Jurnal Teknik: Media Pengembangan Ilmu dan Aplikasi Teknik
Vol 20, No 01, Mei 2021, Hal. 83-93
Journal homepage: http://jurnalteknik.unjani.ac.id/index.php/jt ISSN (e): 1234-1234, ISSN (p): 1412-8810

The Effect of w/c Ratio of Compacted Bored Pile to Friction Resistance of Unjani Clay

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Abstract

The small scale physical model of drum type was set-up to obtain the effect of water cement ratio (w/c) to pile capacity and original soil. The simulation of the process of providing bored piles model, soils model, installation and tests (pile loading tests and direct shear tests) under different water cement ratio of mortar and various moisture content of clay were done. The results reveal that the higher water content of original clay the bigger friction resistance, α value as clay soil is softer and the optimum w/c-ratio (w/c = 0,4) provides more pile capacity. It is understandable that water plays an important role, contributes to the change of surrounding clay properties. The improvement of Su ($\pm$ 75% increase) due to compaction of concrete in bored pile, migration of moisture and reaction with surrounding clay leads to take benefit of design and construction of bored pile in clay soil for the sake of efficiency and stability.

Keywords: Compaction pile, undrained shear strength, water-cement ratio, bored pile

1. Introduction

In order to get a positive effect during installation of bored pile, any type of pile is expected to provide parameters which can behave as stabilizer either on short or long term condition. In the current practice of deep foundation technology, there are some methods of ground improvement pile as mentioned by Apageo, S.V (2016): Ground Improvement with and without admixtures, Ground Improvement with inclusions, Ground Improvement with grouting and Earth reinforcement. The improvement effect during installation of pile to bearing capacity of pile on sandy soil is clearly mentioned in many literatures compared to the effect of improvement on pile installation in clay soil.

To change non displacement pile become displacement type, the surrounding soil should move horizontally by any means. Compaction is one of the ways to displace soil horizontally. At the process of compacting concrete, soil pressure will increase then the change of parameters occur after consolidation is allowed as described by Zhu, Y (2016).

The ultimate capacity Q_u of displacement/drilled pile is shown in eq 1,

$$Q_u = Q_p + Q_f \tag{1}$$

The standard formula for point resistance, Q_p= 9 Ap Cu and skin resistance, Qf= p L α Cu as described eq (2).

$$Q_u = Ap\ 9\ Cu + p\ L\ \alpha\ Cu \tag{2}$$

Based on explanation by Das, B.M (2008) the value of adhesion factor, α normally in the range of 0,3 to 0,8 of undrained shear strength, Su. However, some reported slightly less than 0,6 for top margin.

By the improvement, the impact of improved sub-soil can be as high as two fold to original shear strength even some reported higher. As mentioned in eq. 3, Su value can increase significantly after grouting as elaborated by (Hung, J. L, 2006).

$$\left\{\frac{S_{u-r}}{S_u}\right\} max = 1 + \frac{2S_u}{\sigma'_p} Ln(0{,}5\sqrt{I_r}) \tag{3}$$

In the process of installing a bored pile leads to increase of pressure in the vicinity of piles. At first, the parameters of soil will softening, recovery and after that regain the properties to go up. The phenomena of soil stabilization in this methods are very close to the concept of lateral displacement of material which causes change their structure. Clayton, R. I. and Milititsky, M. (1983) added that the installation of this type of compaction pile will result in a large radial displacement in the surrounding soil and non-uniformly distributed excess pore water pressure (pwp) inside the soil also. If sufficient time is allowed for the excess pore water pressure to dissipate, shear strength increase in the surrounding soil is expected.

Info Makalah:
Dikirim : 05-07-21;
Revisi 1 : 05-23-21;
Revisi 2 : 06-16-21;
Diterima : 06-25-21.

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Majority the causes of improvement in this category closely related with moisture migration, Since either concrete or grouted concrete made of cast-in-place concrete, a certain amount of water will migrate into the surrounding soil from the fresh concrete. The amount of water that migrates between concrete and soil is not well known. Meyerhof and Murdock and Skempton, who studied bored piles in London Clay, concluded that the water migrated from fresh concrete into the surrounding soil to a distance of 2,5 to 3 inches. Meyerhof found that the water migration caused the clay next to the pile wall to have a moisture content from 6 to 7 percent higher than the original moisture content for London Clay. Skempton found further that the increase of water content in the soil surrounding the shaft caused a decrease in the soil strength along the shaft surface.

The nature of moisture migration from cement mortar to soil is a complex problem. Described by Narong, T, et al. (2000) that the influence of factors which affect moisture migration can be studied separately, but the analysis of the relationship of multiple factors to moisture migration is still an intricate problem. However, it can be concluded that the degree of moisture migration between cement mortar and soil is greatly affected by (1) void ratio, (2) initial moisture content, (3) water-cement ratio, and (4) other variables such as temperature, type of cement, hydraulic pressure, and time.

Water-cement ratio is the one to contribute in moisture migration, it is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and to form. Workability can be resolved with the use of plasticizers or super-plasticizers . At high w/c ratio, the strength decreases as the nature of concrete mix was clearly mentioned by Hoque, M.I and Alamgir, M (2014).

