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Technical Note

Experimental study on the influence of Polypropylene fiber on swelling pressure – expansion attribute of silica fume stabilized clayey soil

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Abstract: Expansive soil shows dual swell-shrink which is not suitable for the construction. Several mitigating techniques exist to counteract the problem promulgate by expansive clayey soils. This paper explored the penitential mecho-chemical reinforcement of expansive clayey soil to mitigate the effect of upward swelling pressure and heave. The polypropylene fiber is randomly distributed in the soil for mechanical stabilization, and the industrial residual silica fume is used as a chemical stabilizer. The experimental analysis is made in three phases which involved the tests on mechanical reinforced expansive soil using randomly distributed polypropylene fibers with different percentages (0.25%, 0.50%, and 1.00%), and 12mm length. The second phase of experiments carried out on chemical stabilized expansive soil with different percentages (2%, 4% and 8%) of silica and next phase of the experimental focused in the combination of mecho-chemical stabilization of the expansive soil with different combination of silica (i.e., 2%, 4% and 8%) and polypropylene fibers (i.e., 0.25%, 0.50% and 1.00%). Maximum dry density (MDD), optimum moisture content (OMC), liquid limit (LL), plastic limit (PL), plastic index (PI) grain size, and constant volume swelling pressure test were performed on unreinforced and reinforced expansive soil to investigate the effect of polypropylene fiber and silica fume on the engineering properties of expansive clayey soil.

The experimental results illustrate that the inclusion of polypropylene fiber has a significant effect on the upward swelling pressure and expansion property of expansive soil. The reduction in the upward swelling pressure and expansion is a function of fiber content. These results also indicated that the use of silica fume caused a reduction in upward swelling potential, and its effect was considerably more than the influence of fiber.

Keywords: Expansive soil, polypropylene fiber, silica fume, swelling pressure, expansion

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I. Introduction

Expansive clayey soil, copious in tenacious hydrophilic minerals such as illite and montmorillonite, is widespread typical problematic expansive soil conceive in a natural geological transaction. Expansive soil has characterized by shrinkage, consolidability, and heave(expansion).

Structural damages due to expansive soils occur on roads, buildings, and bridges. Past research focused on perceiving the demeanor of clayey soil and complication that might emanate due to volume fluctuations [1–4]. Expansive soils, due to their inherent properties like minimum strength, maximum compressibility, and high swelling pressure, are considered inadmissible construction materials for building and transportation engineering applications [5]. Therefore, such soil often needs to be modified to meet the design criteria before applying. Expansive soils can be stabilized using mechanical and chemical treatment. Chemical treatment majorly involves the inclusion of chemicals admixtures (e.g., polymers, cement, and lime) to the soil [6–10]. The mechanical approach includes the compaction of soil with the addition of the strengthening material. Common strengthening materials include synthetic fibers (e.g., nylon and polypropylene) [11,12] and natural fibers (e.g., coconut and coir) [13,14] origin or other fibrous materials. The use of fibers can be considered as one of the most widely accepted propositions in this context. The reinforcement of embankment, slopes, retaining walls, subgrade, and base course are the part of transportation infrastructures projects. Soil reinforcement with fibers is an exciting and innovative solution to geotechnical problems. The behavior and beneficial effects of fiber-reinforced soil have been extensively studied and described in the literature. Numerous experiments with fiber-reinforced soil have shown that the unconfined compressive strength of the soil increases with the addition of random fibers to the soil. [15–18]. Other studies have investigated the effect of adding artificial or natural fibers [14,19–22]

There is a rapid increase in the waste quantity of plastic fiber if this waste can be utilized for the stabilization of soil than a sustainable solution of the expansive soil can be achieved [11]. In recent years, the polymeric fibers have also been used to control the volume change behavior of expansive soil as well as to improve its strength. The performance of the reinforcement is persuaded by the properties of the fiber, volume fraction, modulus of elasticity, type of inclusion, , orientation, length, shape, grain size, gradation characteristics and density [23] and also established that peak UCS of soil increased with the inclusion of fiber content and shown meager reduction in shear capacity [19]. Polypropylene fiber does not react with water and soil hence can be used for the soil reinforcement [24].

