

## **EFFECT OF SAND AND CHEMICAL ADDITIVES ON THE STRENGTH BEHAVIOR OF EXPANSIVE SOIL**

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### **ABSTRACT**

Expansive soils pose significant challenges in civil engineering construction due to their high swelling potential and low strength under wet conditions, which leads to damage in road pavements and lightweight structures. The present work aims to study the stabilization of expansive soil using locally available fine sand and chemical additives to improve its strength and durability. The Fineness modulus (FM) of sand 1.12 was blended with expansive soil in different proportions ranging from 5% to 30% to determine the optimum sand content. The selected sand content mixed with the soil was further stabilized with different combinations and percentages of ferric chloride (FeCl<sub>3</sub>) and sodium hydroxide (NaOH) to enhance its strength properties. Standard Proctor Compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests were conducted to evaluate the effects of stabilization. The UCS tests were carried out at the ages of 1,7,14, and 28 days of curing. The CBR test was conducted at 14 days of curing. It was found that the Maximum Dry Density (MDD) increased and the Optimum Moisture Content (OMC) decreased with the addition of sand. The UCS and CBR values improved notably up to 20% sand content added to the soil. The addition of ferric chloride to the soil-sand mixture enhanced the MDD and reduced the OMC, achieving optimal results at 1.5% FeCl<sub>3</sub>, where UCS and CBR increased by 68% and 53%, respectively. Similarly, sodium hydroxide content up to 5% increased the MDD and decreased the OMC. At a 6% NaOH addition, the UCS and CBR improved by 180% and 516%, respectively. Overall, the study showed that the combined use of sand, ferric chloride, and sodium hydroxide provides an effective and sustainable method for stabilizing expansive soils, offering a practical solution for construction applications in Bangladesh.

**Keywords:** *Expansive soil, ferric chloride, sodium hydroxide, UCS, and CBR*

## 1. INTRODUCTION

Expansive soil covers a significant portion of the landmass in Bangladesh. There are seven soil tracts, among them the Barind and Modhupur tracts exhibit high swelling and low strength behaviour with an increase in moisture content, which covers several districts in Bangladesh (Huq & Shoaib, 2013). Bangladesh is a developing country and the most populous in the world. Its infrastructure and road connectivity are rapidly growing due to social and economic improvements among the people across the country. Specifically, the rural road network often suffers from inadequate performance because of the presence of weak clay subgrades. These soils also curtail the continuance of life span and quality of road infrastructure, delaying access to essential goods, services, and opportunities for social and economic growth. Thus, enhancing the in-situ strength of such problematic soils is an indispensable issue for sustainable civil engineering construction. Soil stabilization is a conventional method used throughout the world for improving weak subgrade soils and enhancing strength characteristics. Among the different techniques of stabilization, cement and lime stabilization make use of chemical reactions to bond the soil particles (Islam, 2020). However, production of cement requires substantial energy and accounts for 5-8% of global carbon dioxide emissions, due to fossil fuel consumption (Khayyum et al., 2023). Therefore, it is necessary to investigate sustainable and environmentally friendly stabilizing materials for soft soil improvement. In this study, Expansive soil is stabilized with various percentages of sand to select the optimal dosages that improve substantial strength properties. The selected dosage of sand is then mixed with soil and further stabilized with ferric chloride and sodium hydroxide to enhance the strength characteristics of expansive soil.