Concrete hardens as a result of the chemical reaction between cement and water (known as hydration, this produces heat and is called the heat of hydration) was mentioned by Zhu, Y (2016). For every pound (or kilogram or any unit of weight) of cement, about 0,35 pounds (or 0,16 kg or corresponding unit) of water is needed to fully complete hydration reactions. However, a mix with a ratio of 0,35 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water-cement ratios of 0,45 to 0,60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flowability. Too much water will result in segregation of the sand and aggregate components from the cement paste. Also, water that is not consumed by the hydration reaction may leave concrete as it hardens, resulting in microscopic pores (bleeding) that will reduce final strength of concrete. A mix with too much water will experience more shrinkage as excess water leaves, resulting in internal cracks and visible fractures (particularly around inside corners), which again will reduce the final strength as mentioned by Briaud, J. L (1987).

The main purpose of this research is to observe the behavior of various water content of clay in the installation of bored pile as well as observation into various cement ratio of concrete mortar in the process of installation with compaction effort. Performed in the small scale model as shown in Figure1, the amount of increasing Su at original clay should be compared to Su after treatment in order to obtain the efficacy of this method.

2. Method

Small scale physical modelling consist of 1-gravity simulation and enhanced gravity simulation (centrifugal physical modelling) to simulate geotechnical case. In the condition where the full scale prototype of model is intended to be scaled down, it needs scaling factor law, however, it doesn’t need scaling factors when full scale prototype is similar size with small scale model was described by Sulaeman, A, et.al (2015). In this research, the latter condition was selected.

The works consists of setting up the model tank, sample preparation, simulation of bored pile, loading test and direct shear test, the work was done as follow:

1. Set-up a model tank
   The model tank was set up as shown in Figure 1, consist of drum in half cut equipped with steel frame and other appurtenances then furnished with necessary instrumentations: settlement gauge and loading gauge.
2. Determination of properties of original clay
   Original clay was taken from clay soil 1 to 2 m depth in the Unjani area, Particle size distribution analysis and Atterberg limit test was performed as well as other engineering properties.
3. Simulation of bored pile installation
   After first soil model condition finished, the simulation of drilling a hole to simulate drilling process was initiated before installing pile model. At the same time, the bored pile model (8 nos.) under various water cement ratio were prepared. In the process of making concrete in a bored hole, each piles should be compacted 10 blows by suitable hammer.
4. Pile loading test in small scale
   At the first condition of modeled soil, the PLT to obtain L-S curve were performed to each piles. The second, third and fourth soil model were also prepared subsequently, followed by PLT to each piles.
5. Direct shear test in full scale

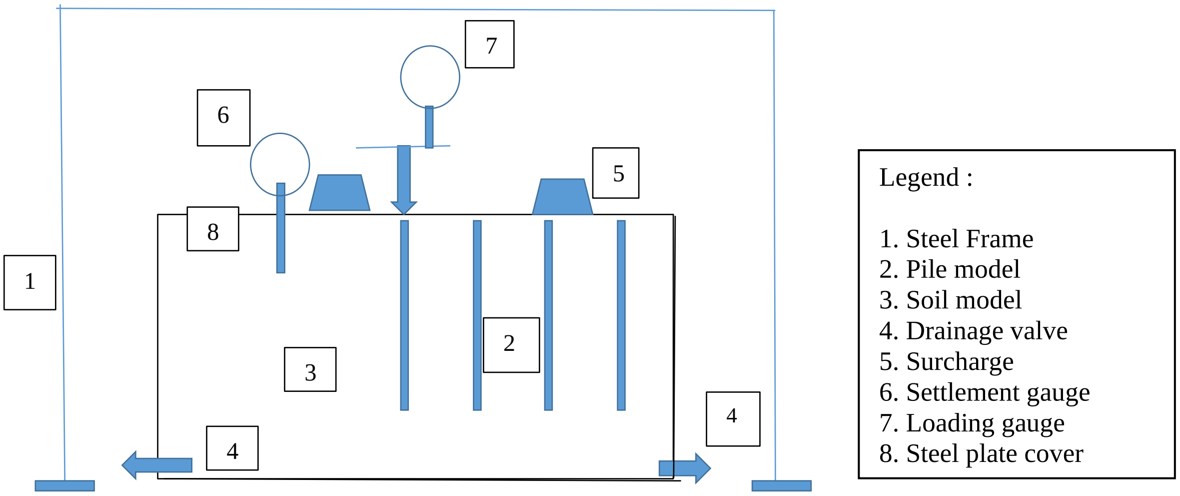

Figure 1. Schematic Diagram of Drum model (ot to scale)

The planned of small scale model in the drum type as shown in the Figure 1 was then materialized. Numbers of pile models as well as clay soil which excavated from nearby Unjani area was selected. The necessary instrumentations to support simulation was then calibrated before performing real test to obtain an accuracy of the results. Figure 2 shows the simulation of pile loading test was being carried out for soil condition of LI-1. The test consist of applying load gradually while at the same time, the settlement in dial gauge is recorded every 30 seconds until the pile is considered failure (pile settlement reach 10 % pile diameter).

Figure 2. Pile loading test was being carried out

The soil condition of LI-2 was then prepared by application of loading on top of clay soil which was consolidated 3 days as shown in the Figure 3. As of LI-2, to obtain the various clay condition LI-3, similar treatment was done. In this step, the water was allowed to drain in a similar 3 days of loading to achieve different properties with LI-1.

