Collapsibility and Strength of Gypseous Soil Treated with Palm Fibers

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ABSTRACT

Collapsible soil is a type of soil that appears strong and stable in its dry state but loses stability when exposed to water, resulting in collapse. Such soil poses a major challenge in the field of geotechnical engineering. Gypseous soils are one type of collapsible soil; they are defined as soils containing a high percentage of gypsum (CaSO4.2H2O), which can make up a significant part of their mineral composition. These soils are found in arid and semi-arid regions, where the climatic conditions favor the gypsum formation due to the low rainfall and high evaporation rates caused by the high temperatures. Gypseous soils are highly soluble in water and have poor stability when used as a foundation for construction; therefore, they require special care and treatments to prevent building failures. In this study, the effect of adding palm fibers as an additive on the compressibility and strength of gypseous soil was examined. The soil used has a gypsum content of 56% and was collected from Tikrit City, Salah Aldeen Governorate, Iraq. Palm fibers were added to the soil at percentages of 0.1%, 0.3%, and 0.5% of the soil weight. Collapse and direct shear tests were conducted on both natural and treated samples. The results show a significant decrease in the Collapse Potential (CP) and a notable increase in the shear strength parameters, namely cohesion (c) and angle of internal friction (φ), for the treated soil. The improvement in CP reached 39.38% at 0.5% treatment. For the direct shear test, the increases in c and the angle of internal friction (φ) reached 52.78% and 18.57%, respectively, at 0.5% treatment.

Keywords- Gypseous soil; palm fiber; collapse; collapse improvement ratio; soil strength; strength improvement ratio

I. INTRODUCTION

In Iraq, gypseous soils are found in several locations, constituting between 20% and 30% of the country's total land area. Fallujah, Baiji, Mosul, Tikrit, Anna, Samarra, Ramadi, Heet, and the area northwest of Baghdad are the best places to find these soils [1]. When the gypsum binder dissolves or breaks into particles upon contact with water, gypsum can be transported as a dissolved matter over long distances, making the soil extremely soft and compressible. This can lead to significant foundation issues because the soil structure collapses. Gypseous soils can cause major problems in civil engineering projects because they exhibit an unpredictable behavior. In dry conditions, gypseous soils have a high load-bearing capacity. However, when soaked, fractures develop in the soils, which can cause breakdown even without additional external loads, under the influence of the initial load [2]. Due to their low densities and large void ratios, collapsing soils are weak. When dry, they are strong, but when wet, they lose much of their void space, leading to failure [3, 4]. The impact of mineral fibers on the mechanical properties and compaction of the clay and silty soils treated with cement and lime was evaluated in [5]. The effects of the stabilizer ratios, fiber types, and fiber quantities were also investigated. The results showed that adding fibers increased the maximum dry unit weight, with 0.5% short fibers and 1.5% long fibers providing the highest unconfined and tensile strength.

Authors in [6] examined how different polymer fiber types influence the physical and geotechnical properties of clayey soils collected at various depths. Glass and PPF, with lengths of 38 mm and 50 mm respectively, were added in different weight ratios. The results showed that the compressive strength and particularly the tensile strength of the clayey soil increased significantly, as the fibers enhanced both c and the angle of internal friction φ. Considering the environmental challenges caused by the improper disposal of plastic waste, authors in [7] explored its use as a reinforcing material for gypseous soil. It was indicated that adding 6% plastic reduced the maximum dry unit weight by 21.48%, while this addition increased the optimum moisture content by 20.68%. Authors in [8] used laboratory models with a relative density of 30% under both dry and saturated conditions, subjected to vertical static stress, to evaluate the improvement of gypseous soil containing 47% gypsum. Geotextile and E-glass layers were applied in single, double, and triple arrangements at different soil depths. The results revealed that using three layers of glass fiber (0.25B, 0.5B, and 1B) doubled the final bearing capacity compared to the geotextile under dry conditions, demonstrating the high effectiveness of the glass fibers in strengthening the gypseous soil. Authors in [9] examined the effects of synthetic Polypropylene Fibers (PPF) and natural Sugarcane Stubble Fibers (SCF) on gypseous soils with different gypsum contents. Fibers were added in proportions ranging from 0% to 0.8% of the dry soil weight. The results showed that under both dry and saturated conditions, PPF increased c more effectively, while SCF improved the φ angle to a greater extent. The optimal fiber content was determined to be 0.4% for PPF and 0.6% for SCF. Overall, PPF outperformed SCF in enhancing gypseous soils. Authors in [10] investigated the use of recycled nylon bag waste to improve gypseous soil containing 60% gypsum. Plastic strips were added at proportions of 0%, 2%, 4%, and 8%. Direct shear and single-compression tests indicated that incorporating plastic strips improved the geotechnical properties of the soil and reduced its collapse susceptibility, highlighting recycling as a sustainable soil improvement method.