Sand is an effective stabilizer for expansive soils, improving their strength properties by increasing the proportion of coarse particles and replacing finer clay fractions. This reduces water affinity and enhances the internal friction within the mixture. Previous research has found that the strength properties of expansive soil are enhanced by the addition of sand (Roy, 2013; Farooq & Virk, 2009; Nagaraj, 2016; Shankar et al., 2012). Ferric chloride exists as a trivalent cation ( $Fe^{3+}$ ) that is adsorbed on negatively charged clay particle surfaces, which reduces the repulsive forces between diffuse double layers and promotes particle interactions. This process promotes flocculation and the formation of larger clay clusters, which leads to improved UCS and CBR of stabilized soil (Raju, 2019; Khudhair et al., 2022; Jandial & Gupta, 2020; Chaitanya et al., 2011). Similarly, sodium hydroxide leach the alumina and silica from the clay minerals to form aluminosilicate and geopolymer gels that act as a binding agent in the soil particles, and these gels reduce water affinity, thereby resulting in an enhancement of cementitious characteristics and improving the UCS and the CBR of the stabilised soil (Abdulkarim & Umar, 2020; Abid, 2016; Syed et al., 2020; Kesha et al., 2018). Therefore, the primary objective of this study is to find out the optimum content of sand at which a substantial enhancement in the strength characteristics of expansive soil can be observed. The soil-sand mixture is treated with different percentages of ferric chloride and sodium hydroxide to assess additional enhancements in UCS and CBR.

## 2. MATERIALS AND METHODOLOGY

### 2.1 Materials

The expansive soil was sampled from Sreepur, Gazipur, by scraping off the top layer of soil in accordance with the (ASTM D420, 2018) standard. The unconfined compressive strength of undisturbed soil is found to be  $131.4 \text{ KN/m}^2$  and the natural moisture content is 32.4%. The CBR value of this soil is found to be very low at 2.07%. The sand, which was used as a stabilizing agent, was collected from Tangail at the riverbeds of the Brahmaputra and Jamuna rivers. The basic properties of both the expansive soil and the sand are presented in Table 1. Ferric chloride ( $FeCl_3$ ) is an industrial chemical compound that contains iron in the +3 oxidation state.  $Fe^{3+}$  ions bond with the negative charge of clay minerals. Sodium hydroxide is a widely used inorganic compound also known as caustic soda. Its chemical composition is NaOH, containing the sodium cation ( $Na^+$ ) and hydroxide anion ( $OH^-$ ). This chemical is a very caustic base and alkali, strongly reacting with the clay mineral.

Sodium hydroxide is soluble in water, and it is also hygroscopic. The properties of ferric chloride and sodium hydroxide are demonstrated in Table 2.

Table 1. Basic properties of expansive soil and fine sand

<b>Expansive Soil</b>		<b>Sand</b>	
<b>Parameter</b>	<b>Value</b>	<b>Parameter</b>	<b>Value</b>
Liquid Limit (LL)	62.4 %	Uniformity Coefficient ( $C_u$ )	1.59
Plasticity Index (PI)	33.2 %	Curvature Coefficient ( $C_c$ )	0.79
Shrinkage Limit (SL)	13.4 %	Fineness Modulus	1.12
Specific Gravity ( $G_s$ )	2.57		2.71
Material Finer than #200 Sieve	99.5 %		1.63
Classification (USCS)	CH		SP

Table 2. The properties of ferric chloride and sodium hydroxide

<b>Ferric Chloride</b>		<b>Sodium Hydroxide</b>	
<b>Parameter</b>	<b>Value</b>	<b>Parameter</b>	<b>Value</b>
Molar Mass	162.21 g/mol	Molar Mass	40 g/mol
Density	2.8 g/cm <sup>3</sup>	Density	2.13 g/cm <sup>3</sup>
pH value	1 (200 g/l, H <sub>2</sub> O, 20 °C)	pH value	>14 (200 g/l, H <sub>2</sub> O, 20 °C)
Solubility	920 g/l	Solubility	1090 g/l

## 2.2 Methodology

The collected soil sample was air-dried, crushed with a rubber hammer, and sieved through a specific sieve for the laboratory test as per the following particular ASTM test standards. Expansive soil was mixed with the sand at 5%, 10%, 15%, 20%, 25%, and 30% by weight. The soil-sand dry mixture was also combined with various percentages of ferric chloride (0.5%, 1.0%, 1.5%, and 2.0%) and sodium hydroxide (1.0%, 2.0%, 3.0%, 4.0%, 5.0%, and 6.0%). Then, the Standard Proctor compaction, UCS, and CBR tests were performed on the natural and treated expansive soil samples. The test that follows is described in the section below:

### 2.2.1 Standard Proctor Compaction

Standard Proctor compaction tests were performed on natural expansive clay and on clay blended with varying dosages of sand, ferric chloride, and sodium hydroxide, according to (ASTM D698, 2021). The sample is passing through a 4.75 mm sieve to prepare the sample. Various known percentages of water are properly mixed with the passing sample and kept in polyethene bags to absorb the moisture content. After absorption is complete, the sample is compacted in 3 layers using a 2.54 kg rammer for different percentages of water mixture. Once compaction is complete, record the value for each compaction weight and take the sample for moisture content determination. Finally, calculate the dry density and moisture content. Plot the graph of moisture content versus dry density to find out the MDD and OMC.

### 2.2.2 Unconfined Compressive Strength

The undrained shear strength test of untreated and treated expansive soil is performed according to (ASTM D2166, 2006) standards on cylindrical samples measuring 72 mm in length and 36 mm in diameter. Multiple UCS tests on all composite soils are conducted in the laboratory to evaluate the increase in shear strength with respect to curing time. Prior to moulding, the OMC of the untreated and treated samples is determined through the standard Proctor compaction test at a range of sand contents and chemical additives. After preparing the sample, it was wrapped in polythene and stored in moist conditions in an airtight desiccator for maturation and to maintain its moisture content during

the application of compressive loads. The influence of curing time on the UCS sample is also investigated by curing the cylindrical specimens for 0, 1, 7, 14, and 28 days.

### 2.2.3 California Bearing Ratio

The CBR specimens were similarly prepared at their respective OMCs for the natural and treated samples following the above-mentioned dosages of the specified additives. Then the tests were conducted in a soaked condition following (ASTM D1883, 2021). Subsequently, the tests were conducted on wet soil samples that had been soaked for 96 hours to determine the appropriate stiffness of a subgrade layer. A 50 mm diameter plunger is used to apply a static load at a loading rate of 1.27 mm/min to the specimen. Record the observed test load corresponding to each penetration value and plot a graph of penetration versus load. Collect data from this graph at 2.5 mm and 5.0 mm depth of penetration, respectively. Finally, calculate the CBR value relative to the standard load according to the relevant standard.

## 3. RESULTS AND DISCUSSION

### 3.1 Stabilization of Expansive Soil Using Sand

The strength properties of sand-stabilized soil, including UCS and CBR, are explained in the results and discussion in the following sections:

#### 3.1.1 Unconfined Compressive Strength

The UCS increases gradually with the addition of sand to the expansive soil, as shown in Figure 1. The UCS value increases from 184.6 kPa to 270.2 kPa when 30% sand is mixed with the expansive soil. The increase in compressive strength is caused by the substitution of coarser sand particles with finer clay particles, which enhances the frictional resistance of the soil grains. The most substantial increases were observed when 20% sand was mixed in the expansive soil. Further addition of sand content to the soil up to 30% the UCS values continue to increase at a slower rate. The slower enhancement may be caused by the inhomogeneity of the soil and sand mix due to the segregation of sand. These results are in agreement with the findings of (Muleta, 2020).

