Investigation of unstable soil stabilized using fly-ash cement grouting

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Abstract: The deep soil with a relatively poor compressive strength has been an issue for the researchers and constructors for years since the hardships faced by them when trying to construct heavy structures on top of them. It is found that weak soils like those can be strengthened by adding different additives. Cement is commonly used for the above purpose but, since it’s expensive to use alone, cement mixed with fly ash was tested with different soils to strengthen them. The aim of the research was to find out the increase/decrease of strength when two different cement and fly ash mixtures were mixed with three different types of soils common in Malaysia in different proportions and to find the optimum percentages of each mixture to be mixed with each soil to obtain a desired strength. The Modified Standard Proctor test and the Unconfined Compressive Strength (UCS) tests were carried to study the behaviour and strength of the soils when mixed with the above additives.

1. Introduction

The unavailability of lands in densely populated city areas and suburbs has caused numerous problems to the local authorities and constructors. Therefore, constructing in lands with unstable soil has been a good option. Deep Soils stabilization is a technique used to stable and strengthen such soil conditions. In this case, Asian countries like Malaysia which has been having a high development speed in the recent decades have been experimenting and using this technique to stabilize the soil conditions considering the advantages of it.

One of the two main ingredients used in this research is fly ash, which is a by-product of the steam generating plants. It is mainly used for soil improvement and to construct the layers of hydraulically bound aggregates. The previous researchers have studied that impact of fly ash was depended on the properties of soil. The countries like Greece, which produce more than 9 tons of fly ash every year are using fly ash to improve the strength of the soil and combining it with various elements such as cement, lime and rice husks have also given improved results [1].

Ordinary Portland Cement (OPC) is the next ingredient used in the research and it’s one of the most popular types of cement used in the world. There are several studies which used OPC and fly ash combined to observe the changes occur in soil’s physical and mechanical properties. Two different blends of OPC mixed with Fly-ash are used in this research and the main intension is to observe the
change of strength when the two different blends are mixed with three different soils (Marine Clay, Residual Soil and Reddish-Brown Sandy Clay).

Since the two different mixtures will have different impacts on the three different soils, the soils were mixed with 10%, 20% and 30% by weight of each mix and each sample were cured for 7 and 28 days respectively. Multiple tests were carried to observe the behaviour of the soil when mixed with different proportions of the two different blends.

2. Literature review

2.1 The ground improvement methods currently being used in Malaysia

The different ground conditions and variable soil conditions in Malaysia has tempted the Malaysian construction companies to use different soil improvement methods in Malaysia. Vibro concrete columns, vibro stone columns, deep soil mixing and jet grouting are some of the methods used in Malaysia and some they are:

- Vibro Stone Columns – used as a support for a highly reinforced soil for a highway construction.
- Vibro Concrete Columns – used to reinforce concrete tanks for a sewage treatment plant
- Deep Soil Mixing – used in a commercial complex to support a deep vertical basement
- Jet Grouting – to establish a stable cutter- head for a project of a tunnel construction

2.2 The Malaysian soil structure

The soil types of Malaysia can be categorized using its age. Kuala Lumpur, which is the capitol and the most populated city in Malaysia has Kuala Lumpur Limestone and Kenny Hill formation. The research here is mostly based on three different soils collected from three different regions of Kuala Lumpur.

2.3 Fly ash

Fly ash is an industrial by-product extracted from the coal combustion process. Generally, fly ash is extracted using the flue gas which is released during the combustion process and machines such as electrostatic precipitators/filter fabric baghouses are used in the extraction process.

There are two main types of fly ash which are Class C fly ash and class F fly ash. Class C fly ash, which is known as high calcium fly ash because of the high Calcium Oxide (CaO) percentage in that, which is more than 20%. Since the amount of Calcium Oxide (CaO) in Class F fly ash, it is known as low calcium fly ash.

Fly ash has been used in the industry for a long time for different purposes. It has been used to increase the mechanical properties of ordinary Portland cement from a long time. It is found that the fly ash was used with cement from the beginning of the 20th century but, it is properly utilized with cement in the mid 1950’s. According to the previous articles, it is mentioned that 15 million tons of fly ash used to mix with cement in order to make concrete in United States in 2005.

