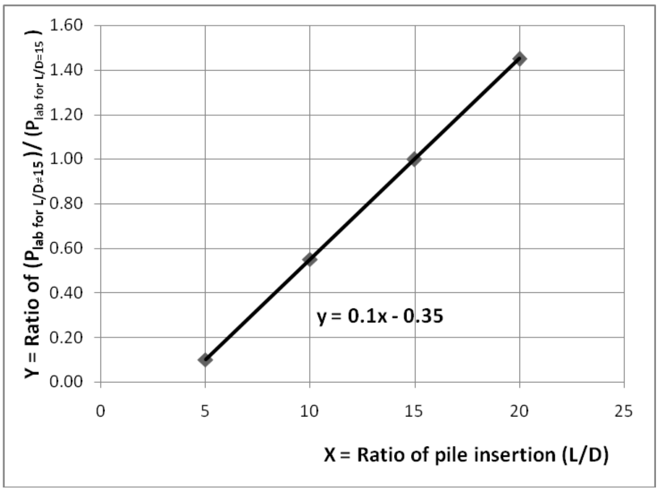


Figure 9: The correlation between various ratio of $(P_{lab\ for\ L/D\ \neq 15})/(P_{lab\ at\ L/D\ =\ 15})$ with the pile insertion ratio L/D.

The influence of the ratio of pile spacing, S/D, to the change of shearing resistance.

To determine the influence of piles space to increased shear strength, in this study piles space of 3D, 5D, and 8D are use. Each spaced variation treatment also looking at the ratio of the applied current shear test execution.

The results of testing with different ratios of pile spacing, S/D, was given in Figure 10, in which the results of $P_{lab}/P_{analitical}$ were plotted against the pile spacing ratio S/D. In this tests, the value of P_{lab} represented the lateral resistance obtained from measuring the resistance of one model pile in this laboratory study with the same soil sample, while $P_{analitical}$ represented the calculated lateral resistance of one model pile when using the formula given by Mochtar(2000) in Equation 1 for the given model pile.

Figure 10 presented data and curves that describe relationship variations in spacing of piles and the ratio Plab/Panalytical for each ratio piles insertion of L/D = 5, L/D = 10, L/D = 15, and L/D = 20

Based on test results shown in the curve in Figure 10, it can be concluded that for a range of piles spaces of 3D to 5D, the value of the ratio Plab/Panalytical has increased. But if the piles use space more than 5D (5D to 8D), the ratio of $P_{lab}/P_{analytical}$ has decreased. Besides, it can be concluded that the piles with spaces of 5D can provide optimal and effective results.

The analysis showed that if a pile using a space between 3D to 5D, soil shear strength will increase since on the range of the piles space, pile group performance will be maximized giving the dowel effect on soil reinforcement. It also shows that it can produce piles detention between the piles of the shear that occurred. Dense spaces (3D to 5D) can minimize the deformation that occurs in the soil since the dense space can increase the retaining slide force.

While a range of spaces more than 5D (ie 8D) ¸ ratio $P_{lab}/P_{analytical}$ decreased because the space is relatively large (not dense), so the piles behave almost like a single pile (individual) which are not bound by his other piles. As a result, the encouragement from the soil shear force does not hold and go through easily between the piles.

This is closely related to the research results of Kourkoulis, et al (2011), Yang, et al (2011), and Ito, et al (1981). Where according Kourkoulis, et al (2011) found pile with small spaces may increase the retaining shear force, minimize the bending moment, and minimize deformation in pile head. As well as Yang et al (2011) have stated that pile with small spaces and the Young's modulus is greater, pile can improve safety factor of slope stability generate greater slope.

Ito, et al (1981) have also been expressed that the spacing between pile can have a considerable influence on the stability of landslide. The safety factor (SF) of slope stability be improved by increasing the ratio D2/D1 (D2 is the distance between pile measured from the outer side pile adjacent to each other, D1 is the distance between the center point of a cross of pile.

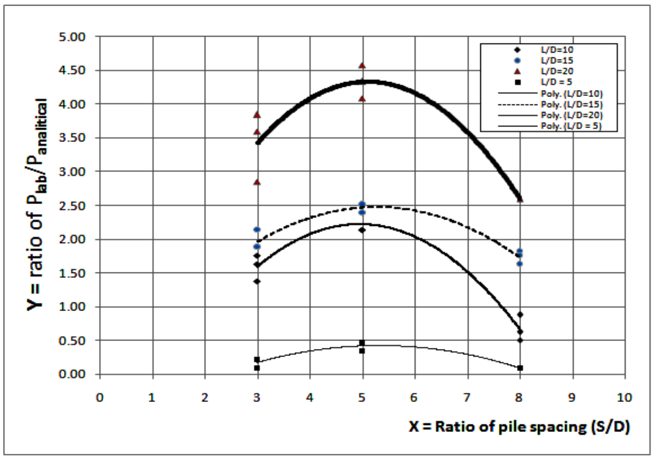


Figure 10: The curves showing correlations between ratios of pile spacing S/D with ratios of $P_{lab}/P_{analitical}$ for different pile insertions, L/D.