Cement is specially used to improve the shearing strength of the expansive soil, and hence, it is preferred as a chemical additive to expansive soil if an improvement of their strength is required a parameter[6,7,25]. The chemical stabilization of expansive soils is a substantiate quick fix method in the short term. However, concerning the long-term sustainability of these methods, there are considerable problems, confide in the mineralogy of the soil clay, environmental fluctuations of clay soil such as water availability and construction methods [26,27]. Chemical stabilization method makes expansive clay soils stable in compression but dispenses minimal to the tension. This becomes a hefty problem in the summer when expansive soils contract and stabilization should withstand tensile cracking [28]. A natural way to improve the tensile strength of a material is by mechanical reinforcement.

The primary focus of this paper is to evaluate the performance of polypropylene fiber effect as a mechanical reinforcement and silica fume as environmental friendly chemical stabilization, alternative for the expansive soil[29,30]. Several researchers studied the effect of polypropylene fiber and silica fume on consolidation and swelling [24]; however, the effect of polypropylene fiber with and without silica fume on upward swelling pressure and expansion rate of the expansive soil have not investigated much. This paper is a contribution towards this where the impact of polypropylene fibers with and without silica fume was studied on both reinforced and unreinforced expansive soils. A constant volume swelling pressure test was conducted by varying the percentage of polypropylene fiber content (i.e. 0%, 0.25%, 0.50% and 1.00%) and silica fume (0%, 2%, 4% and 8%) to propose the optimum amount of the fiber reinforcement and silica fume needed to mitigate the upward swelling pressure exerted by the expansive soil.

II. MATERIAL PROPERTIES

1) Expansive Soil

The expansive clay soil used for the present study was collected from the Indore (India) at a depth of 1.5m – 2m. The free swelling index of the soil was 120%, which is considered to be very high swelling nature. The liquid limit (LL) and the plasticity index (PI) of the soil were 89% and 42% respectively. Based on LL and PI, the soil is classified as high plasticity (CH) silty clay according to UCSC. The various index properties of the expansive soil considered in the study are shown in Table 1

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Table 1 Index properties of expansive soil considered

Property	Value
Specific gravity	2.78
Liquid limit (%)	89
Plastic limit (%)	47
Plasticity index (%)	42
Shrinkage limit (%)	11
USCS soil classification	CH
Grain Size Distribution	
Clay (%)	71.5
Silt (%)	24.5
Sand (%)	4.0
Free swell index (%)	120

2) Polypropylene fiber

Polypropylene fibers have been used in the present study because they have several advantages, such as High strength, microfine reinforcement, chemically inert, non-corrosive, and availability in various lengths. For the present study, fibers with a length of 6 mm were used provided by Bajaj Reinforcements Nagpur India. The physical, chemical, and mechanical properties of PP fiber shown in Table 2 below.

Table 2 Properties of polypropylene fiber considered

Property	Value
Specific gravity	0.91
Tensile strength (kN/mm2)	0.67
Young's modulus (kN/mm2)	4.0
Melting point (°C)	165
Ignition point (°C)	600
Bulk density (kg/m3)	910
Loose density (kg/m3)	250-430
Fiber cut Length (mm)	6mm
Dispersion	Excellent
Acid & Salt Resistance	Chemical Proof

3) Silica Fume

Silica fume is a waste material for industrial applications and, due to its very active and high pozzolanic properties, the most valuable by-product of construction activities. It is a by-product of the production of metallic silicon or ferrosilicon alloys and consists mainly of amorphous silicon (SiO_2). The individual silica fume particles are extremely small, about 1/100 the size of an average cement particle. Silicon smoke is a highly reactive pozzolanic material due to its fine particles, large surface area, and high SiO_2 content. The silica fume used in the research work provided by the Sefew Tech system Indore in powder form and air-dried. The chemical composition of the silicic acid vapor is shown in Table 3

