

Stabilization of Residual Soils Using Chemical Method

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Abstract: This paper presents the results of a research programme carried out with the objective of explicating the mechanism and behaviour between the liquid chemical and the engineering properties of three natural residual soils at laboratory scale. Liquid-formed chemical was selected in this research due to the scarcity of such findings instead of the prevalent solid chemical additive such as lime, cement or fly ash. The focus of the research is on the improvement of engineering properties of three natural soils collected from the Klang valley area and mixed with different proportions of liquid chemical. Series of laboratory tests on engineering properties, such as unconfined compressive strength (UCS), consistency limits, moisture-density relationship (compaction) were undertaken to evaluate the effectiveness and performances of this chemical as a soil stabilizing agent.

1 INTRODUCTION

Soil stability, which every civil engineer is concerned with, is closely associated to the structures and mineralogy of the clay particles, clay-water interactions, clay particles' ionic exchange capacity and the clay-organic or clay-inorganic interaction. The majority of road failures are associated with the action of water, or perhaps more precisely, the interaction between water and the clay particles under the road pavement. The main objective of chemical stabilization on soils is maintaining the characteristics of the soil, favourable from the aspects of the given engineering target, regardless of the moisture in its environment, as explained by Kedzi (1979). It is intended to modify the interactions between water and soil by surface reactions in such a manner as to make the behaviour of the soil with respect to water effects most favourable for the given purpose.

As known in soil chemistry and further commented by Tan (1998), clay minerals consist of layers with a variety of loosely associated ions on the surfaces of these layers and surrounded by a hydrosphere of absorbed water molecules, which are strongly attracted, to clay mineral surfaces. In an aqueous environment, these ions move freely in the hydrosphere of the clay particles and exchange position at random. Most ions are solvated by a number of water molecules in such an environment and enhance the hydrophilicity of clays. The large quantities of water molecules and the mobility of cations and anions in a clay-water system, produce the undesired plasticity. Hence, soils with high clay particles which have bigger specific surface and stronger affinity to water, generate obvious plasticity; whereas non-clay particles which have much smaller specific surface and less affinity to water, do not develop significant plasticity even when in finely ground form.

To reduce such problems, two remedies are suggested. First is by using ionic exchange mechanism. It is postulated that predominant electrical charge of all clays is negative. This causes the clay mineral to have an attraction for cations present. Cations, or positive molecules, are thus attracted to the negative clay mineral like iron filling to a magnet. Chemical compounds having a stronger bond to the surface of the soil particles than that of the water, can be added to modify the clay's original surface and reduce its susceptibility to water. If some powerful positive molecules can be supplied, negative charge of clay minerals can be neutralized and the charge will be balanced out. At the same time, any weaker cations, such as water (H^+) cannot fit easily into these sites and easily be dissociated and replaced. At this stage, this replacement renders the clay inert to water. This will result in making the soil material less sensitive to

moisture and be compacted to better particle interlocking, therefore greater density and less penetration of water.

The second remedy is by using ionization mechanism. Chemical compounds that have enormous potential ionic exchange capacity are added to the water; they activate the ion H^+ and OH^- , ionize the water and then vigorously exchange its electrical charges with the soil particles. This ionization process forces the pellicular water to break its electrochemical bond with the soil particles to become free water and then is drained out from the soil through gravity or evaporation. Once the pellicular water is separated from the fines in an irreversible electrochemical process and drained as free water, the soil particles settle and align themselves in such a way that they attract each other. A higher densification of the soil mass is achieved and thus eliminating all the voids.

2 LABORATORY PROCEDURES

2.1 Classification of Soils

Soil classification tests were performed based on a combined sieving-sedimentation analysis with wet sieving and followed up with a determination of fine particles by the hydrometer procedure as explained by Head (1980) and in accordance with BS 1377 (1990). The results of these three natural soils that were investigated can be summarized as in Table 1 below:

Table 1 Soil Properties of Research Residual Soils

| | Soil 1 | Soil 2 | Soil 3 |
|------------------------------|-----------------|------------|--------|
| Textural Composition | (%) | (%) | (%) |
| Gravel | 17.92 | 1.00 | 0.46 |
| Sand | 51.08 | 48.00 | 14.22 |
| Silt | 13.98 | 13.89 | 27.62 |
| Clay | 17.02 | 37.11 | 52.70 |
| | | | |
| Physical Properties | | | |
| Natural Moisture Content (%) | 8.51 | 17.52 | 20.07 |
| Specific Gravity | 2.72 | 2.68 | 2.64 |
| Liquid Limit (%) | 47.93 | 78.13 | 78.97 |
| Plastic Limit (%) | 30.17 | 39.58 | 41.66 |
| Linear Shrinkage (%) | 17.76 | 38.55 | 37.31 |
| | 11.21 | 13.82 | 13.89 |
| | | | |
| Soil Classification | | | |
| Unified | SM-ML | CL | CL |
| USDA Textural | Sandy clay loam | Sandy clay | Clay |