Figure 3. During Loading and Consolidation

At LI-2 condition, the following similar step with LI-1 was being performed. Subsequently, the similar steps were also done to LI-3. The next stage of this work, was performing direct shear test to 3 type of soil LI-1, LI-2 and LI-3 by using 5 type of sample conditions:

a) Soil – soil
b) Soil – mortar with w/c-1
c) Soil – mortar with w/c-2
d) Soil – mortar with w/c-3
e) Soil – mortar with w/c-4

The schematic diagram of DST to Soil – mortar with various w/c was shown in the Figure 4, the ordinary DST was also being tested as a standard. Figure 5 shows the preparation in making the sample of soil-mortar specimen.

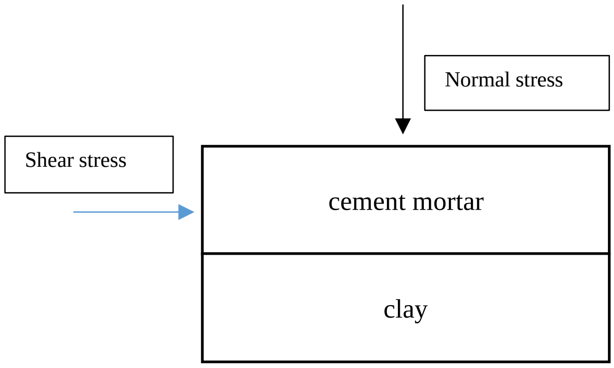

Figure 4. Schematic Diagram of DST on Interface Cement Mortar – lay

The DST to the various specimen of all soil-soil and soil with various w/c ratio of mortar is intended to follow the simulation of correspond condition with LI and w/c condition during pile loading test. The matching soil condition was needed to obtain correct simulation of PLT and DST at various LI-1, LI-2 and LI-3 under various w/c of mortar as representation of the nature of concrete material in PLT and DST.

Figure 5. Preparing a DST material

3. Data collection, Analysis and Discussion

3.1 Data collection and Analysis

In every site investigation to obtain the comprehensive properties of original soil, the physical properties is normally highlighted in advance. The parameters of soil at UNJANI area:

Liquid Limit = 140; Plastic Limit = 48; Plasticity Index = 92 Classified as CH. q_u from UCT = 7,6 kPa leads to Su= 3,8 kPa. Liquidity index, LI-1 obtained from {(82 – 48)/92}×100 % = 37 % = 0,37 and subsequently LI-2 and LI-3 can be calculated accordingly.

The properties of pile model was: Diameter (D) of drilled pile model = 2,2 cm; the length of model pile (Lp)= 11,5 cm; Lp/D ratio = 115/22 = 5,2

Shown in table 1 was soil model at various moisture content and various modelled pile at different w/c ratio to be further used for observation during installation and tests.

Table 1. Data for further soil modelling

	Water to cement ratio
w1 = 82 % LI-1 = 0,37	Water to cement ratio 1 = 0,35
	Water to cement ratio 2 = 0,51
	Water to cement ratio 3 = 0,72
	Water to cement ratio 4 = 0,91
w2 = 61 % LI-2 = 0,14	Water to cement ratio 1 = 0,35
	Water to cement ratio 2 = 0,51
	Water to cement ratio 3 = 0,72
	Water to cement ratio 4 = 0,91
w3 = 54 % LI-3 = 0,07	Water to cement ratio 1 = 0,35
	Water to cement ratio 2 = 0,51
	Water to cement ratio 3 = 0,72
	Water to cement ratio 4 = 0,91

The capacity of pile is normally can be obtained from plotted load versus settlement, interpretation to predict the ultimate capacity from that curves can adopt the Terzaghi method. The L-S curve of 3 days curing period were plotted in the Figure 6, Figure 7 and Figure 8. The curves show that failure occur on 8 – 10 % of D. At the water to cement ratio of 0,40 the ultimate capability is maximum, as it can be elaborated that in small water cement ratio, the migration of water from mortar to clay is considered small, this condition is also agreeable with Hung, J. L (2006).

According to Hung, J.L (2006) 10 nos. of blow given to any piles is significant energy to increase the parameters of clay and it can be recorded on the investigations in the process of installing pile model. For high water cement ratio, there are some amount of water from cement mortar moves out resulting to decrease the properties , due to high portion of water in the cement mortar inducing cement to move then mix with surrounding clay. It can be observed the curves almost coincide each other, start at initial point O, the curves gradually rise linearly then bends until reaching ultimate capacity. The test can be regarded as reaching failure as pile settlement value around 10 % pile diameter (around 2 mm) as shown in Figure 6, 7 and 8.