Table 3 Properties of silica fume considered

Property	Value
Density, (Mg/m3)	92.25
Silt (2–75 μm)	0.67
Clay (<2 μm)	4.0
SiO_2	99.39 %
Al_2O_3	0.08 %
Fe_2O_3	0.02%
K_2O	0.08%
CaO	0.43 %

III. Experimental Investigation

In this present study, optimum moisture content, and maximum dry density, upward swelling pressure, expansion and unconfined compressive strength of the polypropylene reinforced and unreinforced soil investigated. The polypropylene fiber at 0.25%, 0.50%, and 1.00%, and silica fume at 2.00%, 4.00% and 8.00% mixed with the expansive soil. To understand the swelling shrinkage behavior of the expansive soil the constant pressure swelling test has been conducted for the 28 days with the addition of 0.25%, 0.5%, and 1.00% polypropylene fiber and mechanical stabilizer and 2.00%, 4.00% and 8.00% silica fume as chemical stabilize. The study also explores the potential use of the combined mixes of silica fume and polypropylene fiber. The initial moisture content and dry unit weight are essential factors affecting the swelling behaviors of expansive soil [31]. Hence, the specimen was prepared at the dry unit weight (17.65 kN/m3) and optimum moisture content (19.2 %) of expansive soil. The required amount of expansive soil, polypropylene fiber, and silica fume mixes were compact statically using lightweight proctor to achieve the field conditions. In this paper, the expansive soil, polypropylene fiber, and silica fume are referred to as BC, PP, and SF, respectively.

IV. Results and Discussion

The swelling pressure is defined as the pressure to maintain the volume of specimen constant while undergoing saturation in between two successive reading. The variation of the swelling pressure with and without polypropylene fiber reinforcement is shown in Fig. 1. This depicts that the swelling pressure decreases with an increase in polypropylene fiber content and with the increment of the silica fume content. It can be observed from the Fig 5 that at 2% silica fume content the initial swelling pressure was lower than the expansive soil sample, however, before the saturation state, the 2% silica gives higher swelling pressure. The results show, the higher silica fume and polypropylene fiber content are capable of reduces the swelling pressure. As the expansive soil is a visible indicator of swelling, its reduction with the addition of PP fiber and silica fume content is noticeable, as shown in Fig. 1. The reduction can be due to polypropylene fiber and silica fume replacing the expansive soil and consequently, a reduction in the specific surface area of the swelling fraction. It also depicts that the swelling pressure of the clay and reinforced clay changes at an exponential rate till 120 minutes and thereby gradually becomes constant due to saturation. The Fig. 1 shows Combined upward swelling pressure curve of with and without reinforced expansive soil.

The reduction in upward swelling pressure was observed with the inclusion of silica fume contents. The Swelling pressure in the silica fume reinforced expansive soil was decreased with silica fume content, as shown in Fig. 1. It was also observed that the decrease in the swelling pressure occurred with rising silica fume contents, which ranged from 0% to 8%. The swelling pressure of 8% silica fume reinforced samples reduced 78 kPa to 32 kPa, which indicated the 59% reduction in the swelling pressure, as shown in Fig. 2(a). Fig 2(b) depicts that the swelling pressure decreases with an increase in polypropylene fiber content. The 4% silica fume content with 0.25 % polypropylene fiber does not show major swelling pressure for the initial 60 min and then exponential increase in the upward swelling curve as shown in Fig 2(c).

