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Effect of Cement Stabilization on Shear Strength Parameters of Soft Soils on Agricultural Road

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Abstract

Agricultural roads play a crucial role in facilitating transportation in agricultural regions, including horticulture, smallholder farms and plantations. However, the agricultural roads in Sungai Balang, Muar face challenges due to the poor condition of the soft soil. Soft soil is characterized by low shear strength, high compressibility and large settlements, making it unsuitable for efficient road infrastructure. To address these issues, cement stabilization has been proposed in this study as a potential solution to improve the soft soil on agricultural roads in the paddy field area of Sungai Balang. The objectives of this study are to identify the classification of the soft soil on agricultural roads in Sungai Balang through grain size analysis, moisture content test, specific gravity test, Atterberg limit test and standard proctor compaction test and to determine the effectiveness of cement stabilization through direct shear test. The direct shear test was carried out to evaluate the shear strength parameters of the soil on the agricultural roads before and after the addition of different percentages of cement (5%, 10% and 15% by dry weight of the soft soil). The results of soil classification showed that the soft soil on agricultural roads in Sungai Balang was classified as MH, which was silty soil with high plasticity. Besides, the results of direct shear test indicated that the 15% cement specimen achieved the optimum percentages compared to the others. The friction angle of the 15% cement specimen had increased from 28^{o} to 43^{o} and the cohesion had increased from 28.33 kPa to 85.00 kPa compared to the untreated soil samples. By studying the effects of different percentages of cement on soil settlements, the research provides insights into the performance and suitability of cement stabilization in enhancing the stability and strength of soft soils on agricultural roads.

1. Introduction

Agricultural road development plays an important role in rural areas as it aims to alleviate poverty by improving transportation infrastructure (Bertolini, 2019). These roads are specifically designed to facilitate the mobility of agricultural machinery & transportation of production facilities, and agricultural products from land to storage or market (Maryati *et al.*, 2020). However, agricultural roads often marked as very low requirements for design and construction standards due to the low traffic impact and environmental effects (Razali & Malek, 2019). During the rainy season, the condition of the agricultural road deteriorates, making it difficult for locals to pass through with tractors and resulting in travel discomfort, safety concerns, and reduced agricultural production (Fukubayashi & Kimura, 2014).

The issue of soft soil in Sungai Balang, Muar has long been a longstanding problem for local farmers in the area. The soil quality is poor, and it has a high water content, making it challenging for agricultural activities, especially after rainfall. During harvesting, machinery often gets stuck, resulting in damage to paddy fields, while potholes quickly form after multiple transports, causing delays and difficulties in transporting agricultural products. Figure 1 provided the location of study field area, with specific coordinates of latitude 1°52'44.7" N and longitude 102°45'18.3" E. The underlain soil of this area is unconsolidated deposits and characterized as marine clay and silt as shown in Figure 2.