| | | | |
|--|-------|-------|-------|
| AASHTO | A-2-7 | A-7-5 | A-7-5 |
| <i>Engineering Properties</i> | | | |
| Maximum Dry Density (Mg/m ³) | 1.762 | 1.475 | 1.403 |
| Optimum Moisture Content (%) | 10.92 | 22.24 | 23.80 |
| Soaked CBR (%) | 6 | 7 | 6 |
| Unsoaked CBR (%) | 22 | 16 | 15 |
| UCS (MPa) | 0.220 | 0.099 | 0.208 |
| <i>Chemical Properties</i> | | | |
| PH | 6.41 | 4.44 | 2.99 |
| Exchangeable Bases (meq/100g) | 3.20 | 3.80 | 18.20 |
| Ca | 3.01 | 0.20 | 0.70 |
| Mg | 0.24 | 0.06 | 2.39 |
| Na | 0.64 | 0.08 | 0.07 |
| Mg | 0.11 | 0.07 | 0.20 |

2.2 Consistency Limits

Dry soils that passed through 425 μ m BS sieve were used throughout this experiment. Consistency limits utilizing cone penetrometer method was carried out immediately, 7 days and 14 days respectively after being mixed and the designed mix proportions by mass for the stabilized soils are given in Table 2 below:

Table 2 Design Mix Proportion

| Soil (ratio) | Liquid Stabilizer (%) |
|--------------|-----------------------|
| 1 | 0 |
| 1 | 0.010 |
| 1 | 0.015 |
| 1 | 0.020 |

2.3 Moisture-Density Relationship

Dry soils that passed through 5mm BS sieve were applied throughout this experiment to determine the variation of the OMC and MDD of the natural and stabilized soils. Standard compaction test in accordance with the BS 1924 (1990) was performed and the designed mix proportions of the stabilized soils are summarized as in Table 2 above.

2.4 Unconfined Compressive Strength (UCS)

UCS specimens were prepared by static compaction after the respective MDD and OMC of the stabilized soils had been determined through standard compaction test earlier. The specimens were prepared in a 50mm diameter X 100mm height cylinder mould conforming to the BS 1924 (1990). Further mixing procedure can be referred to research by Chew (1990). Specimens prepared were tested immediately after the mixture had been properly mixed and the remaining specimens were tested after 7, 14 and 28 days respectively.

3 RESULTS AND DISCUSSIONS

3.1 Consistency Limits

The results of the consistency limits are shown in Figs. 1 and 2 respectively. From this experiment, different proportions of liquid stabilizer have different effects on the Plasticity Indices

(PI) and Linear Shrinkage (LS) of the natural soils. As noticed, adding liquid stabiliser into the natural soils considerably reduces the PI and LS of the natural soils. The effect of adding liquid stabilizer in reducing the PI and LS of soil 1 is rather subdued but it shows pronounced results on soils 2 and 3. As shown in Figs. 1 and 2, a reduction of up to 10% for soil 3 had been recorded. This can be ascribed by the pronounced reaction between the liquid stabilizer components and the many clay platelets in soils 2 and 3.