Authors in [11], investigated the combined use of fiberglass and Silica Fume (SF) to improve the properties of expansive soil. SF was added in proportions of 8%–13% to soil containing 50% bentonite clay, while 1% fiberglass was incorporated into the soil–SF mixture. The results showed that SF alone reduced the swelling, reloading, and compressibility coefficients, while it increased the internal friction angle φ but slightly reduced c. When 1% fiberglass was added, the soil–SF mixture was further improved, with reductions in swelling and increases in both c and φ. Thus, the combination of SF and fiberglass proved effective in enhancing the engineering characteristics of expansive soils. In [12], the effects of vetiver fiber, bamboo fiber, and *Bacillus subtilis* on the shear strength of poorly graded sandy loam soil were evaluated. The direct shear test results indicated that combining bamboo fibers with microbial treatment significantly increased the soil strength from 13 kPa (untreated soil) to 42.8 kPa. This improvement was attributed to the calcite precipitation and enhanced intermolecular bonding facilitated by the bacteria, with bamboo fibers showing the greatest benefit. Authors in [13] investigated soil particles subjected to crushing loads to monitor the changes in soil behavior. The findings revealed that the particle breakage altered the engineering properties of sand. This research focuses on evaluating the effects of adding palm fibers on the engineering properties of gypseous soils, specifically their collapsibility and shear strength parameters.

II. SOIL AND MATERIALS USED

A. The Soil

The gypseous soil used in this study was collected from Tikrit City and contains 56% gypsum. Standard laboratory tests were conducted to determine its properties. The physical characteristics of the soil are presented in Table I, while Figure 1 illustrates its grain size distribution. According to the Unified Soil Classification System (USCS), the soil is classified as SP. The results of the chemical analysis are summarized in Table II.

TABLE I. PHYSICAL PROPERTIES OF GYPSEOUS SOIL

Properties of soil	values
Specific Gravity (Gs)	2.35
Liquid Limit (LL) %	38
Plastic Limit (PL) %	N.P
Soil classification according to USCS	SP
Maximum dry density (KN/m^3)	19.53
Optimum moisture content (%)	9

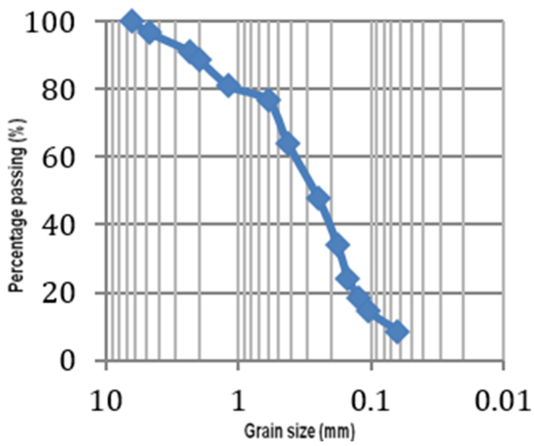

Fig. 1. Grain size distribution of the used soil.

TABLE II. CHEMICAL PROPERTIES OF THE USED GYPSEOUS SOIL

Properties of soil	values
Total soluble salts (%)	59.6
Gypsum content (%)	56
Organic matter (%)	0.81
PH	8.07

B. The Palm Fibers

For this study, palm fibers with a diameter of 0.2 cm were collected from palm trees near Tikrit City and cut into 2 cm lengths to ensure a proper mixing with the soil. The fibers used are portrayed in Figure 2. They were added to the gypseous soil at proportions of 0.1%, 0.3%, and 0.5% by weight for both the collapsibility and direct shear tests.

Fig. 2. The used palm fiber.