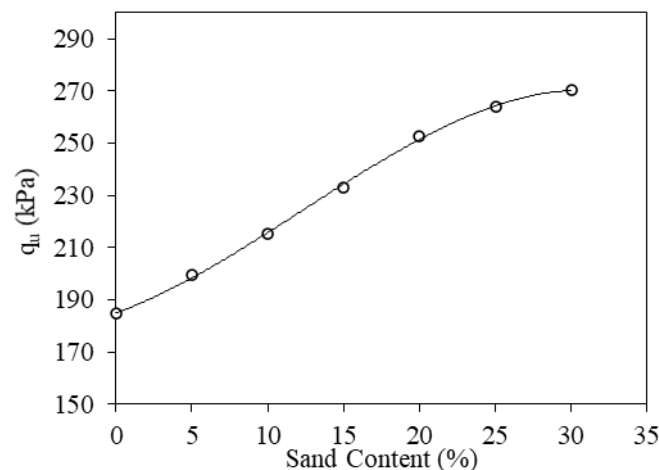


Figure 1: Effect of sand on unconfined compressive strength

#### 3.1.2 California Bearing Ratio

The influence of different sand content on the CBR of sand-stabilized expansive soil is depicted in Figure 2. The CBR values rose from 2.07% to 6.37% with the addition of 30% sand. This improvement may be attributed to achieving a more uniform grain size distribution in the mixed soil sample. The CBR values substantially increase when 20% sand is mixed with expansive soil.

(Shankar et al., 2012) reported that the CBR value increased up to 40% when sand was mixed with lithomargic soil. The results agreed with earlier studies conducted on soil improvement by (Roy, 2013) and (Eisa et al., 2022).

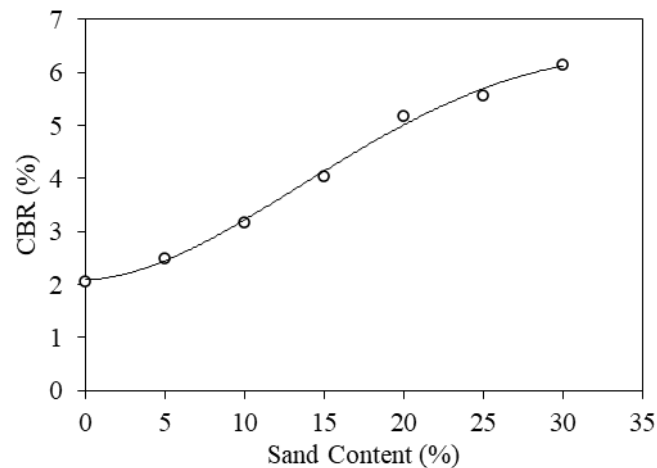


Figure 2: CBR value of stabilized soil vs. percent of sand

### 3.2 Strength Properties of Soil-Sand Mixture Treated with Ferric Chloride

The strength properties of a soil-sand mixture (80% soil and 20% sand) treated with ferric chloride are discussed in the results in the section below. These properties include UCS and the CBR of the soil-sand mixture.

#### 3.2.1 Unconfined Compressive Strength

Figure 3 illustrates the UCS results of the soil-sand mixture with ferric chloride addition. The UCS values increase gradually with increasing ferric chloride content, up to 1.5%, for all curing periods. The enhancement of strength may be due to cation exchange between the soil and sand mineral layers. However, when the ferric chloride content increases more than 1.5%, the peak stress decreases, indicating that 1.5% is the optimal ferric chloride content. The reduction in strength beyond 1.5%  $\text{FeCl}_3$  may be due to increased moisture absorption at higher  $\text{FeCl}_3$  concentrations. A similar conclusion was also reported by (Raju, 2019) and (Chaitanya et al., 2011).