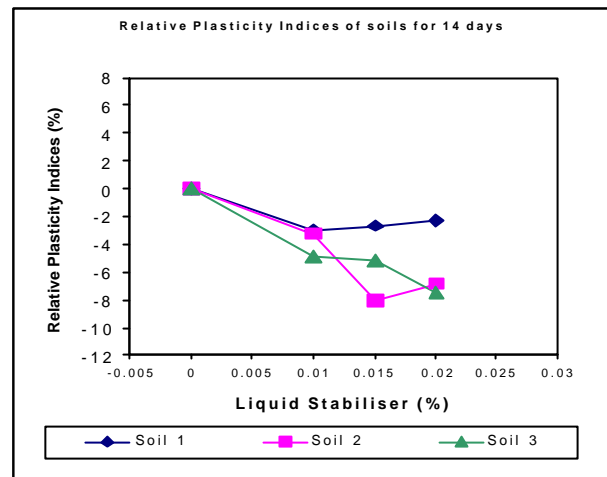


Fig. 1 Reduction of Plasticity Indices after 14 days

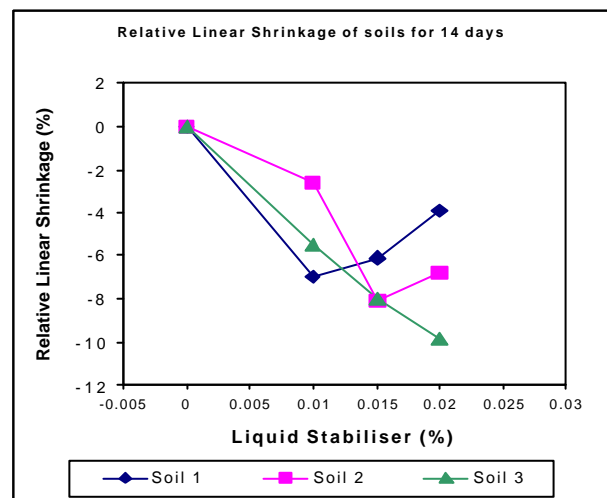


Fig. 2 Reduction of Linear Shrinkage after 14 days

Liquid stabilizer that remains in the soils for some period of time is able to react and decrease the PI and LS of the soils. However, the decreasing rate of PI and LS reduces gradually with time and it can be inferred that the chemical reaction between the liquid stabilizer components and the clay platelets is nearly completed.

3.2 Moisture-Density Relationship (Compaction)

The effect of liquid stabilizer on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the natural soils is presented in Figs. 3 and 4 respectively. As noticed, the liquid stabilizer reduces the OMC and increases the MDD of the natural soils. The liquid stabilizer chemically neutralizes the clay

platelets and dismisses the water molecules that are bonded to the clay platelets. Hence, neutral clay platelets can be compacted in a more orderly arrangement to achieve higher density.

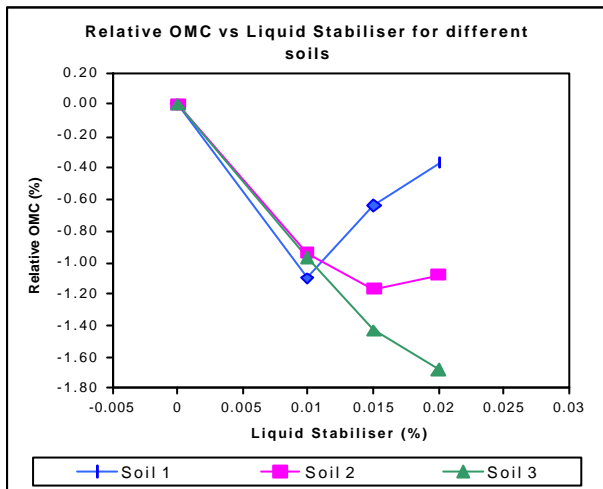


Fig. 3 Relative OMC with Different Proportion of Liquid Stabilizer on Soils

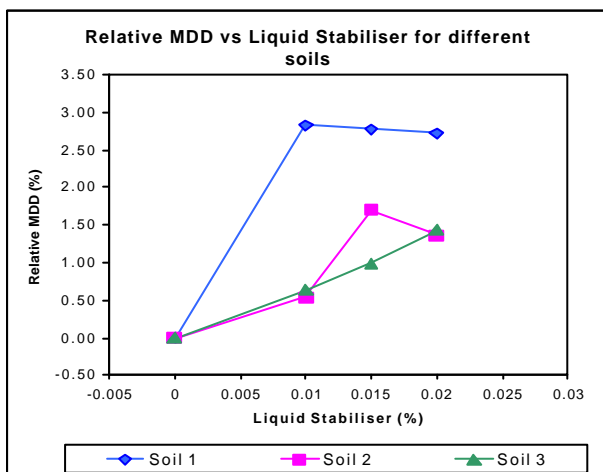


Fig. 4 Relative MDD with Different Proportion of Liquid Stabilizer on Soils

Soils with higher clay content (soil 3) achieve higher reduction of OMC for the same proportion of treatment compared to lower clay content soils (soil 1). It can be postulated that there were abundance of chemical reactions between clay platelets and the components of liquid stabilizer in higher clay content soils, in which they decreased the water molecules content. However, lower clay content soils produce relatively higher MDD compared to higher clay content soils. This may be attributed to the increased consumption of liquid stabilizer components in reacting with the already abundant clay platelets in the higher clay content soils. Extraneous reaction of the stabilizer components with more clay platelets had resulted in slow and less rearranging effect for the clay platelets in which the density of the higher clay content soils showed relatively lower MDD compared to low clay content soils.

3.3 Unconfined Compressive Strength

In terms of compressive strength, liquid stabilizer yields prominent enhancement for the natural soils and this can be shown in Table 3 below. Increment of up to 60% can be achieved by using different proportions of liquid stabilizer in treating the natural soils. The strength developed by each soil with different proportions of liquid stabilizer is shown in Fig. 5 below.

