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Shear Strength Characteristics of Coastal Soil Treated with Sodium Silicate

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Abstract. In recent times, rapid developments near coastal areas are gaining attraction and attention from industry players. This necessitates further understanding of soil behavior found in these areas. Soil stabilization can further enhance the physical and engineering characteristics of soils used for development purposes. For this study, a series of laboratory tests were conducted to determine the potential of Sodium Silicate (TX-85), a liquid-type chemical soil stabilizer, to improve the properties of coastal soil obtained in Kota Kinabalu, Sabah. The soil samples were subjected to a series of laboratory tests, which includes the pH and Unconfined Compression Strength (UCS). The dosages of Sodium Silicate mixed with the soil were 4, 5, and 7% by soil sample weight, with curing intervals of 3 hours, 24 hours and 48 hours, respectively. The optimal dosage of Sodium Silicate observed in this study is 4%, at 48 hours curing period. This combination of stabilizer dosage and curing period produced the highest strength increment, where the UCS value increased by 90.3%, from 262.1 kPa to 498.8 kPa.

1. Introduction

Development projects near coastal areas are currently in demand within the construction industry. Therefore, the characterization and enhancement of coastal soil properties is an emerging research area to be explored by researchers in the geotechnical engineering field. Improvement of soil properties can be achieved through soil stabilization, where the increased resistance to softening by water is possible via water proofing the soil particles, better bonding of soil particles, or a combination of both [1].

The stabilization of naturally occurring or native soil has been in practice for centuries [2]. In order to solve the problem of weak soils, high costs might be incurred if good quality fill soils are needed to replace the weak soils for land development purposes. However, soil stabilization is as an economic solution to this weak soil problem. For this study, the soil stabilization method chosen to fulfil the research objectives is chemical stabilization. More specifically, the chemical stabilization technique involves adding a chemical compound in order to promote improved soil particle bonding through the formation of a stronger soil mixture when the stabilizer is mechanically mixed and compacted with the natural soil [3].

According to Eisazadeh [4], chemical soil stabilizers are either categorized as traditional or non-traditional stabilizers. While the use of traditional stabilizers i.e. cement, lime and fly ash have been well documented, this is not the case for non-traditional stabilizers i.e. enzymes, liquid polymers, and silicates [5]. Sodium Silicate, or its commercial name, TX-85 is a liquid-type of non-traditional stabilizer produced by Probase Manufacturing Sdn. Bhd. and is typically marketed as a material used to stabilize plantation road soils [6]. However, several studies conducted to study the TX-85 performance when combined with other types of soils, i.e. laterite [5, 7, 8], marine clay [9], and soft clay [10] have shown encouraging results in terms of improvement of soil engineering properties. In general, the trend for soil strength improvement for the abovementioned soils is about three to four times the strength increment compared to the untreated soil [5, 9, 10].

Therefore, the aim of this study is to improve coastal soil by determining the optimum dosage (percentage by weight) of soil stabilizer (TX-85) and optimum curing period to obtain the highest unconfined compression strength (UCS) value; where the stabilized soil strength characteristics was compared to the untreated soil.

2. Methodology

2.1. Coastal Soil

In this study, the soil sample was collected at a coastal area at a depth of 1.5 meters in Sepanggar Bay, located about 13 kilometres from Kota Kinabalu, Sabah. The color of the soil is dark brown. The samples were air-dried and broken into individual particles using a rubber mallet before testing. Table 1 shows the physical and engineering properties of the untreated soil sample, in comparison with soils tested by other researchers using the TX-85 soil stabilizer. From the tabulated data, the coastal soil sample was classified as low plasticity clay and silt soil (CL+ML) according to Unified Soil Classification System (USCS) [11].

Table 1. Characteristics of the untreated soil sample and comparison with past studies [5, 9- 10]

Physical and Engineering Properties	Values			
	This Study	Laterite Soil [5]	Marine Clay [9]	Soft Clay [10]
Liquid Limit, LL (%)	28	75	58	73
Plastic Limit, PL (%)	22	41	23	29
Plasticity Index, PI (%)	6	34	35	44
pH Value	5	5.35	-	-
Specific Gravity, Gs	2.51	2.69	-	-
Maximum Dry Density ($kg\text{-}m^{-3}$)	1640	1310	1600	1343
Optimum Moisture Content (%)	18	34	21	30
Unconfined Compressive Strength (kPa)	262.1	270	23	33.6
Soil Classification (USCS) [11]	CL+ML	MH	MH	MH
Type of Soil	Low Plasticity Clay and Silt	High Plasticity Silt	High Plasticity Silt	High Plasticity Silt