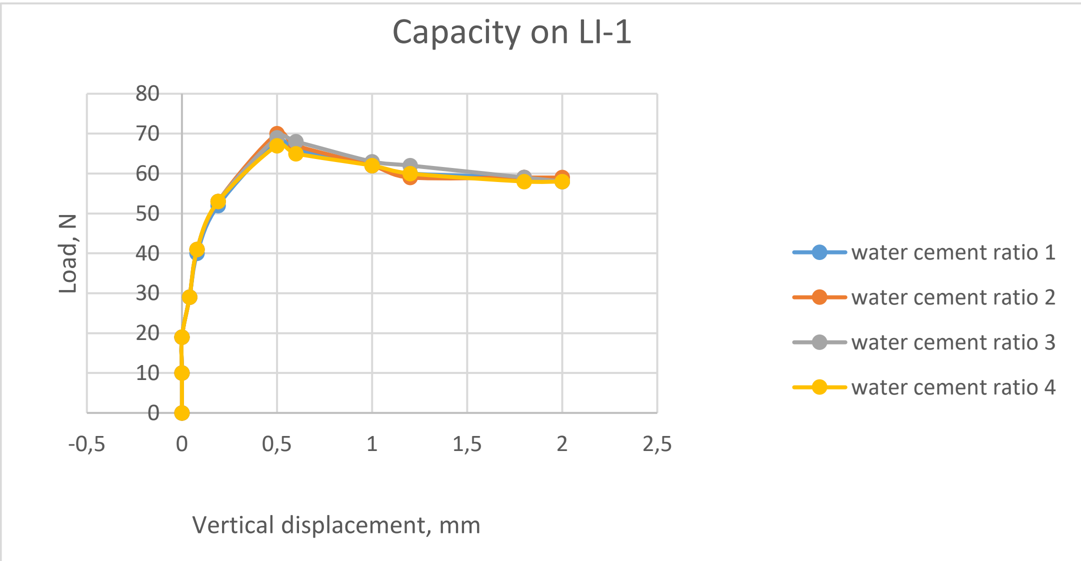

Figure 6 L-S Curve of PLT on LI-1 at Various w/c Ratio at 3 Days Curing

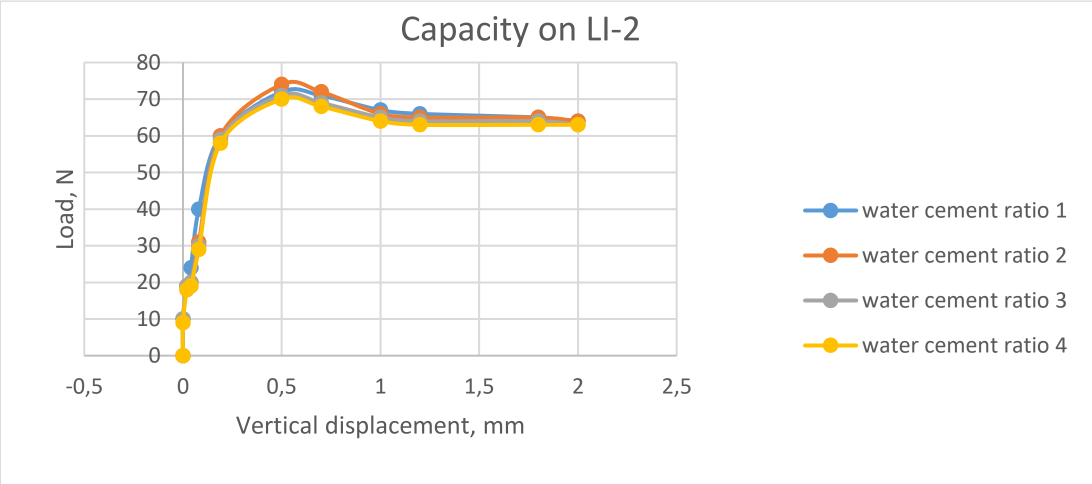

Figure 7. L-S Curve of PLT on LI-2 at Various w/c Ratio at 3 Days Curing

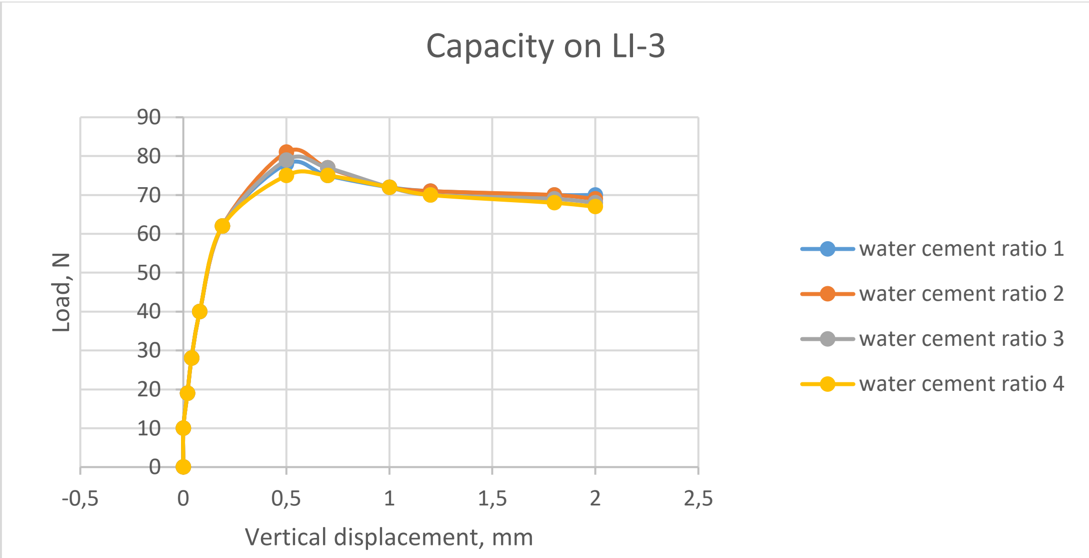

Figure 8. L-S Curve of PLT on LI-3 at Various w/c Ratio at 3 Days Curing

In seven days of curing, the pile capacity increases slightly, as a result of mixture of cement with clay.