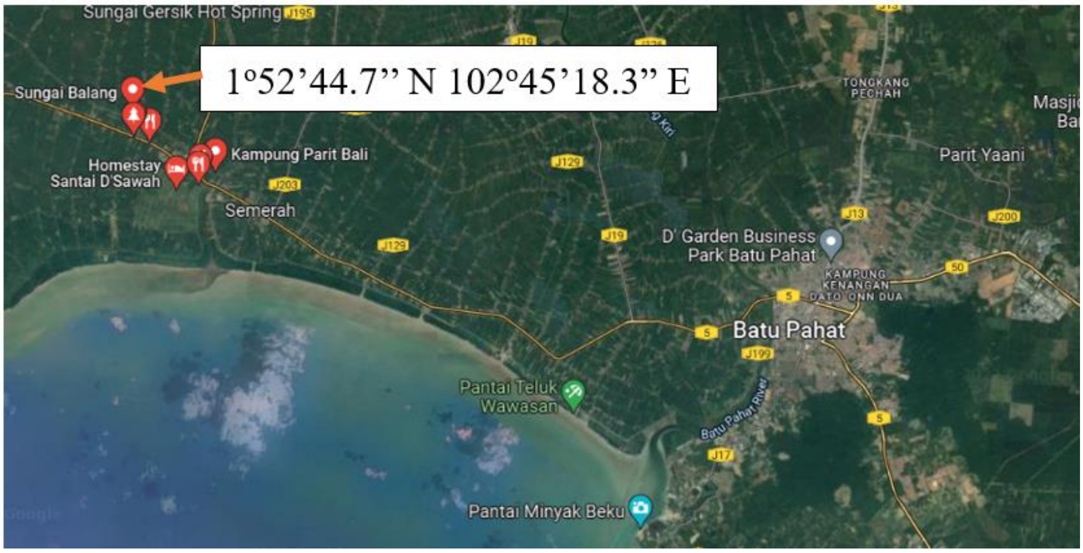

Fig. 1 *The location of the study field area*

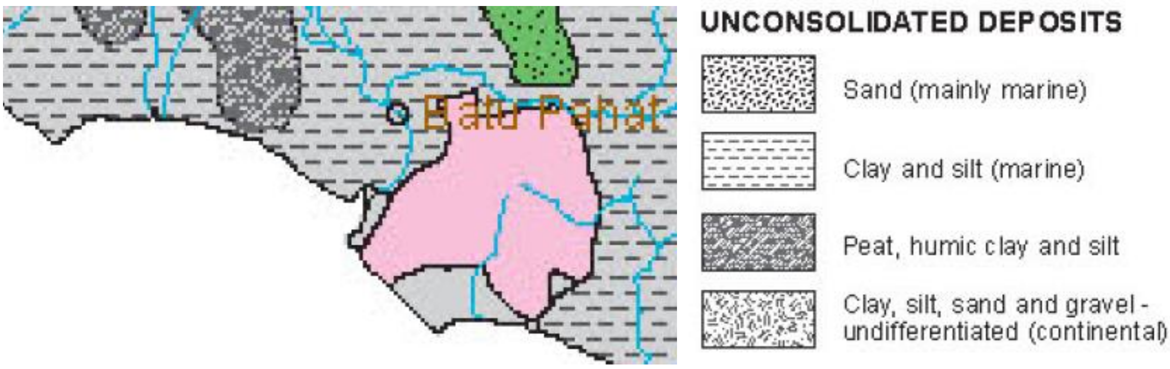

Fig. 2 *Geological formation of the study field area (GSM, 1985)*

Soft soil, typically comprised of soft clay, silt, and peat and has the characteristics of low shear strength, high-water content, high compressive capacity, low permeability, and certain tendency to swell or shrink (Zhan & Meng, 2022, Qiao *et al*., 2020). Soft soils are normally unsuitable for use in construction engineering due to their undesirable characteristics. This has led to the need for alternative soil improvement methods (Ozdemir, 2016, Mohamad *et al*., 2015).

In Malaysia, soil stabilization methods are commonly used in the construction of estate or plantation roads and rural roads rather than major roads, as these roads are designed and constructed to accommodate low traffic volumes in which occasional encounters with heavy loads (Razali & Malek, 2019). In addition, according to Bandara, Mampearachchi & Sampath (2017), cement has the potential to stabilize almost all types of soils and in most cases, Type I or Type II Portland cement is typically used for stabilizing soils. It will reduce the plasticity of the soil thus influencing the swelling and similar behaviour of soil (Marian & Raymond, 1999). Since 1915, cement stabilization has been utilized in the soil for the base, subbase, and subgrade of pavements because cement is excellent in enhancing a range of soil properties, including granular materials, silts, and clays (PCA, 1992). In addition, cement stabilization is widely used due to its ability to react with any water present in the soil, independent of the soil minerals (Makusa, 2012).

Therefore, cement stabilization was proposed as a potential solution in this study to improve the soft soil conditions on agricultural roads in the paddy field area of Sungai Balang. Besides that, this study also focused on classifying the soil and investigating the shear strength parameters of the soft soil by conducting various laboratory tests. Direct shear test was conducted to analyse the changes in the soil's properties when different percentages of cement (5%, 10%, and 15% by dry weight of the soft soil) were added. The test aimed to evaluate the effectiveness of cement stabilization in enhancing the shear strength of the soft soils on agricultural roads.