Although the main use of fly ash is to utilize and increase the performance of cement, there are other industrial uses as well. It is used to mix with the aggregates to make a solid road base and to fill embankments. Finally, the main purpose of this research, is the other use of fly ash which is to increase the soil strength and performance of soil.

2.4 Ordinary Portland Cement (OPC)

Ordinary Portland cement is one of the world’s most commonly used types of cement. Joseph Aspdin in 1824, named this as Portland cement because the colour of the cement was similar to Portland.

2.5 The influence of fly ash mixed with cement to strengthen the soil

The focus of this research, which is improving the soil strength using fly ash and cement, has been previously discussed in various other researches by different people.
Kolias S has done a research about involving cement and fly ash to improve the properties of different soils. In his research, he has found a lot of advantages of mixing soil with different proportions of fly ash and cement. It’s mentioned in his research that the strength of the soil after mixing the above additives depends mostly on the amount of stabilization agents used and the time the samples are cured. Also, he has found that the use of fly ash and cement mix in road pavements will increase the properties of the soil such as compressive, tensile and flexural strength. Finally, he has mentioned that the layer thickness of the pavement can be reduced since it gives more strength and since the thickness is less, the probability of having cracks is less causing the pavement to have significantly less amounts of cracks [1].

Many studies have been conducted to reduce the damage to the environment done by the production of cement. Since the use of Ordinary Portland Cement contributes to a huge amount of the annual global CO\textsubscript{2} emission which is around 5% in total, studies were conducted to replace some parts of cement using environmentally friendly substances. In his research, Deb et al has used geopolymer cement and fly ash instead of using OPC cement, fly ash and slag. Moreover, it has been found that by using fly ash, it will have 80%-90% less greenhouse gas emission and by using slag, it will have 80% less greenhouse gas emission [7].

In another study done in 2007, Fly ash, Polyester Fibres and lime were mixed with soil to find out the effects. It was found that rather than using fly ash alone, it’s more advantageous to use fly ash and lime combined in soil. Also, it was concluded in that research that the increase of strength in the soil doesn’t depend much on the curing time until 4% of lime added and by adding lime, it decreases the maximum dry density (MDD) of the soil while it increases the optimum moisture content (OMC).

In another experimental project done by Shenbaga R. Kaniraj and Vasant G. Havanagi, the effects of randomly oriented fibres included in fly-ash soil and cement mixtures were put into test. They carried out Unconfined Compression tests for raw fly ash-soil samples mixed with 3% cement and raw fly ash-soil samples mixed with 3% cement with 1% fibre and cured for different periods. They found out that the fibres increase the strength of fly ash soil mixtures and change both the brittle and ductile behaviour of the samples. Also, the different curing times used have shown that the increasing curing time will cause high strength of the specimens [8].

Sunil and Ahmet researched about class F fly ash and cement added to soils to use as highway-based mate- rials. It is mentioned that class F fly ash alone can’t be used in soil improvements as it is not self-cementing. Pozzolan stabilized mixtures are made by mixing either Ordinary Portland cement or Lime or both into Class F fly ash according to their research. Their re- search concludes by finding that the strength of fly ash, cement and soil mixture is mainly based on cement content, water content and the period of curing [9].

3. Material
Three different soils were used in this research with the two different fly ash-cement blends. The reason for choosing these soils are the fact that them being three of the most available soils in Malaysia.

3.1 Residual soil (S1)
Residual Soils are created when the different types of soils and rocks go through a chemical process of weathering. One of the dominant features of residual soil is the fact that the particles bond together during the chemical process of weathering [10].

The soil samples were taken from a abandoned site in Loron Tun Ismail, Kuala Lumpur. The Atterberg’s Limit values of the residual samples obtained are shown in the table below.
3.2 Marine clay (S2)
Marine Clay is a type of clay which exist near fresh water and in coastal corridors.
The soil samples were taken from the Pantai Remis beach in Port Klang. The Atterberg’s Limit values of the residual samples obtained are tabulated below.

| Geotechnical Properties | Value |
|-------------------------|-------|
| Plastic Limit           | 22.3  |
| Liquid Limit            | 42.17 |
| Specific Gravity        | 2.34  |

3.3 Reddish brown sandy clay (S3)
Sandy clay is a soil consisting sand sized particles and the type of sandy clay used in this research is, reddish brown sandy clay.
The Atterberg’s Limit values of the Reddish Brown Sandy Clay samples obtained are tabulated below.