2.2. Sodium Silicate

The Sodium Silicate (TX-85) stabilizer material used in this study is a proprietary chemical compound and its chemical composition is not known to the public. Pakir [9] conducted an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) on the TX-85 stabilizer to discover that the material largely comprises of Sodium, Aluminium, Silicone and Ferum; while Latifi [5] revealed that the stabilizer has a pH value of 12.54. Table 2 shows the average pH values for untreated soil and soils stabilized with

TX-85, tested based on BS 1377 [12]. The alkalinity of the stabilizer has significantly influenced the final pH value of the stabilized soil since the silty soil tested in this study is highly acidic in nature (pH 5). According to Eisazadeh [13], the pH of soil mixture reflects the changes occurring in the medium, where it influences the solubility of clay materials and the distribution of charge on clay lattice. After the initial mixing, the chemical reaction takes place almost immediately and no further changes to the pH value is observed after a short period of curing, similar to the findings by Latifi [5].
In Table 2, the pH value of the soil mixture stopped increasing after 9% and the value plateaued at pH 10.1. The selected dosage of TX-85 added to the soil sample in this study (by sample weight) were 4%, 5% and 7%, with the consideration of limited amount availability of TX-85 to complete this study.

Table 2. Average pH values for soils stabilized with Sodium Silicate based on British Standard [12]

Percentage of Stabilizer Added (%)	pH Value
0	5.0
1	8.4
2	8.7
3	9.0
4	9.2
5	9.5
6	9.6
7	9.8
8	9.9
9	10.1

2.3. Testing Programme

Before commencing the Unconfined Compression Strength (UCS) tests, the soil sample compaction characteristics were determined. A series of Standard Proctor Compaction (SPC) tests was conducted based on BS 1377 [14]. The obtained SPC results were used to plot the compaction curve of the soil which is a graph of dry density versus moisture content. Subsequently, the optimum moisture content (OMC) can be obtained by ascertaining the maximum dry density (MDD) on the graph. As previously shown in Table 1, the maximum dry density was valued at 1640 kg-m^{-3}. Subsequently, the MDD value for soil mixed with 7% of sodium silicate was valued at 1528 kg-m^{-3}. Although the results of the Standard Proctor Compaction (SPC) test results of soils mixed with TX-85 is not discussed in depth in this paper, the observed trend of the MDD value was found to have decreased with an increasing TX-85 content.

In order to prepare the silt sample for the UCS test, the soil was mixed with each proportion of TX-85 and the optimum water content. The sample was then compacted in a mould, before three (3) specimens are extruded using thin-walled sampling tubes for each compaction [14]. The specimens were trimmed to produce specimen sizes of 38 mm in diameter and 76 mm in height. Then, the samples were wrapped in several runs of cling film [5] before being labelled correctly, stored in polythene bottles and placed in a well-ventilated room [9]. The curing period chosen for this study is 3 hours, 24 hours and 48 hours. Even though other researchers had chosen curing periods of 3 days, 7 days, and 28 days [5,9,10], the short curing period for this study was chosen to see the short-term chemical reaction between the sodium silicate and the weak soil. The specimens wrapped with cling film and were cured at a temperature-controlled room with a temperature of 27^{o} ± 2^{o}C, before the specimens were subjected to the Unconfined Compression Strength (UCS) test. This specimen preparation method was applied for the untreated silt soil specimens and for the stabilized silt soil specimens.

After the curing process, the specimen was taken out of the polythene bottle and was placed carefully on the lower platen on the Unconfined Compression Strength (UCS) machine. The platen was adjusted manually until the sample just makes contact with the top platen, where this was indicated by a fractional movement of the load dial gauge.

Next, the load was applied so that the equipment produces a compression rate of 0.5% to 2.0% per minute [15]. In this experiment, a compression rate of 1.0% was chosen. Then, the load and deformation dial readings were recorded on a data sheet at every 0.2 mm to 0.5 mm divisions on the deformation dial. Subsequently, the testing continued until peak load was achieved to cause the sample to fail, and the last loading applied was recorded. Lastly, the sample was removed from the equipment, and all recorded readings were tabulated.

3. Results and Discussion

The original and stabilized soil specimens with varying percentages of TX-85 were subjected to a series of UCS Tests. Table 3 shows the summary of the unconfined compression strength test results, while Figure 1 shows the UCS values of stabilized soil specimens plotted against varying curing periods.