2. Literature Review

Numerous literatures have studied the effectiveness and percentage content of cement as a stabilizer in improving soils with different problems in different parts of the world. However, the optimal percentage of cement content in soil stabilization varies by region and soil characteristics, and it is essential to determine the appropriate percentage (Solihu, 2020). According to Nicholson (2014), the percentage of cement used in the soil mixtures varies from 6 to 10% by weight for soil that has been amended with cement, and up to 15% for clays. In general, the higher the clay content of the soil, the more cement is needed for effective stabilization (Bandara *et al*., 2017).

In a study conducted by Ho & Chan (2011), the mechanical properties of cement stabilized soft clay were studied through direct shear tests. The experiment involves preparing samples with different cement content: 0% (untreated), 5%, and 10% by the dry weight of the soil. These samples were then subjected to curing periods of 3, 28, and 56 days. Table 1 showed the results of direct shear tests after cured 28 days. The results demonstrated that the addition of 10% cement content increased the strength by approximately twice as much as the untreated clay. In addition, the samples with 10% cement content at 28 days showed the highest value of friction angle and cohesion compared to the samples with 0% and 5% cement content at the same age (Ho & Chan, 2011).

Table 1 *The results of direct shear test after cured 28 days (Ho & Chan, 2011)*

Specimen	σ'_v (kPa)	σ'_h (kPa)	ϕ' (°)	c'(kPa)	τ_f (kPa)
0%-28d	50	17.83	15.1	10.8	24.29
	100	42.25			37.78
	200	59.23			64.76
5%-28d	50	38.03	16	36	50.34
	100	64.81			64.67
	200	92.95			93.35
10%-28d	50	45.8	22.4	64.1	84.71
	100	97,01			105.32
	200	143.8			146.53

Besides that, Nazir & Bhalla (2020) conducted an experimental study to determine the shear strength of sandy soil on subgrade using different percentages of cement. 5%, 10%, and 15% of cement content (based on the dry weight of the soil) were used to perform the direct shear test. The results revealed that the angle of internal friction increased from 35° to 40.3° when 5% and 10% of cement were added. However, it decreased to 9.4% when 15% cement content was added due to shrinkage. Moreover, the shear strength of the soil increased by 13.75% and 19.19% with the addition of 5% and 10% cement, respectively, but it decreased by 9.4% with the addition of 15% cement content (Nazir & Bhalla, 2020).

According to the study conducted by Shooshpasha & Shirvani (2015) on the effect of cement stabilization on sandy soils, the addition of lime Portland cement at varying percentages (2.5%, 5% and 7.5% based on the dry weight of the soil) resulted in an improvement in shear strength parameters. They found that the specimen with 7.5% cement content exhibited significant improvement in cohesion and friction angle compared to the untreated specimen. The cohesion increased from 0.101 to 244.7 kPa, indicating that a substantial enhancement in the binding strength of the stabilized soil. The friction angle increased from 35.82° to 49.76°, demonstrating an improvement in the shear resistance of the soil. Besides, the researchers found that after reaching the peak of shear stress, the maximum shear stress decreased toward a value that was similar to that of the direct shear test performed on the natural soil.

3. Methodology

This study primarily involved experimental laboratory work, focusing on the use of soft soil as the main material and cement as a stabilizer agent. The main objective of the study was to investigate the shear strength parameters of the soil-cement mixture with varying proportions of 5%, 10% and 15% cement based on dry weight of the soft soil. These specific cement ranges were selected based on the findings of Nicholson (2014), which stated that the cement percentages in soil mixtures range from 6% to 10% and up to 15% for clays. In order to achieve the research goals, several relevant laboratory tests were conducted. The initial phase of the study involves determining the geotechnical and shear strength of the untreated soil. Then, the soil samples were mixed with the cement proportions of 5%, 10% and 15%, followed by a curing period of 28 days. After the 28 days curing period, the direct shear test was performed to obtain the shear strength parameters of the cement stabilized soils.