Similarly with the previous method, the results in Figure 10 can all be recalculated back using the value of P_{lab} at S/D =5 as the pivoting value for every family of result with the same L/D ratio. Therefore, if the values were recalculated so that ($P_{lab\ for\ S/D\neq 5}$)/($P_{lab\ for\ S/D=5}$) obtained from the same L/D ratio were all plotted against the spacing ratio S/D, the results showed very good correlation in quadratic polynomial in Figure 11.

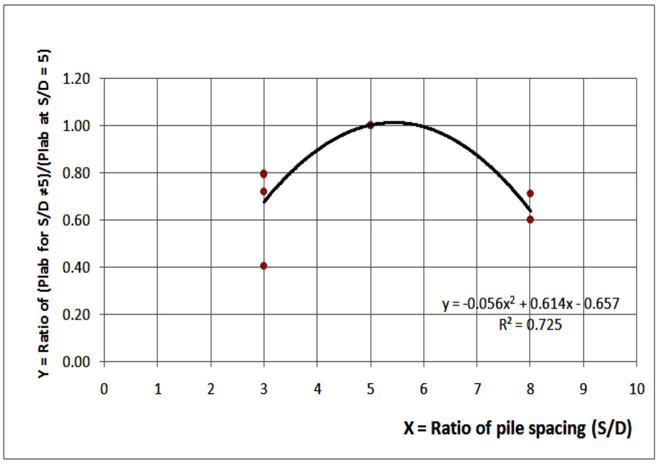


Figure 11: Correlation between ratios of ($P_{lab\ for\ S/D\neq 5}$)/($P_{lab\ for\ S/D=5}$) for various ratios of pile spacing, S/D.

The influence of the number of piles in a row to the increase of shearing resistance.

In order to determine the effect of the number of the piles in receiving the horizontal shear force is carried by the shear testing treatment piles number variation. The number piles applied, namely 1, 2, 4, and 6 piles. For each specimen with a unified treatment, namely: 3mm diameter used piles, spacing of piles group that are applied 5D (5xdiameter), and insertion piles with ratio of (L / D) = 15.

In Figure 12 shows the relationship ratio $P_{lab}/P_{analitical}$ and number of pile groups. The addition amount of piles can improve soil shear strength to horizontal shear force. Where the greater number of piles are embedded into the clay soft soil, the greater the contribution of the piles providing resistance to the horizontal shear failure.

The more the number of piles embedded into the so so the increased stiffness and the equivalent diameter between piles in the soil. This causes changes in soil conditions around the piles become relatively more dense than the previous conditions. An increase in the density of the soil contributed to the mobilization of soil-piles to provide resistance to horizontal shear failure happens. By installing a pile on the soil, so shear strength increased from the previous conditions. It also serves as a dowel or reinforcement in the soil so as to provide additional support for the horizontal shear force.

Figure 13 shows, the ratio of Y (= $P_{lab}/P_{analitical}$) was plotted against X (=the number of piles in a row). The number of piles (each piles number has been reduced to a single pile which has taken into account the effect of the group). Parameter Plab X≠1 is the magnitude of the shear force which can be held by a specimen for numbers of pile is not equal to 1 pile, while P_{lab} X = 1 is the magnitude of the shear force that can be retained by the test object just to use piles amounted to

1 pile. In this case the ratio $P_{lab\ at\ X=1}$ /$P_{lab\ at\ X\neq 1}$ can be expressed as well as the representation of soil shear strength.

The correlation obtained from Figure 13 was very well represented by a straight line. The correlation was given in Figure 13. The equation can be regarded as an efficiency equation group pile in the soil to provide resistance to horizontal shear force. This is because the equation of the number of piles has considered the effect of the pile group on a single pile for each pile number

Based on Figure 13, the greater number of the piles group to resist horizontal shear force, the shrinking value of the efficiency of the piles group. This could mean that the group's ability to withstand shear piles will not be the same with their respective capabilities multiplied by the number in the group concerned. This condition indicates that the number of piles in groups in the ground to resist the horizontal shear force it produces an overlapping condition of the lines of tension around the piles in the soil which is called the phenomenon of group action (the effect of efficiency) as well as during this happened on the pile of the group receiving the axial force.

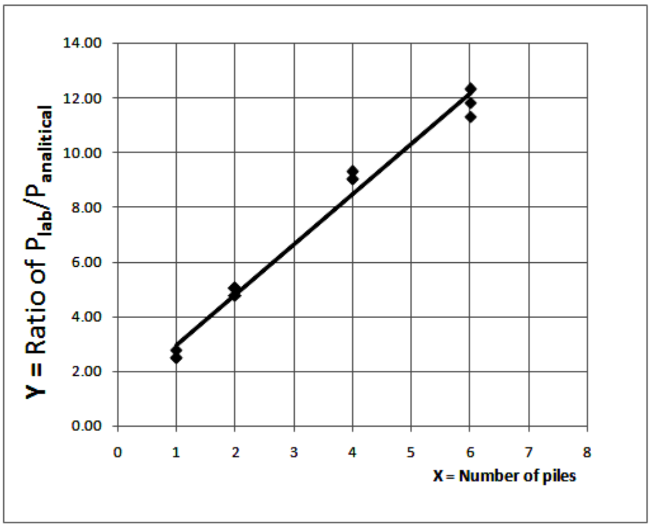


Figure 12: Correlations between ratio Y =P_{lab}/$P_{analitical}$ against the number of piles in a row