| Geotechnical Properties | Value |
|-------------------------|-------|
| Plastic Limit           | 43    |
| Liquid Limit            | 76    |
| Specific Gravity        | 2.59  |

4. Methodology
4.1 Modified proctor compaction test
The optimum moisture content (OMC) is the moisture content which occurs when the soil is compacted until the maximum dry unit weight occurs. The maximum dry density (MDD) is the dry density of the soil sample interrelated to the optimum moisture content. The optimum moisture content is useful
because it’s been used to prepare the samples for the Unconfined Compression Test (UCS) which is the main test in this research. The Modified Proctor Compaction test was used to determine the optimum moisture content and maximum dry density. Standard Proctor Compaction Tests were done, and 5 points were used to plot the graphs for each soil combination. The test was conducted according to the ASTM D-1557 standards and 25 blows were used to compact the soil into three layers in the molds according to the standards. The moisture content was increased gradually, and the test were repeated while adjusting the moisture content until a minimum of 5 points were taken.

4.2 Unconfined Compression Strength Test (UCS)

The main focus on this research is to strengthen the soil using the different blends of fly ash and cement. To replicate the real-life soil stress conditions, the UCS test was used here with the soil samples. The three different soils mixed with 10%, 20%, 30% of the two different blends of the cement + fly ash mixtures were used to make samples and then the samples were cured for 7 and 28 days.

5. Result and discussion

5.1 Summary of modified proctor compaction test results

Figure 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6 below consist of the graphs obtained from the standard proctor test done by mixing the three different soils with different proportions of the Mix 1 and Mix 2. The proportions of the Mix 1 and Mix 2 combined with the soils were 10%, 20% and 30%.

It is observed that the Maximum Dry Density (MDD) of the soil samples were increasing when mixed with cement + fly ash mixes and the Optimum Moisture Content (OMC) decreased when mixed with cement + fly ash mixes.

![Figure 5.1. Dry density vs water content in residual soil mixed with different proportions of mix 1](image1)

![Figure 5.2. Dry density vs water content in residual soil mixed with different proportions of mix 2](image2)
Figure 5.3. Dry density vs water content in marine clay mixed with different proportions of mix 1

Figure 5.4. Dry density vs water content in marine clay mixed with different proportions of mix 2

Figure 5.5. Dry density vs water content in sandy clay mixed with different proportions of mix 1
5.2 The effect of cement and fly ash towards the maximum dry density of the soils
The reason for the increase of the MDD is the fact that cement and fly ash has relatively higher specific gravities than the soils. So, when the proportion of fly ash and cement increases, the maximum dry density of the soil increases compared to the natural soil.

5.3 The influence of cement and fly ash towards the optimum moisture content of the soils
The optimum moisture content of the soils mixed with the cement + fly ash has a relatively lower moisture content compared to the natural soil. The main reason for this is that the hardening procedure of the cement absorbs some of the water added to the soil. The reactions happen between the different components of cement and water creates a solid substance. One of the substances is crystalline calcium hydroxide (CaO) but the primary substance is what is called “Cement Gel”. It consists of 3CaO.2SiO2.2H2O [11].

5.4 Summary of unconfined compression test results
The soil samples from 3 different soils were mixed with different proportions of Mix 1 (OPC cement) and Mix 2 (75% OPC Cement and 25% Fly Ash) and were cured for 7 and 28 days respectively. The samples were checked for the compressive strength after 7 days and 28 days and the results obtained from the tests are summarized below in Table 4, 5 and 6. The plots of the compressive strength against the amount of days cured is shown below each graph.

Table 4. 7 day and 28-day strength of Marine clay mixed with different proportions of mix 1 and mix 2

| Marine Clay | 7-day curing (kPa) | 28-day curing (kPa) |
|-------------|--------------------|---------------------|
| 10% mix 1   | 302                | 329                 |
| 20% mix 1   | 777                | 740                 |
| 30% mix 1   | 1546               | 1167                |
| 10% mix 2   | 373                | 518                 |
| 20% mix 2   | 1375               | 1111                |
| 30% mix 2   | 1195               | 1640                |
| 100% Soil   | 190                | 278                 |
Figure 5.7. Compressive strength vs amount of days cured of marine clay mixed with different proportions of mix 1

Figure 5.8. Compressive strength vs amount of days cured of marine clay mixed with different proportions of mix 2

The mix 2 which is OPC cement mixed with 26% pure fly ash gives a better strength to Marine Clay as we can see in the above table 4 when compared with the mix 1 but, both the mixes with 10%, 20% and 30% proportions with Marine Clay fails to reach the acceptable strength which is 2000kPa.