3.1 Preparation of Soil Samples and Materials

In this study, the soft soil samples (disturbed soil and undisturbed soil) were collected from the agricultural road located in Sungai Balang, Muar. The samples were taken at a depth of approximately 1.0 m from the ground surface to ensure that the soil samples represented the native conditions. Ordinary Type 1 Portland cement was selected in this study as it is commercially available and widely used for stabilization (Bandara *et al*., 2017).

To prepare the soil – cement specimens, the collected soft soil samples were first air-dried to remove the excess moisture. Then, the air-dried soil was mixed with cement at proportions of 5%, 10% and 15% (based on dry soil weight). All specimens were prepared at the optimum moisture content and maximum dry density of the soft soil samples, which were determined through a standard proctor compaction test.

The preparation of specimens for the direct shear test followed the guidelines and standards specified in BS 1377: Part 1 (2016). Firstly, the soil samples were mixed with cement and water. The soil-cement mixture was hand-stirred for approximately 5 minutes to prevent hardening. Then, the stabilized soil sample was compacted into a 1 L compaction mould with 20 blows for each layer. The number of blows (20) was determined through trial and error during the compaction test to achieve the desired density which was the maximum dry density.

The specimens were then trimmed into the direct shear specimen cutters with dimensions of 60 mm x 60 mm in plan and 20 mm in thickness. To prevent excessive moisture loss, the specimens were wrapped with plastic wrapping paper. Then, the specimens were placed on raised platforms inside a tightly sealed polystyrene box for a dry curing period of 28 days, as shown in Figure 3. Furthermore, Table 2 provided a summary of the total number of specimens used for testing in this study. A total of 51 specimens were prepared in this study to ensure the accuracy and reliability of the results obtained.

Fig. 3 *Specimens preparation for direct shear test*

Table 2 *Total number of specimens used in each test*

Tests	Number of specimens
Grain size analysis	3
Moisture content test	3
Specific gravity test	3
Atterberg limit test	3

Standard proctor compaction test	3
Direct shear test	36
Total	**51**

3.2 Direct Shear Test

All the procedures of these laboratory tests were carried out in accordance with the procedure of BS standard, which are listed in Table 3. The tests were conducted using a small shear box apparatus with dimensions of 60 mm x 60 mm in plan and 20 mm in depth on original soil and cement stabilized soil specimens as shown in Figure 4. The normal stress was selected as 50, 100 and 200 kPa for all specimens to obtain the Mohr-Coulomb failure plane, based on the literature review from Ho & Chan (2011) and Naeini & Malek (2012). The cohesion and the friction angle of the specimen were determined from Mohr-Coulomb failure envelope.

During the shearing process, the specimens were sheared at a constant rate of 0.5 mm/min. This specific rate was chosen based on the recommendation of Thermann, Gau & Tiedemann (2006) which stated that 0.5 mm/min is suitable for silt soil testing. Panthi & Soralump (2022) also denoted that a slow shearing rate provides reliable and accurate result. Throughout the shearing process, the shearing force and the horizontal displacements were recorded, ensuring that a minimum of 20 readings were recorded before reaching the maximum load.

Table 3 *Summary of laboratory tests and the test references*

Tests	Reference
Grain size analysis	BS 1377: Part 2 standards – Section 9
Moisture content test	BS 1377: Part 2 standards – Section 3
Specific gravity test	BS 1377: Part 2 standards – Section 8
Atterberg limit test	BS 1377: Part 2 standards – Section 4 & 5
Standard proctor compaction test	BS 1377: Part 2 standards – Section 3
Direct shear test	BS 1377: Part 2 standards – Section 5

Fig. 4 *Direct shear test*

4. Results and Discussion

4.1 Geotechnical Properties of Untreated Soil Samples

The summary of the geotechnical properties of the untreated soil samples based on the laboratory test results were shown in Table 4. The specific gravity value obtained from the laboratory test results was found to be 2.67. According to Honsi *et al*. (2015), soil samples with a specific gravity range between 2.65 – 2.7 were classified as silt. Hence, the soil sample in this study can be classified as silty soil.