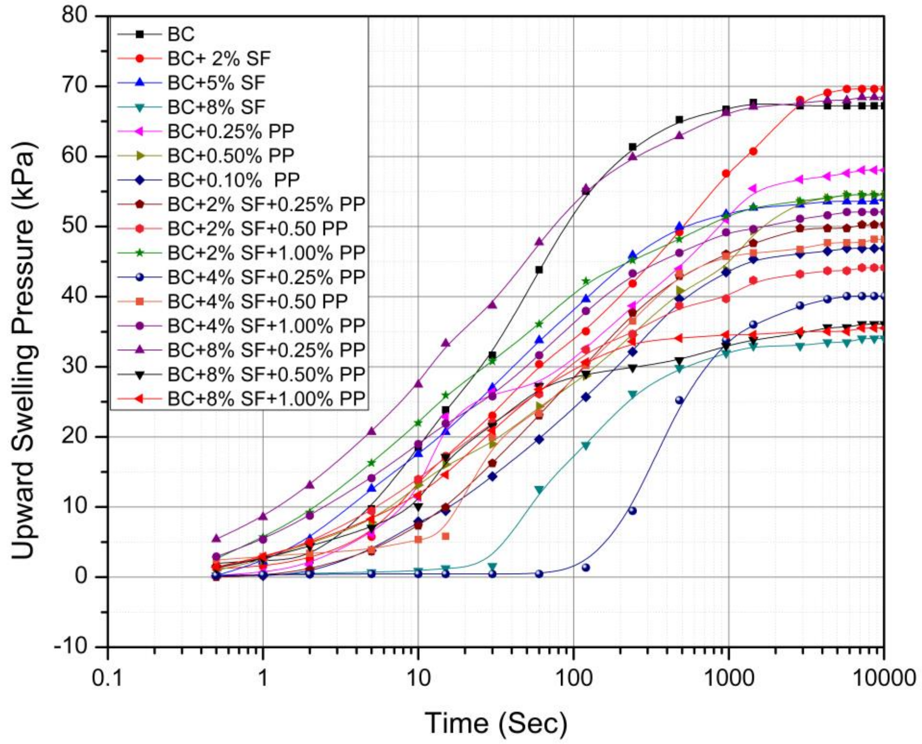

Figure 1 Combined Upward Swelling Pressure Curve of with and without reinforced expansive soil