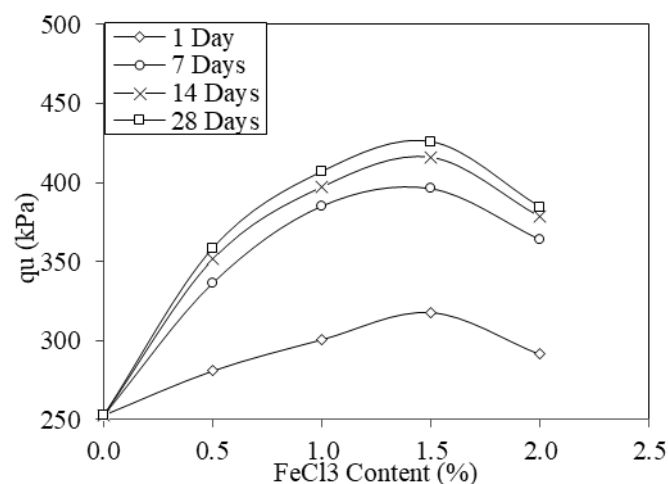


Figure 3: Influence of ferric chloride on unconfined compressive strength

#### 3.2.2 California Bearing Ratio

The CBR test was carried out on soil-sand mixtures treated with varying percentages of ferric chloride after 14 days of curing. The influence of adding  $\text{FeCl}_3$  to a soil-sand mixture is shown in Figure 4.

The CBR value increased from 5.7% to 8.7% with an increase in  $\text{FeCl}_3$  content from 0% to 1.5%. The strength enhancement is due to a cation exchange between  $\text{FeCl}_3$  and the soil mineral layers and the formation of a silicate gel in the system. However, a decreasing trend in the CBR value was observed beyond 1.5% content, which was associated with an excess of  $\text{FeCl}_3$  that could not react and acted as a bonding inhibitor in the mixture. The stabilization of expansive soil with  $\text{FeCl}_3$  electrolytes was investigated by (VenkaraMuthyalu et al., 2012) and reported findings consistent with the CBR value with these results.

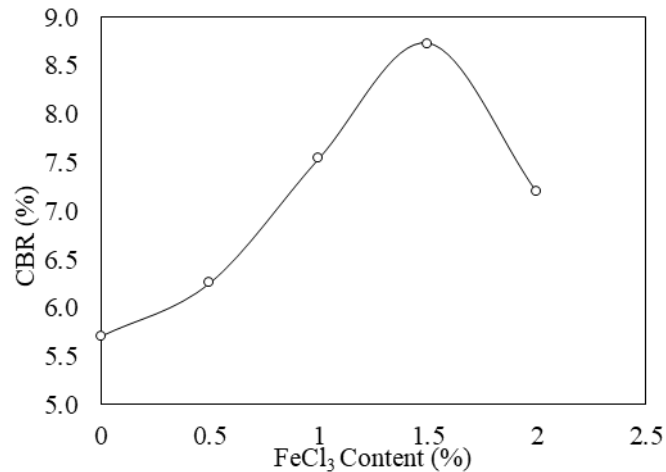


Figure 4: Variation in the California bearing ratio of treated soil

### **3.3 Strength Properties of Soil-Sand Mixture Treated with Sodium Hydroxide**

In the following sections, the strength properties of a soil-sand mixture (80% soil and 20% sand) treated with sodium hydroxide are explained in the results and discussion. These properties include UCS and the CBR of the soil-sand mixture.

#### **3.3.1 Unconfined Compressive Strength**

Variation of the UCS of the soil-sand mixture with sodium hydroxide concentration for different curing times is illustrated in Figure 5. The UCS of the stabilized soil-sand mixture samples increases significantly with both sodium hydroxide content and curing time. The UCS values were increased by 180% with increasing NaOH concentration to 6% for 28 days curing period. This strength enhancement is attributed to the capacity of the alkaline activator (NaOH) to dissolve the silica and alumina contained in the soil, which leads to the polymerization process and increases the cementitious matrices among the soil particles. These findings are comparable to those achieved by (Abdulkarim & Umar, 2020).