For the grain size analysis, two methods were used to determine the particle size distribution: sieve analysis for particles larger than 63 μm (retained on 63μm sieve) and hydrometer analysis for particles smaller than 63 μm using a sedimentation process. Figure 5 illustrated the graph of grain size distribution of the soil samples. The results showed that the soil samples consisted of 6.97% gravel, 24.34% sand, 34.51% silt and 32.05% clay.

It is important to note that the total percentage of the soil samples did not add up to 100%. This may be due to the loss of fines during the grain size analysis process. The loss of fines can occur during the handling and transferring of the sample between containers. Fine particles, such as silt or clay may adhere to equipment or be lost during the testing process. As a result, this can lead to a lower percentage of fine particles in the analysis and result in an incomplete total percentage.

The Atterberg limit test was conducted to determine the plasticity characteristics of the soil and it involves two tests, namely the plastic limit test and the liquid limit test. Through these tests, the plasticity index was obtained. The soil classification was determined according to the soil classification system in BS 5930 (2015). Figure 6 displayed the graph depicting the plasticity chart for soil classification incorporating the laboratory test results. Based on Figure 5, the soil sample was classified as MH, which was silty soil with high plasticity.

For the standard proctor compaction test, the average values obtained for the maximum dry density and optimum moisture content of the untreated soil samples were 1.142 g/cm^3 and 37.23%, respectively. Figure 6 showed one of the results showing the graph of the optimum moisture content curve for the untreated soil sample.

Table 4 *The geotechnical properties of untreated soil sample*

No	Soil Sample	Value
1	Moisture content (%)	43.94
2	Specific gravity	2.67
3	Bulk density (g/cm^3)	1.50
4	Grain size analysis	
	a. Gravel (%)	6.97
	b. Sand (%)	24.34
	c. Silt	34.51
	d. Clay (%)	32.05
5	Atterberg limit test	
	a. Plastic limit (%)	43.97
	b. Liquid limit (%)	69.54
	c. Index Plasticity (%)	25.57
6	Standard proctor compaction test	
	a. Maximum dry density (g/cm^3)	1.142
	b. Optimum moisture content (%)	37.23
7	Soil Classification	MH

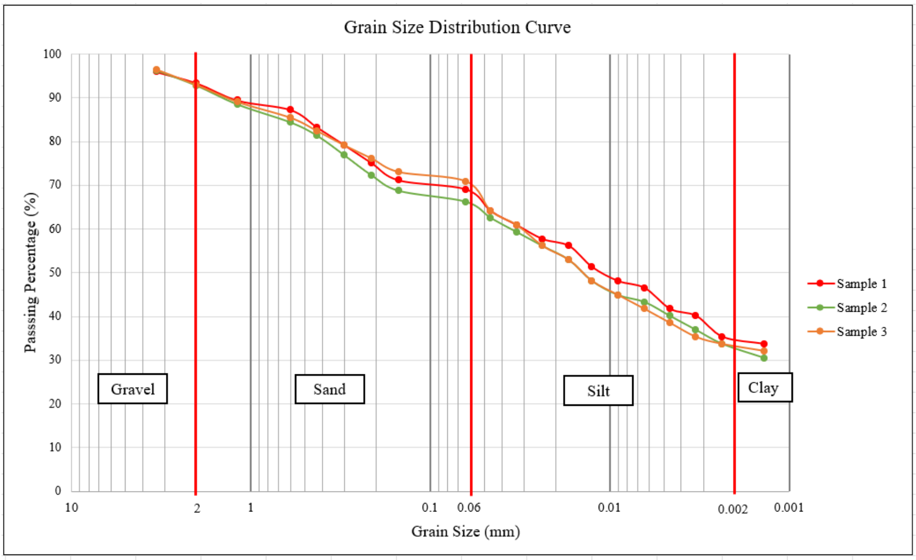

Fig. 5 *Grain size distribution curve*

4.1 Engineering Properties of Soil Samples Before and After Treatment

The direct shear test results revealed a clear relationship between the shear stress generation and the cement content, as shown in Figure 8. All the specimens reached its ultimate shear stress in a short period which were less than 20 min. Head (1982) stated that as the permeability of clay is low, so virtually there will be no drainage takes place from a clay during the short period (usually up to a maximum of 20 min) of a quick shear test. Thus, it can be confirmed that the shearing rate of 0.5mm/min is suitable for this case to determine the undrained shear strength and undrained friction angle of untreated and treated soil.

