Effects of Carbon Fiber & Sika Fiber on Improving the Geotechnical Properties of Clayey Soil

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Abstract: The effects of carbon & sika fibers on the Undrained unconsolidated strength (UUS) of weak clay soil have been studied in this research. The soil sample obtained from Al Basra city south of that can be classified according to USCS as weak silty clay of low plasticity (CL). The additives are carbon & sika fibers. The soil samples were improved by mixing with four ratios of each additive 0.5, 1, 1.5 and 2% of the dry soil weight. Mixture samples prepared using the optimum water content. Bearing capacity of samples measured by the unconsolidation undrained tri-axial shear test. Based on the results of tests at failure, the undrained unconsolidated strength (UUS) increased with increasing the ratio of additives, except in the case of sika fiber, which gave negative effects. In addition, it is important to avoid using carbon fiber in a high ratio of upper than 1% of dry soil weight due to a decrease in the (UUS).

Keywords: Weak clay, carbon fiber, sika fiber, undrained unconsolidated strength (UUS), improvement.

1. Introduction

Soil strength can be enhanced through a range of \textit{in situ} treatment interventions, such as density treatment based on compaction and preloading, alleviation of pore pressure through electro-osmosis and dewatering, bonding of soil particles through ground freezing, grouting and chemical stabilisation, as well as reinforcement with various materials (e.g. geotextiles, stone columns) \cite{1}. Improvement of particle size gradation and addition of binders to soil with low strength are the most straightforward methods for stabilising soil. As emphasised \cite{2}, the chemical reactions occurring between the stabilising agent and soil minerals are essential for the achievement of stabilisation. Furthermore, an efficient soil reinforcement method must be affordable, uncomplicated to apply and have a major impact on soil proportion.

Clay that is characterised by normal or slightly excessive consolidation and has a liquidity index higher than 0.5 is classified as soft clay \cite{3}. The undrained shear strength \((C_u)\) and cohesion intercept in relation to effective stress \((C)\) of soft clay are both small, not exceeding 10 kpa and 25 kpa, respectively. The content of clays is dominated by mineral particles of small size, which are characterised by plasticity when they are combined with specific volumes of water. This property derives from the fact that the platelet-shaped mineral particles of ultra-microscopic size can alter their size to the order of microns when they cluster together. Within engineering practice, clay is considered to have a fraction of less than 0.002 mm. The characteristics of clay sediments are the result of the chemical and physical processes that they undergo when they are formed from the chemical
weathering of rocks. Once they are deposited in particular environments, clay sediments are differentiated into normally consolidated young clay and normally consolidated aged clay.

Within the context of building projects, the issue of soft clay can be addressed via several methods, including soil substitution, pile foundations, and soil enhancement or stabilisation.

2. Literature Review

Within the context of building projects, the issue of soft clay can be addressed via several methods, including soil substitution, pile foundations, and soil enhancement or stabilisation.

Despite the issues that suboptimal soils can pose for engineers, there are a number of measures that can be adopted in order to achieve soil improvement or stabilisation.

As indicated [4]: a number of aspects have to be taken into account when deciding, which method of soil stabilisation to employ, including the reason why soil needs to be stabilized? the soil surface, depth and total volume requiring treatment, the type of soil and its original characteristics, the availability of materials (e.g. sand, gravel, admixtures), the availability of equipment and skills, considerations related to equipment (e.g. waste disposal, erosion, water pollution impact on nearby structures and facilities), local experience and productivity, time availability, as well as costs.

3. Materials Used

3.1 Soil

The southern Iraqi city of Al Basra was the site of soil collection. Table (1) provides an overview of the physical and chemical features of the employed soil. With a composition of sand (2.3%), silt (38.7%), and clay (59%), the soil was identified as CL based on the Unified Soil Classification System (USCS) Figure (1).

| Index                        | Value |
|------------------------------|-------|
| Liquid Limit (L.L) (%)       | 41.7  |
| Plastic Limit (P.L) (%)      | 21.1  |
| Plasticity Index (P.I) (%)   | 20.6  |
| Specific Gravity (Gs)        | 2.60  |
| Gravel (%)                   | 0     |
| Sand (%)                     | 2.3   |
| Silt (%)                     | 38.7  |
| Clay (%)                     | 59    |
| Undrained compressive strength, Cu (KN/m²) | 24.5 |
| Natural water content, Wc (%)| 40    |
| SO₃ content (%)              | 0.37  |
| Total soluble salt (%) (TSS)| 3.64  |
| O.M content (%)              | 7.35  |
3.2 Carbon Fiber
The SikaWrap-300 c/60 company supplied the carbon fiber, the physical and mechanical properties of which are listed in Table (2). As indicated in this table, the carbon fiber had a normal modulus of elasticity.

Table 2: Mechanical / Physical Properties of the carbon fibers

| Index                              | Value            |
|------------------------------------|------------------|
| Density (g/cm³)                    | 1.79             |
| Average length (mm)                | 12               |
| Tensile strength (N/mm²)           | 3900 (normal)    |
| Tensile modulus elasticity (N/mm²) | 230000           |
| Elongation at break (%)            | 1.5 (normal)     |

3.3 The Sika Fiber
The Sika Company supplied the sika fiber, the physical and mechanical properties of which are indicated in Table (3). This fiber exhibited zero water absorption.