III. COLLAPSIBILITY TESTS

Collapsibility tests were conducted using an oedometer. The soil's CP was determined by progressively loading the sample under initial conditions until a vertical stress of 200 kPa was reached. The sample was then submerged in water for 24 h during which significant settlement occurred at the 200 kPa stress level. After soaking, the test continued with additional loading and unloading cycles. The CP was calculated using:

$$c.p. = \Delta\varepsilon = \frac{\Delta H_e}{H_0} = \frac{\Delta e}{e_o} \quad (1)$$

where $\Delta\varepsilon$ is the vertical strain, Ho is the soil's starting height (total height), ΔH_e is a decline in soil height brought on by soaking, e_o is the natural proportion of voids, and Δe is a difference in the sample's void ratio brought on by wetting. The collapsibility test is applied on the soil and Soil/Palm Fiber mixture 0.1%, 0.3%, and 0.5% to obtain the CP according to [14].

IV. DIRECT SHEAR TEST

The direct shear test was deployed using the shear test machine. The machine features fixed and roving boxes that can be screwed together. A 5kN load cell was used to apply the shearing force. The loading apparatus applied a shear force to the sample at a rate of 1 mm/min in a direction parallel to the roving box. The displacements were measured with transducers, and the data were automatically sent to the data recorder and computer. This test was implemented to the original soil and mixture of soil/ Palm Fiber to obtain the shear strength parameters (c and φ), according to [15].

V. RESULTS AND DISCUSSION

A. Collapsibility Tests

Table III presents the collapsibility test results, displaying the values of the Collapsibility Improvement Ratio (CIR) and CP for gypseous soil treated with palm fiber and natural soil. Figure 3 illustrates how the CP varies with varying palm fiber fractions. It was observed that as the proportion of the palm fiber increased, the CP dramatically dropped. This phenomenon can be verified by the fact that the fiber reduces the collapse capability as the fiber concentration increases, forming an interconnected structure that restricts fragments from migrating as the gypsum dissolves. Additionally, because the fiber stops the soil particles from slipping relative to one another, the volumetric change decreases. At 0.5% treatment, the CP value decreased from 3.07 to 1.85. It is found that the improvement increases with an increasing palm fiber content, reaching 39.74% for 0.5% palm fiber. Figure 4 portrays the fluctuation of the Collapse Improvement Ratio (CIR) with the palm fiber content.

TABLE III. CP VALUES AND CIR FOR NATURAL AND PALM FIBER-TREATED SOIL

Palm Fiber (%)	C_P (%)	CIR (%)
0	3.07	0
0.1	2.69	12.38
0.3	2.09	31.92
0.5	1.85	39.74

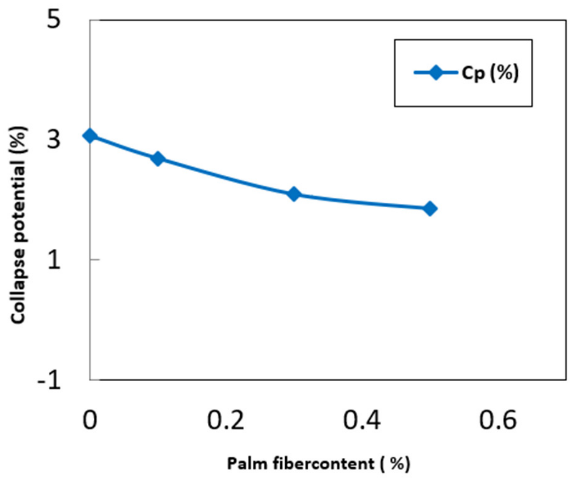

Fig. 3. Variation of CP with different percentages of palm fiber.

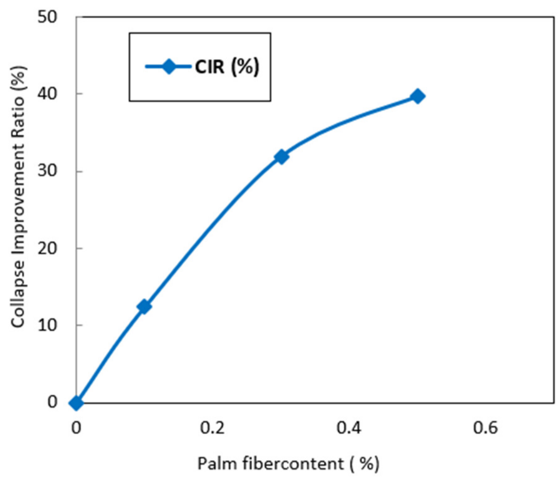

Fig. 4. Variation of CIR with different percentages of palm fiber.