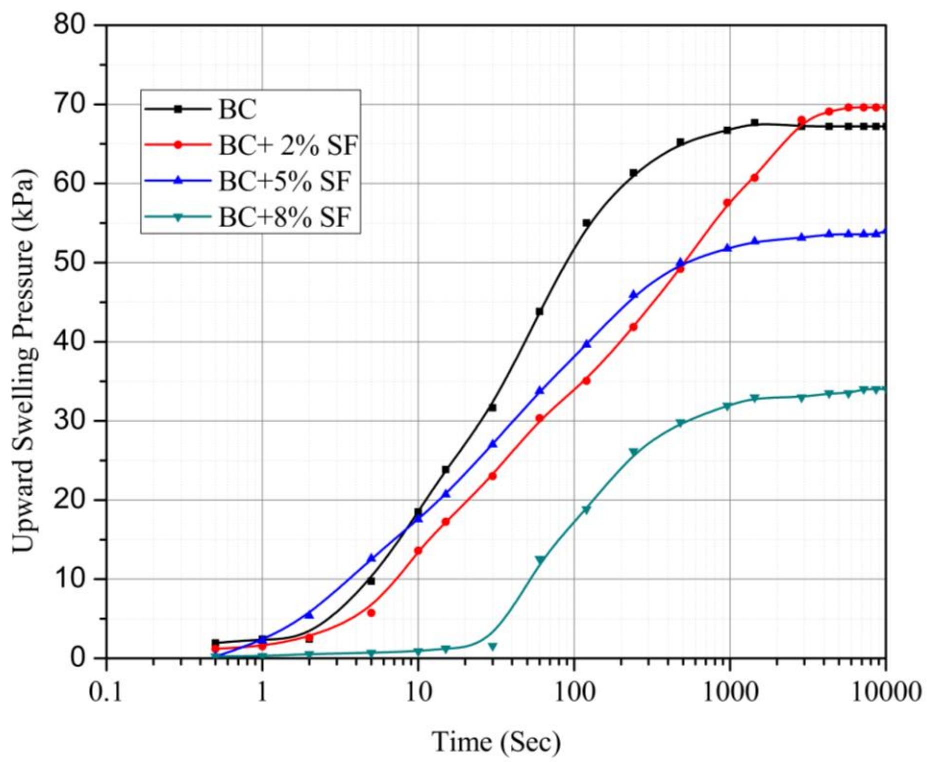

Figure 2 (a) Upward Swelling Pressure Curve for silica fume reinforced expansive soil

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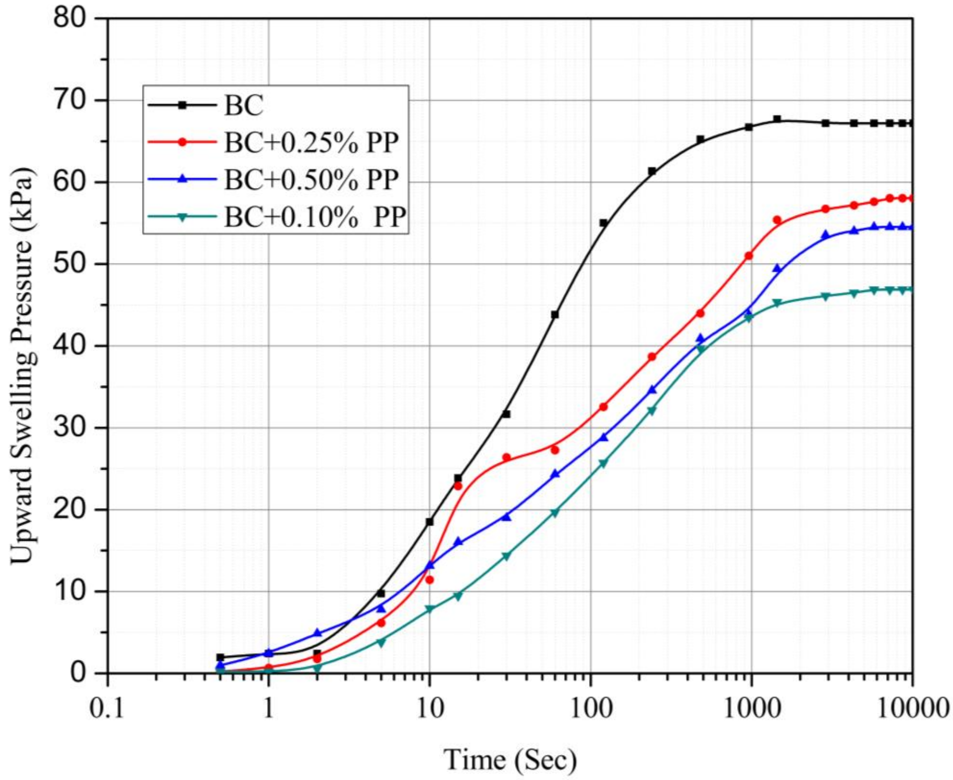

Figure 2 (b) Upward Swelling Pressure Curve for polypropylene fiber reinforced expansive soil