Table 5. 7 day and 28-day strength of residual soil mixed with different proportions of mix 1 and mix 2

| Residual Soil | 7-day curing (kPa) | 28-day curing (kPa) |
|---------------|--------------------|---------------------|
| 10% mix 1     | 668                | 1296                |
| 20% mix 1     | 4305               | 5343                |
| 30% mix 1     | 4956               | 4809                |
| 10% mix 2     | 993                | 1723                |
| 20% mix 2     | 4007               | 4790                |
| 30% mix 2     | 4070               | 5334                |
| 100% Soil     | 398                | 251                 |
The mix 2 which is OPC cement mixed with 26% pure fly ash and mix 1 which is 100% OPC cement almost equally gives a better strength to Marine Clay when mixed in 20% and 30% proportions but mix 2 gives a better strength than mix 1 when Marine clay’s mixed with 10% of both mixes separately.

Table 6. 7 day and 28-day strength of sandy clay mixed with different proportions of mix 1 and mix 2

| Sandy Clay | 7-day curing (kPa) | 28-day curing (kPa) |
|------------|--------------------|---------------------|
| 10% mix 1  | 1000               | 1047                |
| 20% mix 1  | 1239               | 2372                |
| 30% mix 1  | 2943               | 4539                |
| 10% mix 2  | 1129               | 1462                |
| 20% mix 2  | 1761               | 1306                |
| 30% mix 2  | 2020               | 2161                |
| 100% Soil  | 266                | 246                 |
Both mix 1 and mix 2 gives a huge increase of strength to Sandy clay but the samples with mix 1 has a relatively higher strength overall when compared with samples mixed with mix 2.

6 Conclusion

The laboratory experiments and the researches done about investigation of unstable soil stabilized using fly ash, cement grouting has come to end, and the following conclusions can be made.

- The high specific gravity of fly ash and cement increases the maximum dry density of the soil samples when mixed in different proportions since 30% was the highest proportion mixed, the soil samples mixed with 30% of the mix 1 and 2 gave the highest maximum dry density values.
- The hydration procedure in the cement particles absorbs water and because of that, the soil samples mixed with cement and fly ash has a relatively lower optimum moisture content compared to the natural soil. The lowest optimum moisture contents were obtained when the soil samples were mixed with 30% from mix1 and mix 2.
- The strength desired from this experiment as suggested by the cement industries for deep cement and soil mixing, is around 2 MPa. It can be concluded that Marine Clay fails to reach the desired strength of 2 MPa in both 7 and 28 day curing periods so it has to be re tested with higher percentages of mix 1 and mix 2. Residual soil gives that desired strength in 28 days when combined with 10-20% of both OPC cement and Mix 2 and Sandy Clay will give that desired strength in 28 days when combined with 20% of OPC cement and 30% of Mix 2.
7 Limitation and future improvements

7.1 Limitations faced during this research
The main purpose of this research is to find an optimum percentage of suggested mixture 1 and 2 to get the desired strength of the soil which is suggested as 2MPa by the industries. Since 3 different soils were used in this research, only 10%, 20% and 30% of the mixes were mixed and tested for strength although it’s better to test more percentages and narrow the error and increase the accuracy (10%, 15%, 20%, 25%, 30%, 35% etc.) Also, some of the samples gave a 28-day strength greater than the capacity of the UCS machine which is 10kN and it was forced to stop although the samples did not fail yet.

7.2 Future improvements
It is obvious that there are a lot of types of soils around so it’s better to conduct similar tests using more different soils in the future. Also, the soil used in this research were not entirely pure and since the properties of the soils varies in different areas, it’s better to use soil taken from different areas and compare and at the same time, to take soils from different elevations to check the impact it has on the results.

Different additives were added to fly ash and cement in past researches to obtain different strengths and different other soil properties. It can be improved in the future to test furthermore on those additives alongside fly ash and cement as deep soil stabilization is becoming popular everyday as the need of land is becoming an issue every day.

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