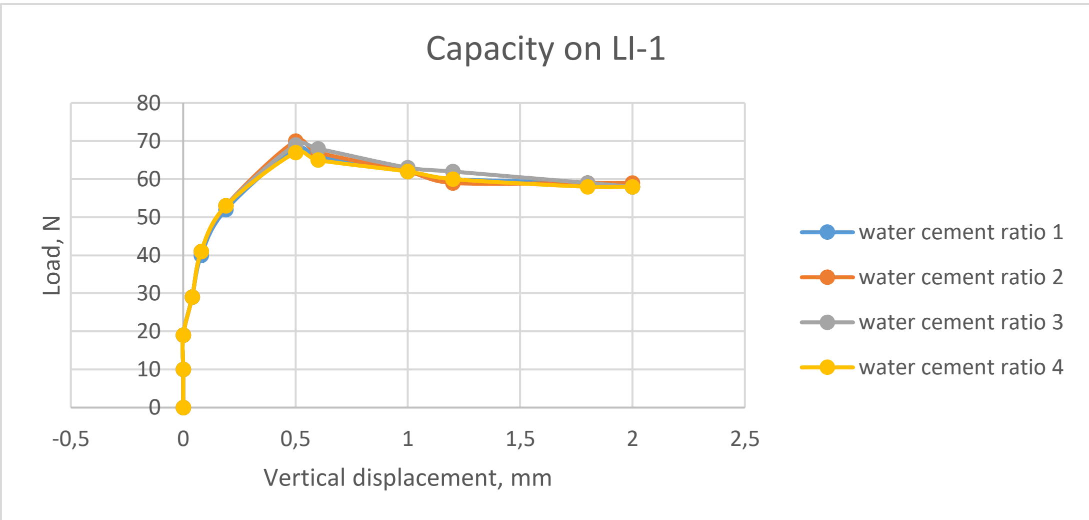

Figure 9. L-S Curve of PLT on LI-1 at Various w/c Ratio at 7 Days Curing

This results is slightly comparable with the findings by Chuang, J. L and Reese, L. C (1969), They concluded that by w/c = 0,2 the optimum moisture content was settled. The curves as shown in Figure 10 described that at low moisture content the bearing capacity is high. As some amount of water increases, the capability of pile to resist load become decreases, this condition is make sense and agreeable with natural phenomena. Optimum w/c ratio of 0,4 was found from this research of Unjani clay indicates that this optimum water to cement ratio is needed to increase undrained shear strength or pile capacity, slightly need more water compared to what was found by Chuang, J.L and Reese, L.C (1969).

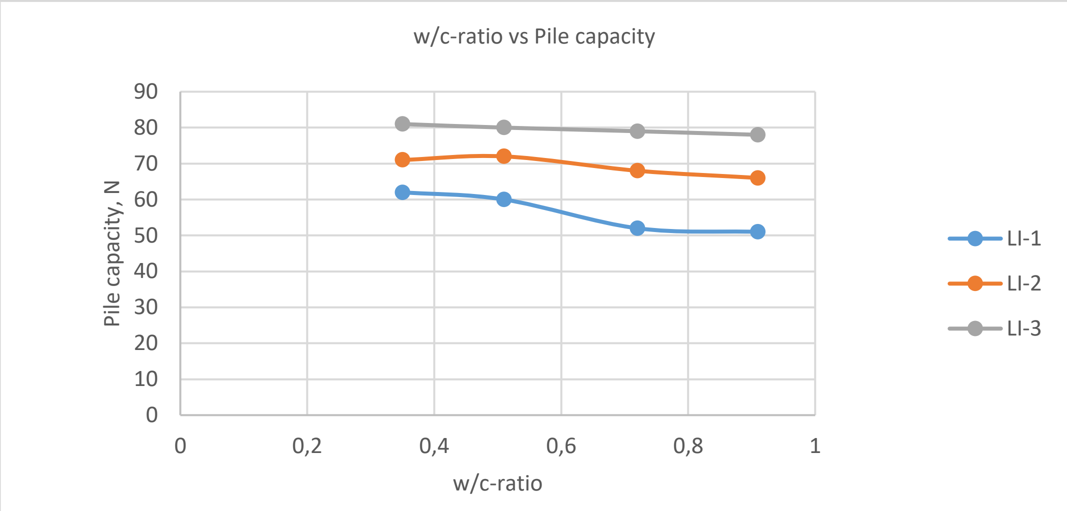

Figure 10. The decreasing trend capacity of pile on various Liquidity Index

The α values is linearly corresponds with pile capacity, The α values as a result of investigation, revealed the tendency of decreases when liquidity index getting high or vice versa as can be seen in Figure 11.