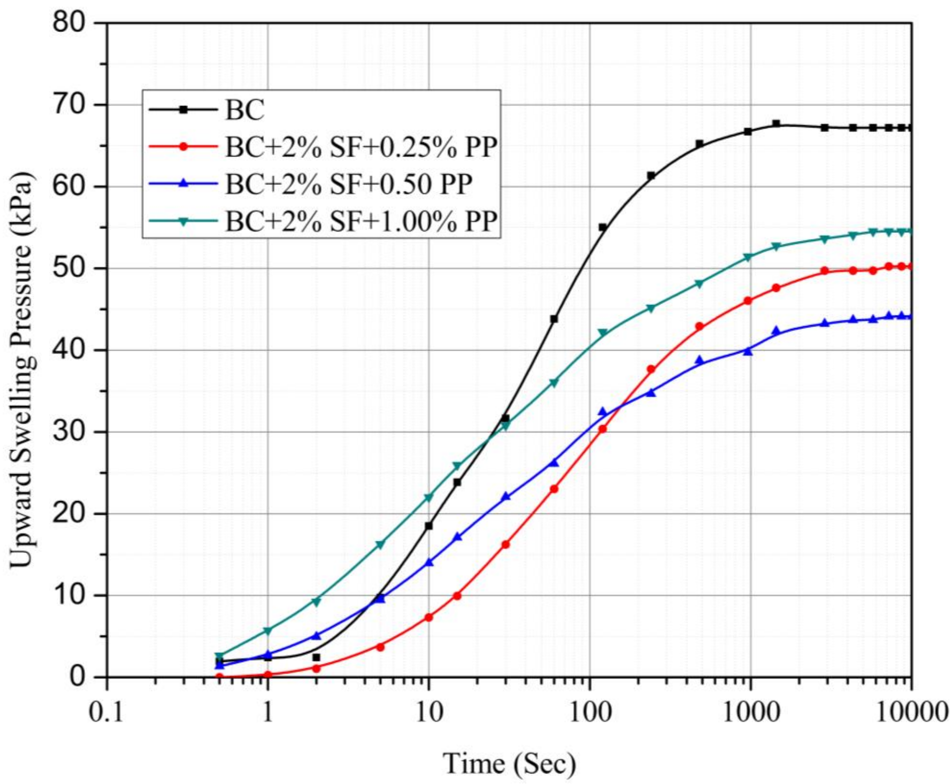

Figure 2 (c) Upward swelling pressure curve for polypropylene fiber reinforced with 2% silica fume expansive soil

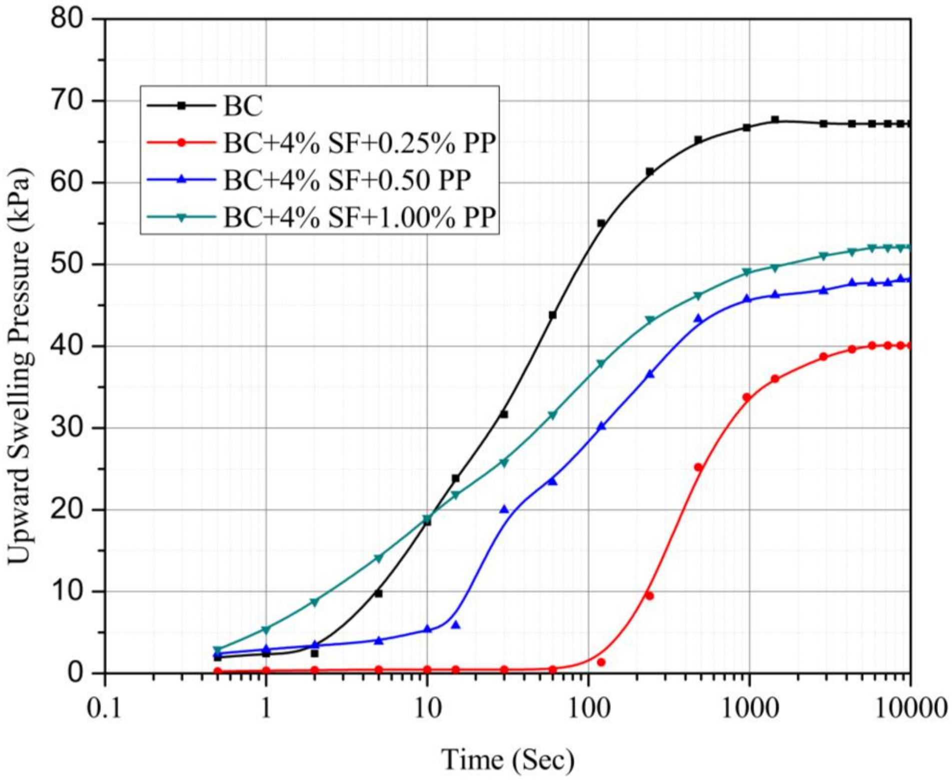

Figure 2 (d) Upward swelling pressure curve for polypropylene fiber reinforced with 4% silica fume expansive soil