Laboratory results showed that as the vertical stress levels applied to the specimen increased, the shear stress also showed a proportional increase. For example, in the untreated specimen, at 50 kPa normal stress, the shear stress at 3.40 mm horizontal displacement was 28.90 kPa, while at 200 kPa normal stress, it was 53.83 kPa. In contrast, for the specimen with 5% cement, the shear strength increased to 54.97 kPa at 50 kPa normal stress and 88.40 kPa at 200 kPa normal stress, representing an approximate 1.7 times increase compared to the untreated specimen. Moreover, it was observed that the maximum shear stress was achieved at a very low strain for the specimen with lower effective stress, while for the specimen with higher effective stress, the maximum shear stress occurred at a larger strain. This was evident for the specimen with 15% cement, where the specimen subjected to lower effective stress (50kPa) reached the maximum shear stress at 3.40 mm, whereas the specimen under higher effective stress (200kPa) reached the maximum shear stress at 3.80 mm. As a result, it can be concluded that the treated silt tends to fail more slowly under higher stresses. The stabilization process consolidates the silt, allowing it to withstand more pore water diffusion and consequently providing greater strength (Ho & Chan, 2011).

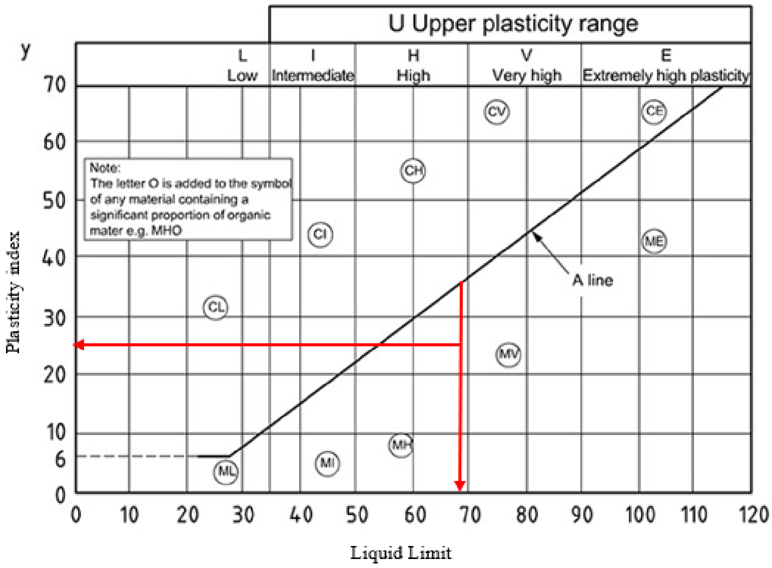

Fig. 6 *Result of plasticity chart soil classification*

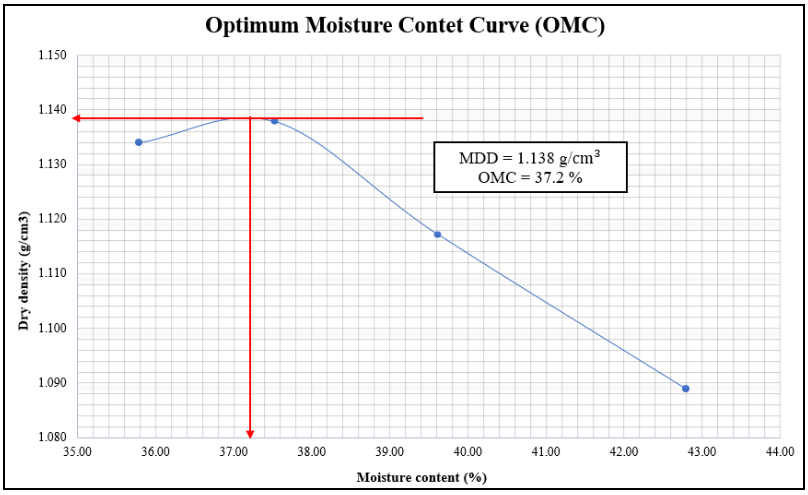

Fig. 7 *Optimum Moisture Content Curve*

On the other hand, the results of direct shear tests for all specimens are listed in Table 5. The results of tests clearly showed that the addition of cement significantly improved the shear strength parameters compared to the untreated soil samples. When comparing the untreated soil samples to the 15% cement specimen, there is a notable increase in both friction angle and