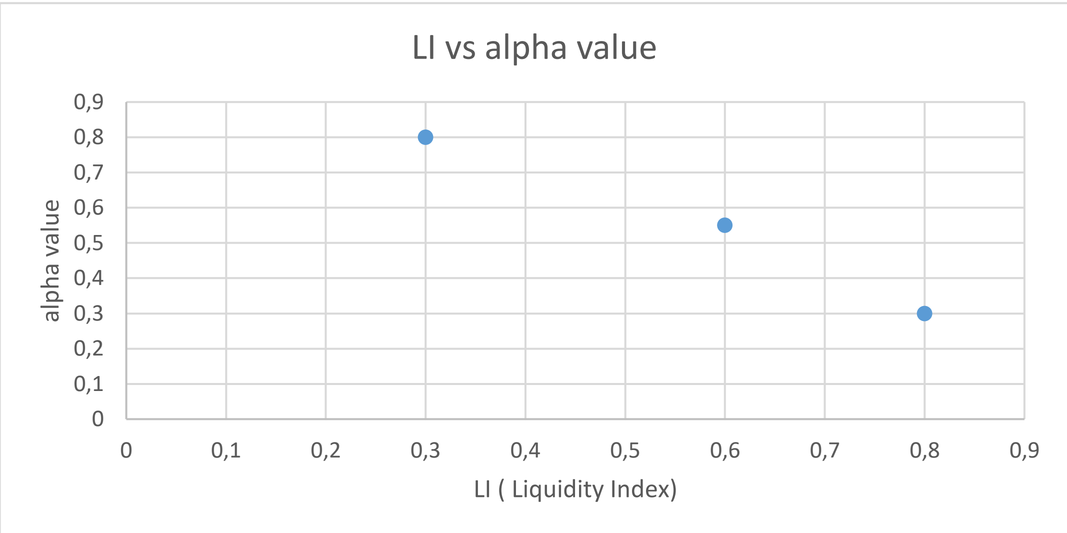

Figure 11. Correlation between α with LI

The liquidity index is corresponding with moisture content, from this reason, it is clear that α values can be correlated with moisture content. According to the data in the previous figures show the similar trend with above mentioned, this is agreeable with the basic understanding of the nature of clay soil. DST result on Fig.12, 13 and 14 showed agreeable with the results of pile simulation test. By the condition of LI-3 < LI-2<LI-1 indicated increasing strength of LI-1 due to high water content of LI-1 compared with LI-3.