Table 3. Summary of UCS test results for silt soil treated with Sodium Silicate (SS)

Soil Sample Type	**Unconfined Compressive Strength (kPa) at given curing period**		
	3 hours	**24 hours**	**48 hours**
Untreated Soil (US)	262.1	262.1	262.1
Soil + 4% SS	322.4	448.4	498.8
Soil + 5% SS	330.4	444.4	468.2
Soil + 7% SS	385.5	448.7	462.7

Based on Figure 1, when the soil was added with TX- 85 and cured for 3 hours, the compressive strength of each soil sample had increased from 262.1 kPa to 322.4 kPa (4% TX-85), 330.4 kPa (5% TX-85), and 385.5 kPa (7% TX-85), respectively. The highest compressive strength cured for 3 hours was contributed by the soil added with 7% TX-85, with an increment of about 45% compared to the original soil sample.

Meanwhile, for the compressive strength of specimens cured for 1 day does not show a marked improvement compared to the soils cured for 3 hours. Soil added with 4% TX-85 gained strength from 322.4 kPa to 448.4 kPa, while soil added with 5% and 7% TX-85 gained strength from 330.4 kPa to 444.4 kPa, and from 385.5 kPa to 448.7 kPa, respectively.

Lastly, when the modified soil was cured for 2 days, the soil added with 4% TX-85 gained the highest strength of all specimens, which had a value of 498.8 kPa. The soil added with 5% and 7% TX-85 does not show significant strength gain with only 468.2 kPa and 462.7 kPa respectively, which is about only less than 2% increment compared to soil sample cured for 1 day.

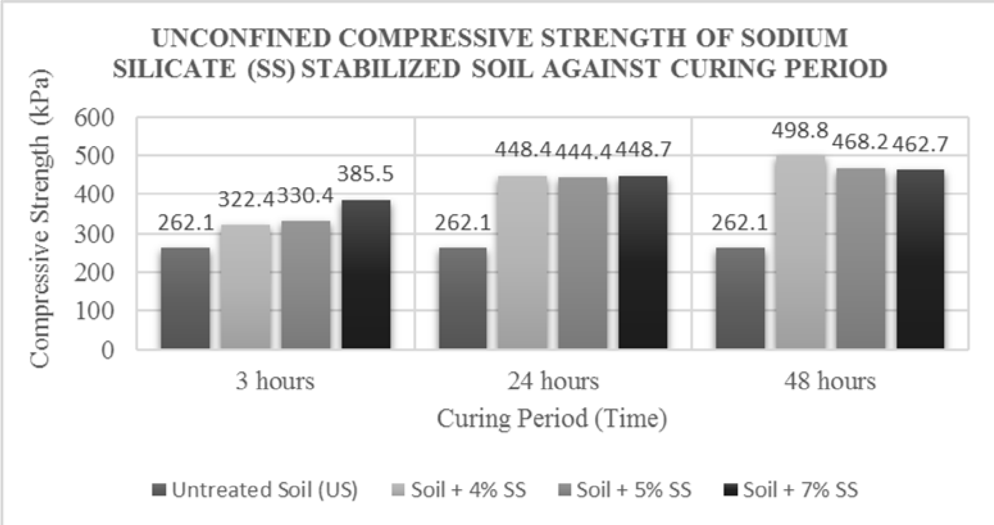

Figure 1. Unconfined Compressive Strength values of soil specimens stabilized with varying percentages of Sodium Silicate (SS) against curing period

In general, the soil gained more strength with an increasing curing period. According to Latifi [7] and Eisazadeh [13], this is due to an increase in the positive surcharge, causing the repulsion of soil particles inside the soil stabilized with Sodium Silicate - this soil particle repulsion phenomenon improves the soil-stabilizer reaction, but this process is time-dependent. On the other hand, the strength gain during curing was enhanced through the presence of cementitious material formed via soil-stabilizer, similar to that reported by Pakir [9].

For this study, it was found that the major improvement of soil strength was observed in the first day of curing, and only minor increments of strength improvement were seen after that. Due to the limitations of this study, where the maximum curing duration was set at 48 hours, a direct comparison to the other researchers' findings of soil improvement for curing duration of more than 48 hours cannot be directly compared [16, 17]. This is because in comparison with the other types of treated with Sodium Silicate i.e. laterite [6], marine clay [9] and soft clay [10], the silt soil used in this current study has lower plasticity index compared to the other soils. Since TX-85 is an ionic type of soil stabilizer (which causes cation exchange inside the soil and influences the surfaces of soil charge area) this increases the plasticity index of the soil. Hence, it is suitable to be used with the silt soil in this study since it is not an expansive soil [5] and has been shown to improve the soil strength in a shorter curing period.