cohesion. The friction angle had increased from 28^{o} to 43^{o}, which improved about 1.7 times while the cohesion had increased from 11.01 kPa to 52.88 kPa, which improved approximately 5 times. The increase in the friction angle indicates an improvement in the soil's resistance to shear forces while the increase of the cohesion indicates a substantial increase in the soil's ability to withstand tensile forces (Han *et al.*, 2020).

These findings indicated that the shear strength parameters of silt increased with an increase in cement content. This can be attributed to the fact that the shear strength of silt increases as the water content decreases (Zambri & Ghazaly, 2015, Shooshpasha & Shirvani, 2015). The water content had a significant impact on both cohesion and friction angle (Han *et al.*, 2019). Chew, Kamruzzaman & Lee (2004) explained that the decrease in water content is due to the cement hydration and the pozzolanic reaction, where water is absorbed and converted into cement-based products. Furthermore, the continuous cementing reactions contribute to the increase in both cohesion and friction angle (Boutouba *et al.*, 2019). During periods of low humidity, the soil lacks free water and a thin film of water forms between the soil particles. This thin water film acts as a bonding agent between the soil particles, enhancing cohesion and preventing movement between them (Han *et al.*, 2020, Wei *et al.*, 2018).

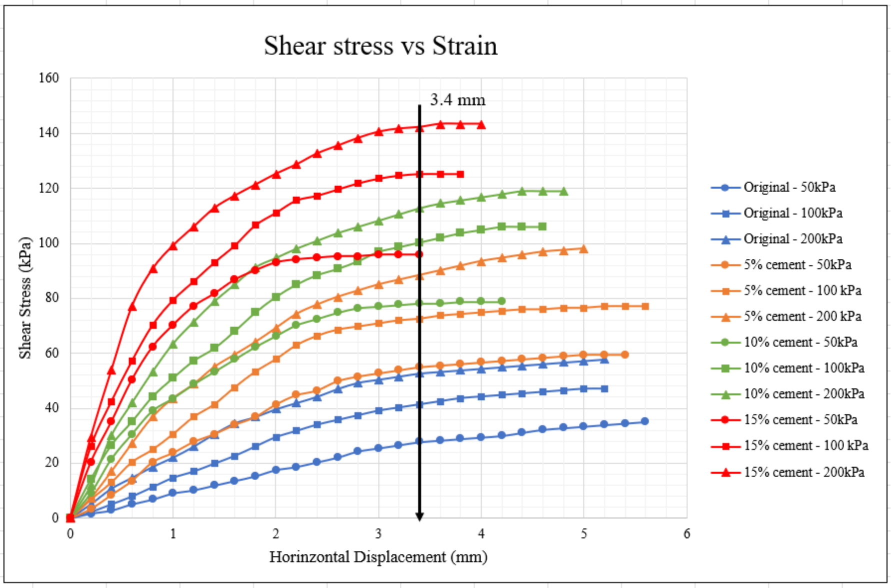

Fig. 8 *Summary results of shear stress versus horizontal displacement*

Table 5 *Summary results of direct shear tests of all specimens*

Specimen	σ_v (kPa)	τ_f (kPa)	ϕ_u (°)	c_u (kPa)
0% cement	50	33.43	28	11.01
	100	48.92		
	200	59.12		
5% cement	50	56.10	28	34.25
	100	73.10		
	200	92.56		
10% cement	50	74.04	43	34.18
	100	100.87		
	200	115.41		
15% cement	50	92.93	43	52.88
	100	120.13		
	200	136.00		