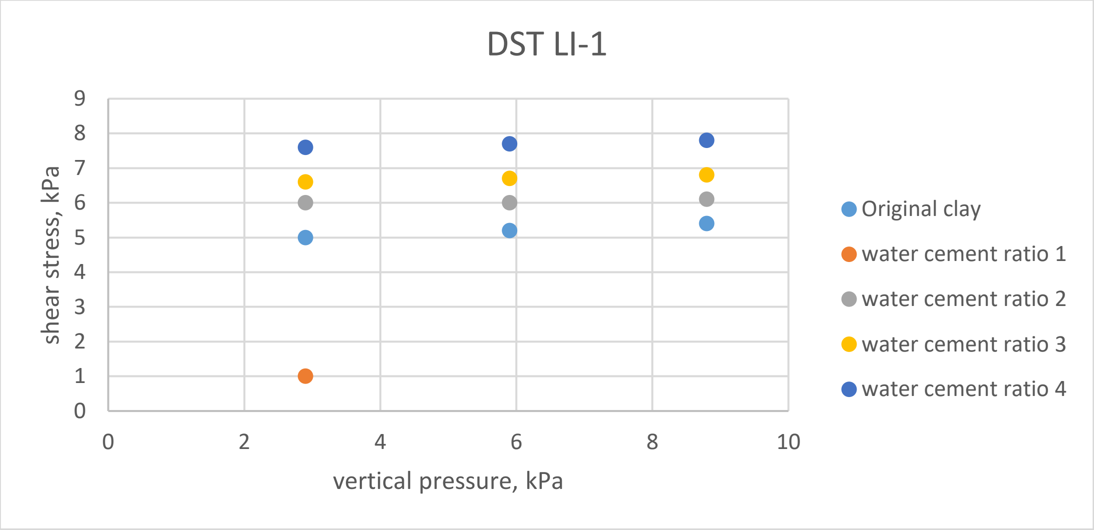

Figure 12. DST on LI-1

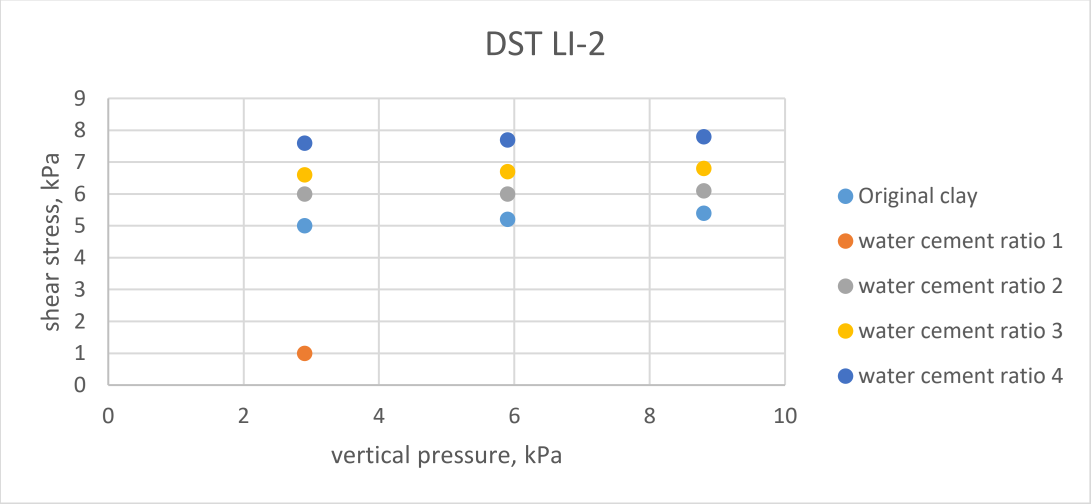

Figure 13. DST on LI-2

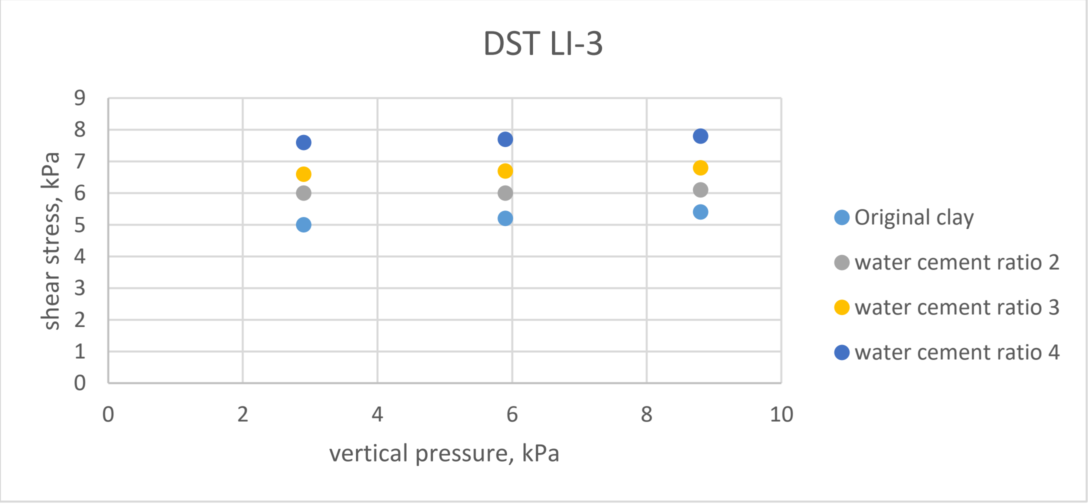

Figure 14. DST on LI-3

In order to gain the possibility of stabilization, the followings are the calculation and analysis to support it.

Pile diameter, D = 22 mm; Cross sectoon, Ap = 2,98 cm^2 ; outskirts, p = 6,9 cm ; span of model, Lp = 11,5 cm
Based on loading test result: 0,06= Su (0,00268 + 0,00792), So Su = 0,06 / 0,009 = 6,64 kN/m^2

Whereas, Su = 3,8 kPa from Unconfined Compressive Strength and Cohesion = 3,6 kN/m^2; Ø = 5º in Direct Shear Test. From this calculation it shows improvement of strength properties is clear (100%×(6,64-3,7)/3,7 = 75% increase). The percentage of increased Su can use eq.3, however since the rigidity index of the soil sample was not measured, that of the equation 3 was not used. Another encouraging observation is shown in the Fig.15 and Fig.16 reveals that there are chemical reaction between cement with clay as a result of moisture migration, Some mm's thickness of clay-cement mix was produced. Diameter of failure slip surface is slightly bigger than original diameter of bored hole, which in turn increasing pile capacity. The real picture also shown in the Figure 16 on comparison of some extracted pile model (dark color) and the size of bore hole (white color in the middle), clearly showed the dark color size is bigger indicating chemical reaction and puzzolanic reaction occurs. The thickness of this hardened soil (t) was around 3 to 6 mm (take 4 mm average) or the t/D = (4/22)×100% = 18%. This increased in thickness should be verified further for different L/D and other clay type.

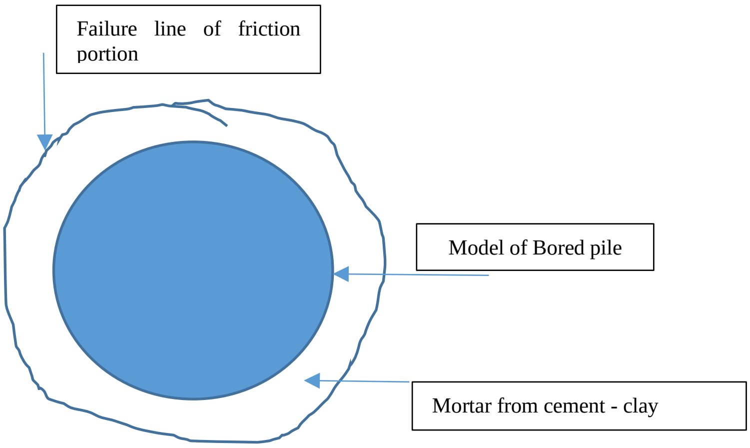

Figure 15. Schematic Diagram of Diameter of Drilled Bore Hole and Slip Failure Surface

Figure 16. Pile Model was Being Taken Out after Tested

3.2 Dicussion

Equation 3) was a result of research by Hung, J. L, et.al in 2006's revealed that there was improvement of clay soil after grouting by cement mortar. The magnitude of increased Su was more than 100 % even 200 % depending on soil rigidity, over-burden pressure and initial Su. The behavior of increased Su of this research is almost as similar as performed earlier by Chang, M.F and Zhu, H (2004), however the increasing of Su as such that 75 % of original clay soil. It can make sense that there is slightly different of improvement mechanism between grouting and compaction pile.

In general, sandy soil is easily and effectively react with cement or lime to produce hardened soil which contribute in increasing strength added by Kinoshita, H, et al. (2010), instead the clay soil when blends with cement or lime produced less efficient mixture and less Su. Nevertheless, in cement column or lime column stabilization, both sand

and clay soil can be used to be blended with cement or lime. Based on this reasons, this concept was adopted to be implemented on bored pile on clay. From the observations of this research, it can be pointed out that to obtained an effective increasing Su, some elements should be taken into consideration during preparation and installation of this type, i.e : water migration, compaction, consolidation, chemical reaction and pozzolanic reaction/cementation.