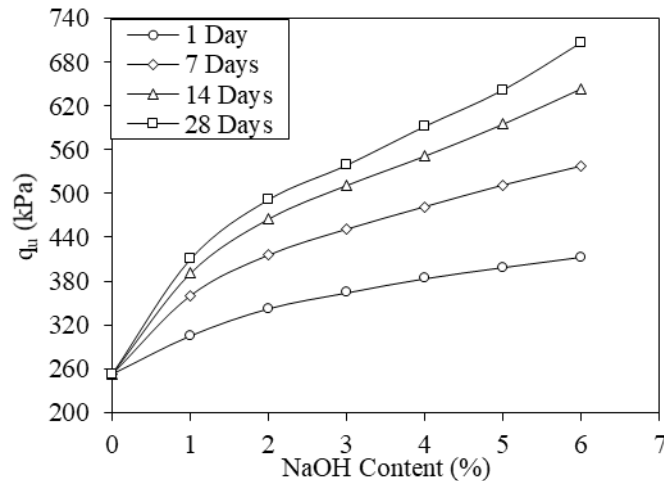


Figure 5: Effect of sodium hydroxide on unconfined compressive strength

### 3.3.2 California Bearing Ratio

The CBR test was performed on soil-sand mixtures with various dosages of sodium hydroxide after 14 days of curing. The CBR test results of the untreated and NaOH stabilized soil-sand mixture are presented in Figure 6. It shows that the CBR value increases with a higher percentage of sodium hydroxide mixed with the soil-sand mixture. The CBR value significantly increased from 5.7% to 35.1% as the sodium hydroxide content was increased in the range of 0% to 6%. The strength enhancement may be due to the fact that the alkaline activator dissolves a certain quantity of the silica and alumina in the soil. This process enables geopolymerization and starts the pozzolanic reaction of the geopolymer within the soil. Similar findings were reported by (Abdulkarim & Umar, 2020), who found that the CBR values increased in different proportions of sodium hydroxide added to lateritic soil. (Syed et al., 2020) reported similar behaviour in the CBR test on expansive clays, sodium hydroxide was used as an alkali-activated binder.

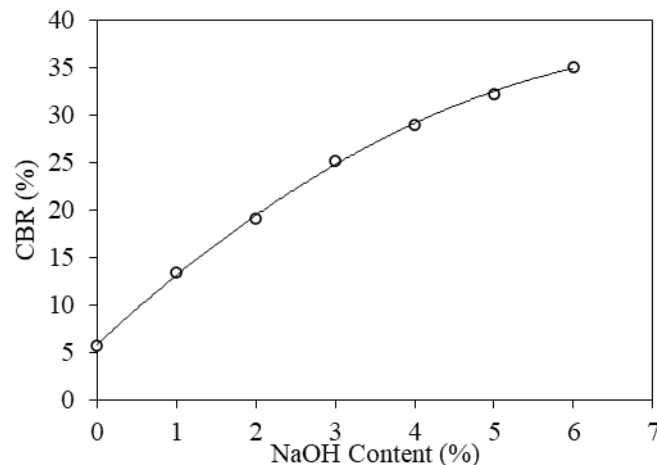


Figure 6: Influence of sodium hydroxide on the California bearing ratio

## 4. CONCLUSIONS

The effectiveness of sand, ferric chloride, and sodium hydroxide on the strength properties of expansive clay has been investigated in the present study. The following conclusions are drawn based on the laboratory investigation:

- The UCS and CBR test results are enhanced with the addition of sand. When 30% sand was added to the expansive soil, the UCS increased by 46%, and the CBR value increased by 197%.
- The value of UCS is increased by the addition of different percentages of FeCl<sub>3</sub> and NaOH to the soil-sand mixture. The UCS increases by 68% with 1.5% FeCl<sub>3</sub> and 180% with 6.0% NaOH after 28 days of curing. The most significant strength gains occur during the first 14 days of curing.
- The CBR value significantly increases with the addition of different percentages of FeCl<sub>3</sub> and NaOH to the soil-sand mixture. The CBR value increases by 53% with 1.5% FeCl<sub>3</sub> and by 516% with 6% NaOH after 14 days of curing.

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## DECLARATION

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation of this manuscript for the purposes of content generation, data analysis, interpretation of results, or drawing conclusions. Generative AI tools have only been applied for editing the language, in terms of grammar corrections and sentence restructuring, and have not been involved in the scientific content or the meaning of the manuscript.

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