Table 3: Mechanical / Physical Properties of the sika fibers

| Index                              | Value            |
|------------------------------------|------------------|
| Specific Gravity (g/cm³)           | 0.91             |
| Average length (mm)                | 12               |
| Tensile strength (N/mm²)           | 300-400          |
| Modulus elasticity (N/mm²)         | ~4000            |
| Water absorption                   | Nil              |
| Melt point                         | 160°C            |
| Ignition point                     | 365°C            |
| Thermal conductivity               | Low              |
| Electrical conductivity            | Low              |
4. Methodology

The soil properties (specific gravity, liquid limit, plastic limit, USCS classification, swell index and organic content) of particular soil selected for this study were determined in the laboratory according to the Das Laboratory Manual. Soil improved with carbon fiber and sika fiber had in order to predict the effect of fiber inclusion into the soil. Compaction test and Unconsolidation Undrained Tri-axial Shear Test were carried out on the prepared soil specimen. 0.5%, 1%, 1.5% & 2% by weight of raw soil were added to the soil and mixed randomly to obtain a uniform mixture of reinforced soil. All the samples for UU test were prepared at the corresponding maximum dry density and optimum moisture content obtained from the compaction test can be observed in Figures (2) and (3).

![Graph](Figure 2. Findings of the compaction assessment of the soft clay soil with varying measurements of carbon fiber.)

![Graph](Figure 3. Findings of the compaction assessment of the soft clay soil with varying measurements of sika fiber.)
5. Test Result

5.1 Carbon Fiber

5.1.1. Assessment of Compaction

A comparative analysis was performed between the effects of carbon fiber on the maximum dry weight and optimal water content of the samples Figure 4. (a) and (b). This revealed that the $\gamma_d$ max declined whereas water absorption and, implicitly, OMC increased when the carbon fiber clay was increased. It was thus deduced that the clay was made more flexible by the carbon fiber.

![Figure 4](image)

**Figure 4.** The link between (a) the highest moisture levels and varying percentages of the additives, (b) the units’ optimized weight and varying percentages of the additives

5.1.2. Unconsolidation Undrained Tri-axial Shear Test

Table (4) provides the strength value and growth rate yielded by the UU test for soil with varying levels of carbon fiber samples. Alongside Figure (5), this table indicates that soil was made stronger by the addition of carbon fiber, whilst also lending support to the hypothesis that such addition could help regulate dry density and water content. However, the strength of the soil did not continue to rise in direct proportion with the content of carbon fiber. The addition of 1% carbon fiber was associated with maximal soil strength, which increased by nearly 56%. By contrast, at levels higher than 1%, carbon fiber addition did not contribute to greater soil strength.

| Additive % | 0   | 0.5 | 1   | 1.5 | 2   |
|------------|-----|-----|-----|-----|-----|
| C (kpa)    | 122.55 | 124.46 | 178.22 | 98.47 | 76.07 |
| $\Theta$ (°) | 19.02 | 18.64 | 5.08 | 2.64 | 2.32 |
Figure 5. The relationship between Shear strength index (C) and different percentage from additive material

5.2 Sika Fiber
5.2.1. Assessment of Compaction:
A comparative analysis was performed between the effects of sika fiber on the maximum dry weight and optimal water content of the samples Figure 6. (a) and (b). This revealed that the $\gamma_d$ max declined whereas water absorption and, implicitly, OMC increased when the sika fiber clay was increased. It was thus deduced that the clay was made more flexible by the sika fiber.

Figure 6. The link between (a) the highest moisture levels and varying percentages of the additives, (b) the unit’s optimized weight and varying percentages of the additives.

5.2.2. Unconsolidation Undrained Tri-axial Shear Test
Table (5) provides the strength value and growth rate yielded by the UU test for soil with varying levels of sika fiber samples. Alongside Figure (7), this table indicates that soil was made stronger by
the addition of sika fiber, whilst also lending support to the hypothesis that such addition could help regulate dry density and water content. However, the strength of the soil did not continue to rise in direct proportion with the content of sika fiber.

Table 5. The result of shear strength parameter for treated and untreated soft clay soil

| Additive % | 0   | 0.5 | 1   | 1.5 | 2   |
|------------|-----|-----|-----|-----|-----|
| C (kpa)    | 122.55 | 23.60 | 49.36 | 56.36 | 38.32 |
| Θ (°)      | 19.02 | 6.01 | 2.98 | 2.6  | 5.32 |

Figure 7. The relationship between Shear strength index (C) and different percentage from additive material

6. Conclusions
The results of this study show that the:
- Undrained unconsolidated strength (UUS) of the clayey soil fibers, when the proportion of the fiber increases, the strength also increases and the best improvement is obtained for fibers of 1% (carbon fiber). The strength increases first, then decreases with increasing fiber content, and the best content is 1%. Compared to natural soil, fibrous soil has higher breaking strength and more stable performance, while the fibrous soil with sika fiber the (UUS) decreases compared with the natural value of the soil.
- The maximum MMD value 1.6088 g/cm³ shown by the sample with 2% carbon fiber content at an OMC of 23.53%, well by using 2% of sika fiber the maximum MMD value 1.59 g/cm³ at an OMC of 24%.

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