Das, B.M. (2008) mentioned the value of α (coefficient of friction resistance) is in the amount of 0,3 to 0,8 of initial Su, The bigger the Su, the smaller value of α. The results of this research reveals the correlation of α with LI which LI has a correlation with consistency. Lower LI correlates with a drops of α as shown in Figure 11, therefore the lower LI is almost similar with the bigger Su. In other words, the results of this research is supportive and agreeable with Das, B.M (2008).

4. Conclusion

The main objectives of ground improvement technology is to improve the unstable condition of original soil by some treatment to reach or exceed the minimum requirements. This observation and investigation reveal that clay soil in the bored pile can be improved by adding certain amount of energy (it could be hammer blow, injection of pressure in grouting, displacement of soil during installation process as well as selection of w/c ratio and consolidation). This Condition can increase 75 % of Su compared to no treatment, the point should be kept in mind are:

1. Water content of original soil
   The more water content of original clay the bigger α value as clay soil become softer. This is indicated by lower value of pile capacity of L-S curve from LI-3 to LI-2 and to LI-1.
2. Time
   Sufficient time is needed to allow dissipation of excess pore pressure after hammer blow. Normal clay needs 30 days to fully dissipation. In this context, fully loading from upper structure is not allowed before complete dissipation.
3. Water cement ratio of concrete mix
   The lower w/c-ratio provides more pile capacity, minimum w/c – ratio of 0,40 was selected in this type of clay, the other reference shows different value. To obtain minimum w/c – ratio for certain case, It is recommended to do some tests prior to begin installation of bored pile.
4. Energy from hammer blow
   Hammer blow numbers was not studied thoroughly, too much hammer blow will produce uncontrolled compaction. Insufficient compactive effort will result in inefficient improvement. To control effectiveness of improvement, this blow count should be thoroughly investigated.

Recommendations

Further research is recommended to use soil media of another clay with various PI, as well as in order to save energy during bored pile installation, research to obtain optimum hammer blow in clay soil which contribute to maximum improvement is necessary.

Acknowledgements

This work was financially supported by the LPPM-UNJANI, The Authors is grateful to the fully support and encouragement to this project.

List of Symbols

α	= unit friction resistance /adhesion
$\emptyset$	= internal friction angle
$\sigma_{p\prime}$	= effective vertical stress
Ap	= Area of base
c	= Cohesion
Cu	= Undrain cohesion
D	= Pile diameter
DST	= direct shear test
Ir	= Rigidity Index
LL	= Liquid Limit
LI	= Liquidity Index
L-S	= Load settlement
PL	= Plastic Limit
Qf	= Capacity of friction
Qp	= Capacity of base/point
Qu	= Ultimate capacity
q_u	= Unconfined compressive strength

Su = Undrained shear strength
S_{u-r} = Undrained shear strength after grouting
t = thickness of mortar

References

Apageo, S.V,et al.(2016) "Ground Improvement vs. Pile Foundations" *ISSMGE - ETC 3 International Symposium on Design of Piles in Europe.* Leuven, Belgium,

Briaud, J.L, (1987) "*Drilled and Grouted Piles: Construction, Integrity*, Capacity" Department of Civil Engineering. Texas A&M University

Chang, M.F and Zhu, H (2004), "Construction effect on Load Transfer along Bored Piles", *Journal Geotechnical and Geoenvironmental engineering ASCE*

Chuang, J.L and Reese, L.C (1969)." STUDIES OF SHEARING RESISTANCE BETWEEN CEMENT MORTAR AND SOIL "UNIVERSITY OF TEXAS at AUSTIN

Clayton, R. I. and Milititsky, M. (1983) *"Installation effects and the performance. "of bored piles in stiff clay" Ground Engineering, Brazil*

Das, B.M. (2008). *Foundation Engineering*. Publisher Co, New York.

Hoque, M.I and Alamgir, M (2014) "STUDY ON THE FIELD PERFORMANCE OF GRANULAR PILE AS A GROUND IMPROVEMENT TECHNIQUE *"Journal of Engineering Science 05(1), 2014, 103-114, Bangladesh*

Hung, J.L, et al. (2006) "Ground Improvement piles induced shear strength in NC clay *"Journal of the Chinese Institute of engineers.*

Kinoshita, H, et al. (2010) "Sand Compaction Pile Technology and its Performance in both Sandy and Clayey Grounds "ISSMGE-TC 211 *International Symposium on Ground Improvement IS-GI Brussels 31 May & 1 June 2012.*

Narong,T, et al. (2000) "CONCRETE FOR WET PROCESS BORED PILES, *GEOTECH-YEAR 2000 Developments and Geotechnical Engineering 27-30 November 2000, Bangkok, Thailand*

Sulaeman, A, et.al (2015) "The Determination Of Scaling Factor of Clay Properties On One-gravity Small Scale Physical Modeling , *International Journal of Integrated Engineering,* Vol. 7 No. 1 (2015) p. 12-20

Zhu, Y (2016) "Mechanisms of Property Changes of Soft Clays Around Deep Mixing Column, *International Forum on Energy, Environment and Sustainable Development (IFEESD 2016)*