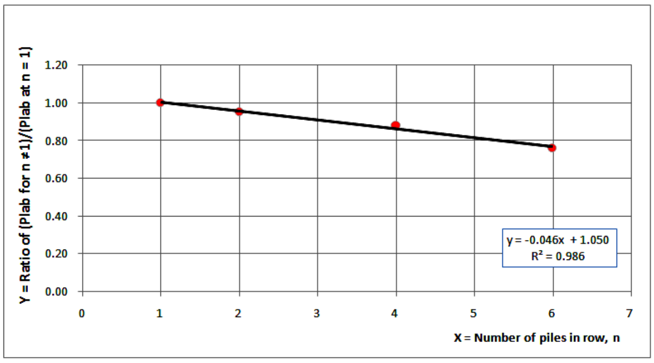


Figure 13: Correlation between ratio of $P_{lab\ at\ x\neq1}$/ $P_{lab\ at\ x=1}$ and number of piles in a row (=X). (In here $P_{lab\ at\ x=1}$ is the pivoting point and is assumed = 1. 0)

The influence of the pile diameter to the increase of shearing resistance.

In Figure 14, the ratios of pile diameter D/T were plotted against the ratios of P_{lab} for diameter of In this case the values of $P_{lab\ at\ D=3mm}$ was used as the pivoting point and was assumed = 1. 0 when D = 3mm pile 3 mm and other diameters (4. 5 mm and 6. 0 mm).

The correlation between the ratios ($P_{lab\ at\ D\neq3mm}$/$P_{lab\ at\ D=3\ mm}$) and the ratios of D/T was found to be best fitted by a straight line. The value of T represented the relative stiffness factor of piles compared to the soil strength (as given in NAFVAC DM-7, 1971), which is:

$T = [(EI_{\ of\ piles})/(f_{\ of\ soil})]^{0.2}$

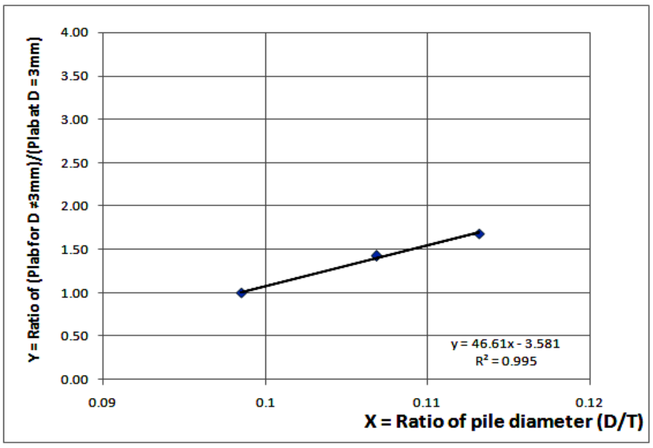


Figure 14: Correlation between ratio of pile diameter D/T and ratio of P_{lab}

It was apparent from Figure 14 that the increase in pile diameter would have also caused the increase of shearing resistance of the pile-soil interaction model.

The influence of pile inclination against direction of failure plane.

Different pile inclinations were tried in this laboratory study of pile-soil interaction model. The results showed that all other pile inclinations against the directions of the failure plane, other than 0˚ angle, would result higher resistance than the standard value of testing at 0˚ angle. In here, angle of inclination 0˚ meant the model pile was perpendicular with the failure plane, or the model pile made 0˚ angle with the line normal to the failure plane. Furthermore, considering the difficulty in determining the actual angle of pile inclination in the field (in reality), while most of the piles insertion can be assumed to have 0˚ angle with the failure plane, the results of pile inclination of other angles than 0˚ was not investigated further. By assuming all the piles to be in the right angle with the failure plane, the assumed result will give a lower resistance values (therefore, result better safety factor) than the actual pile resistance in the field.

CONCLUSION

The conclusion of this study can be given as follows:

1. The lateral resistance of pile will be influenced mainly by the ratio of pile insertion, the ratio of spacing between piles – with the ratio S/D = 5 is the most effective for pile spacing, number of piles in row, and the ratio of pile diameter.
2. Shear strength decreased while spaced piles being used increasingly likely, in this case spaced piles used more than 5D (space 8D).
3. The length of the piles embedded under the sliding plane also increase the generated shear strength.
4. The more the number of piles used, the greater the shear strength generated soil.
5. Efficiency factors may also affect the shearing resistance reinforcing soil pile group that receives the horizontal shear force. Where the group's ability to withstand shear piles will not be the same with their respective capabilities multiplied by the number in the group concerned.

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