B. Shear Strength Tests

In geotechnical engineering, direct shear tests are commonly used to evaluate the soil shear resistance by determining its shear strength parameters. The test applies a horizontal force to a soil sample under constant normal stress to measure the relationship between the shear stress and displacement. From this, c and φ are obtained, which describe the soil's behavior under shear forces. The results of the direct shear tests are presented in Table IV, while Figure 5 shows the variation of c and φ with the palm fiber content. The results indicate that both c and φ increase as the palm fiber content increases. This improvement can be attributed to the rough surface of the palm fibers, which enhances the interparticle φ and creates stronger bonds between the soil particles, thereby increasing c. Additionally, in moist conditions, the fibers swell, further increasing surface φ between the fibers and soil particles, which contributes to a greater soil strength.

TABLE IV. DIRECT SHEAR TEST RESULTS

Palm fiber (%)	c (KN/m^2)	φ (°)
0	18	35
0.1	22.4	35.6
0.3	25.1	38.4
0.5	27.5	41.5

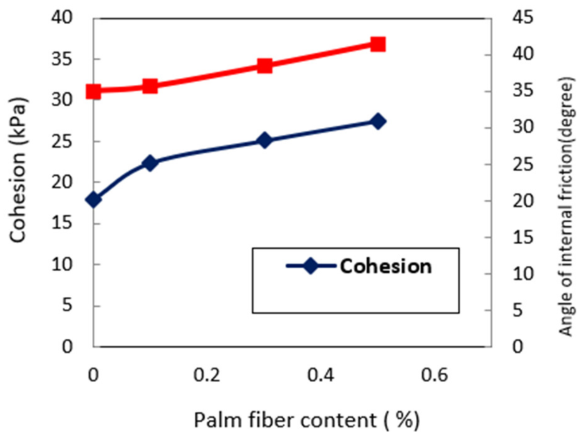

Fig. 5. Variation of c and φ with different percentages of palm fiber.

TABLE V. SIR RATIO FOR TREATED GYPSEOUS SOIL

Palm fiber (%)		0%	0.1%	0.3%	0.5%
SIR (%)	c	0	24.44	39.44	52.78
	φ (°)	0	1.71	9.71	18.57

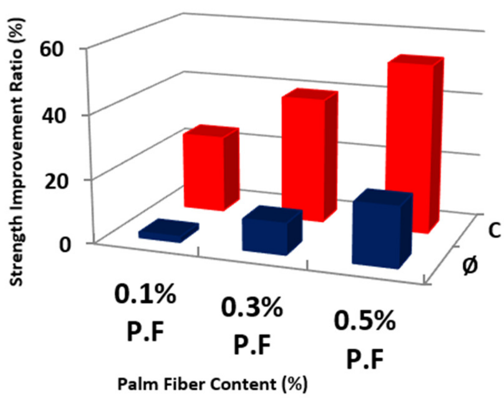

Fig. 6. Variation of SIR ratio with different percentages of palm fiber.

Table V and Figure 6 show the Strength Improvement Ratio (SIR) for both the φ and c with the palm fiber content. SIR increases with increasing palm fiber content, but in general, the rate of improvement in c is greater than that for φ.

VI. CONCLUSIONS

The use of fibers in soil treatment has gained increasing attention. Most of the previous studies focused on synthetic fibers and fine clay soils, whereas this research highlights the effectiveness of environmentally friendly natural fibers in improving the sandy gypseous soils. The results show that the Collapse Potential (CP) of the gypseous soil decreases with a higher palm fiber content, while both shear strength parameters, cohesion (c) and angle of internal friction (φ) (Ø), increase. The improvement in c was greater than that of the internal angle φ. At 0.5% palm fiber content, the Collapse Improvement Ratio (CIR) exceeded 39%, while the Strength Improvement Ratio (SIR) reached more than 52% for c and 18% for φ . Overall, a palm fiber content below 1% can effectively enhance both the collapsibility and strength properties of gypseous soils.

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