Figure 9 illustrated the Mohr-Coulomb failure envelopes for both untreated and treated specimens. Failure envelope of untreated specimen and 5% cement treated specimens show a sightly curved line which is lookalike the representative envelopes for overconsolidated clay as illustrated by Head (1982). The untreated and treated specimens were prepared with maximum dry density which is much higher than in-situ density of untreated soil. Hence, the failure envelope showed that the compaction process not only increased density of specimens and able to change the behaviour of unconsolidated deposits as overconsolidated soil.

The other two plots show that the Mohr-Coulomb failure envelopes for 10% and 15% cement stabilized silts are more obviously curved with increasing of cement content. These findings are aligning with the previous study conducted by Shooshpasha & Shirvani (2015). Apart of it, the data also indicated that the shear strength parameters increased with increasing of cement content.

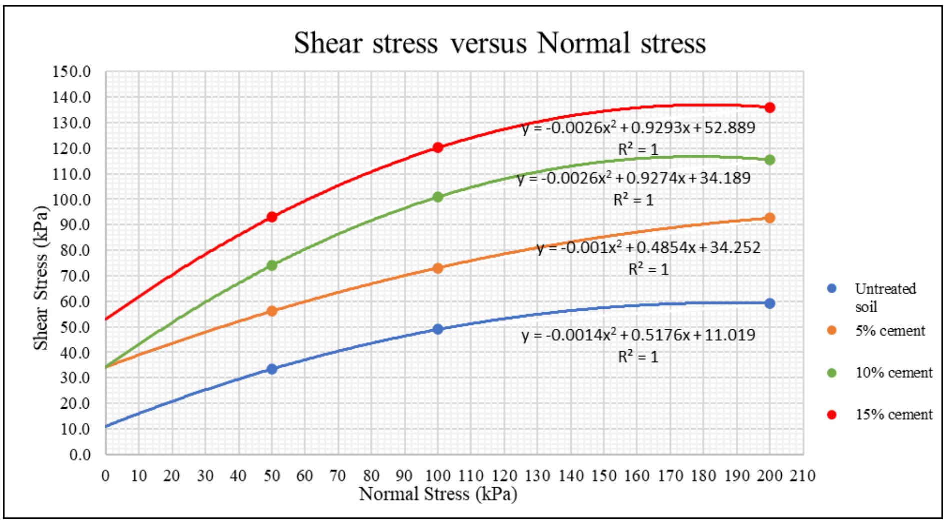

Fig. 2 *Summary results of shear stress vs normal stress*

5. Conclusion

Based on the research conducted on the geotechnical properties and the engineering properties of the soft soil on agricultural roads in Sungai Balang before and after soil improvement using cement stabilization, the following conclusions can be drawn:

- Soil classification: The soft soil samples obtained from the agricultural roads in Sungai Balang were classified as MH, indicating silty soil with high plasticity.
- Shear Strength Improvement: The addition of cement to the soft soil significantly increased the shear strength, via higher friction angle and undrained cohesion. The higher the cement content, the greater the improvement in the shear strength of the soft soil. This indicated that cement stabilization effectively improved the ability of the soft soil to resist the shearing forces.
- Low content cement treated specimens (5% cement) are found to be lookalike with untreated compacted specimens.
- The failure envelope of high content cement treated specimens (10% cement and 15% cement) are more alike and different from low cement content treated specimens and untreated specimens.

The research provides a deeper understanding of the geotechnical and engineering properties of soft soil on agricultural roads and the effects of cement stabilization. By studying the soil properties and behaviour before and after stabilization, the study enhances the knowledge of soil mechanics and provides valuable insights into the behaviour of soft soils under different conditions. The findings can guide engineers and practitioners in selecting appropriate stabilization methods and optimizing the design parameters for agricultural roads and similar infrastructure projects under similar soil conditions.

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