Table 3 Effect of Liquid Stabilizer on Unconfined Compressive Strength of Soils

| Soil | Liquid Stabilizer (%) | UCS of Curing Period (day/days) (MPa) | | | |
|--------|-----------------------|---------------------------------------|-------|-------|-------|
| | | 1 | 7 | 14 | 28 |
| Soil 1 | 0 | 0.220 | 0.221 | 0.221 | 0.221 |
| | 0.010 | 0.285 | 0.343 | 0.355 | 0.361 |
| | 0.015 | 0.281 | 0.337 | 0.350 | 0.354 |
| | 0.020 | 0.279 | 0.334 | 0.349 | 0.351 |
| Soil 2 | 0 | 0.099 | 0.099 | 0.099 | 0.099 |
| | 0.010 | 0.110 | 0.129 | 0.142 | 0.148 |
| | 0.015 | 0.113 | 0.135 | 0.147 | 0.152 |
| | 0.020 | 0.111 | 0.132 | 0.145 | 0.148 |
| Soil 3 | 0 | 0.208 | 0.211 | 0.212 | 0.212 |
| | 0.010 | 0.229 | 0.272 | 0.291 | 0.300 |
| | 0.015 | 0.232 | 0.277 | 0.303 | 0.310 |
| | 0.020 | 0.236 | 0.285 | 0.310 | 0.315 |

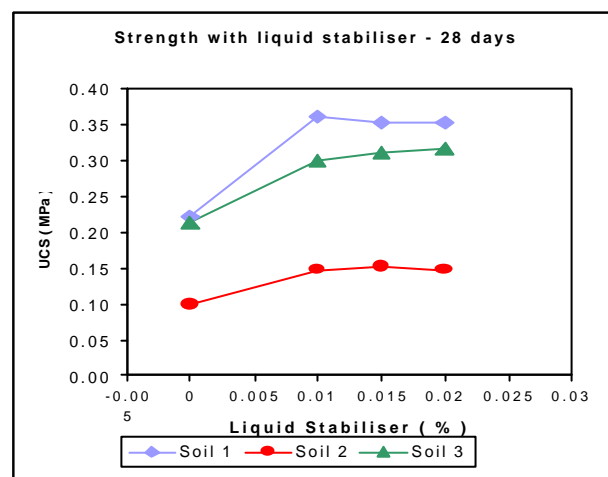


Fig. 5 Effect of Liquid Stabilizer on Strength Improvement on 28 Days of Curing

As seen from Table 3, strength growth for all the soil mixtures profusely increase especially after 7 days of curing period and begin to slow down after 28 days of curing period. This can be best elucidated that during that period, the chemical components of the liquid stabilizer had actively reacted with the clay platelets. The clay platelets that were neutralized were orderly arranged and produced relatively better inter particles bonding between each molecule. Higher inter particle bonding between each molecule is an indication of strength improvement.

Fig. 6 indicates that different proportions of liquid stabilizer in different soils produce different strength improvement. As noticed in Fig. 6, soil 1 achieves the highest improvement whereas soil 3 shows the least improvement for the same proportion of liquid stabilizer. Soil 1, which has the least clay content, possessed extra components of liquid stabilizer reacting with each clay platelets whereas for higher clay content soils, each clay platelets had limited components of liquid stabilizer that can be reacted with. Higher concentration of stabilizer component on each clay platelet would produce better

neutralisation, bonding and higher strength compared to low concentration of stabilizer components.

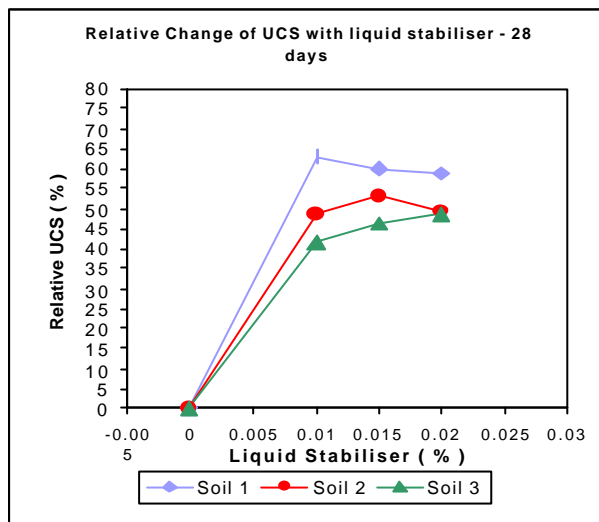


Fig. 6 Relative Strength Enhancement by Liquid Stabilizer on 28 Days of Curing

4 CONCLUSIONS

Based on the results presented herein, the following conclusions can be made on the performances of the liquid stabilizer that had been used:

- 1) It reduces Plasticity and Shrinkage by eliminating re-adsorption of water molecules.
- 2) It reduces Optimum Moisture Content by ionizing and exchanging the water molecules on the surface of the clay platelets.
- 3) It increases Maximum Dry Density by neutralizing and orderly re-arranging the clay platelets.
- 4) It increases the compressive strength by increasing the inter-particle bonding.

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