Meanwhile, Figure 2 shows the UCS values of stabilized soil specimens plotted against varying percentages of Sodium Silica. The addition of 4% TX-85 in the soil sample produced a marked improvement in the soil strength characteristics, especially after it was cured for 2 days (in comparison with the addition of 5% and 7% TX-85 in the soil sample). As seen in Figure 2, the compressive soil strength value after 48 hours curing period reached its peak value at 4% TX-85, and the UCS value drops after an addition of 5% of TX-85. This finding is in line with the observation made by Latifi [5], which saw a similar phenomenon in laterite soils treated with Sodium Silica – whereby an addition of more than 6% of Sodium Silicate had reduced the strength of the laterite soil due to an increase of the soil moisture content and caused the soil to weaken. Furthermore, as seen in Section 2.2, the pH value for silt soil treated with 5% and 7% of Sodium Silicate is pH 9.5 and 9.8, respectively – which is close to the highest pH value obtained for a Sodium Silicate stabilized soil (pH 10.1). Sukmak [18] suggests that the increased amounts of the highly alkaline Sodium Silicate (pH value of 12.54) may have exceeded the requirement for chemical reaction in the soil samples, hence causing a reduction in the soil strength value. Therefore, it appropriate to conclude that the optimum dosage of TX-85 to improve the strength of the selected soil sample in this study is 4%.

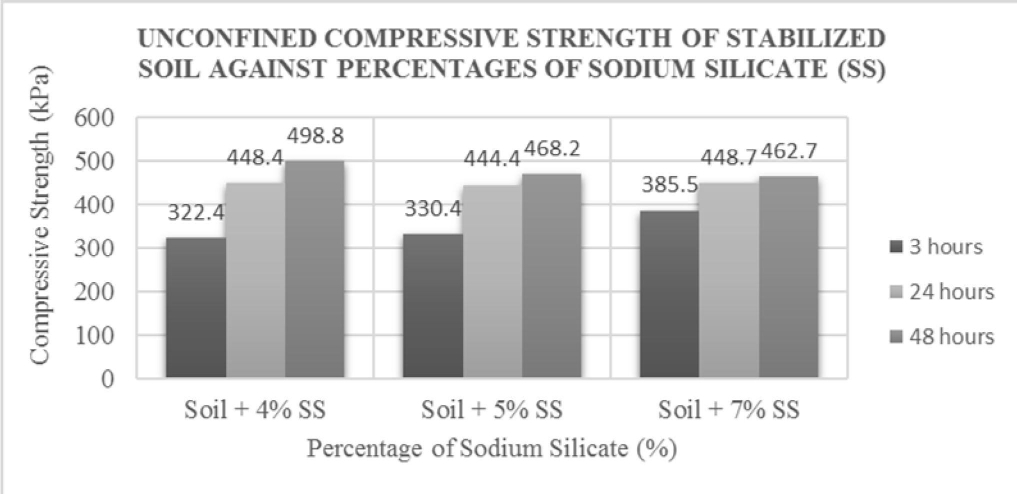

Figure 2. Unconfined Compressive Strength values of soil specimens stabilized with curing period against varying percentages of Sodium Silica (SS)

4. Conclusion

Based on the findings, the soil was classified as CL+ML (Low Plasticity Clay and Silt) according to the USCS standard. The tabulated data of each test shows that the addition of soil stabilizer TX-85 in silt soil for this study has enhanced its unconfined compressive strength characteristics. In this study, the optimum curing period for the modified soil to obtain its optimal strength was found to be 48 hours. However, if the curing time is extended further beyond 48 hours, as reported by [9] a further increase in strength (up to three to four times its original strength) is possible with seven (7) days curing. The general trend of unconfined compressive strength improvement is directly proportional to the curing period, whereby longer curing periods produces soil specimens with high compressive strength values. As such, the recommended curing period for the soil used in this study is 48 hours. However, the optimum dosage of TX-85 chemical stabilizer to improve strength and compression characteristics of the silt soil found to be 4% (90% improvement compared to original soil). At 48 hours curing period, the silt soil compressive strength was found to have reduced with the increment of TX-85 after 4%. Consequently, Sodium Silicate was found to be a viable product to be used to enhance the physical and engineering characteristics of coastal soil, especially for land development projects. As a part of an on-going research project, further experimental works are in progress to investigate the effectiveness of Sodium Silicate as a soil stabilizer for other types of soils e.g. marine clay and peat soil.

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