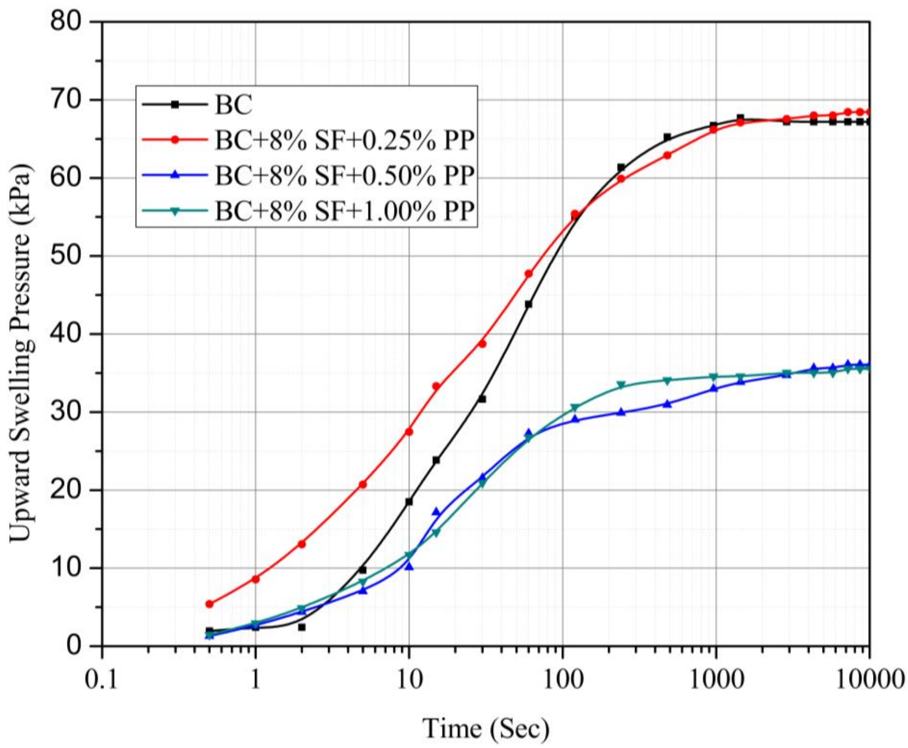

Figure 2 (e) Upward swelling pressure curve for polypropylene fiber reinforced with 8% silica fume expansive soil

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It can be ascertained that expansive soil absorbs water and upon saturation, changes in swelling ratio without pressure can be roughly divided into three stages: (1) rapid expansion period. In general, this stage will be finished in 30 min after the expansive soil absorbs water and the swelling amount accounts for about 60% - 80% of the total. (2) Slow expansion period. In this stage, the expansion rate is slow compared to rapid expansion and will be finished in about 20 hours. (3) Stable expansion period. After expansive soil absorbs water and becomes saturated, its density is less, and the space between the soil enlarges. The time taken by the water to fill the area is more, so the expansion period lasts longer. But these changes are slight low hence the curve shown in Fig. Three is relatively stable. The Fig. 3 shows a combined expansion rate curve of with and without reinforced expansive soil, which shows that the 4 % silica fume inclusion in the soil gives more expansion rate than the normal soil.   the

It has been observing that 8% silica fume and 0.50% polypropylene fiber gives very in the initial phase, as shown in Fig 4 (e). However, 4% silica fume and 1.00 polypropylene fiber exhibited more potential to reduces the expansion rate of expansive soils shown in Fig 4(d).

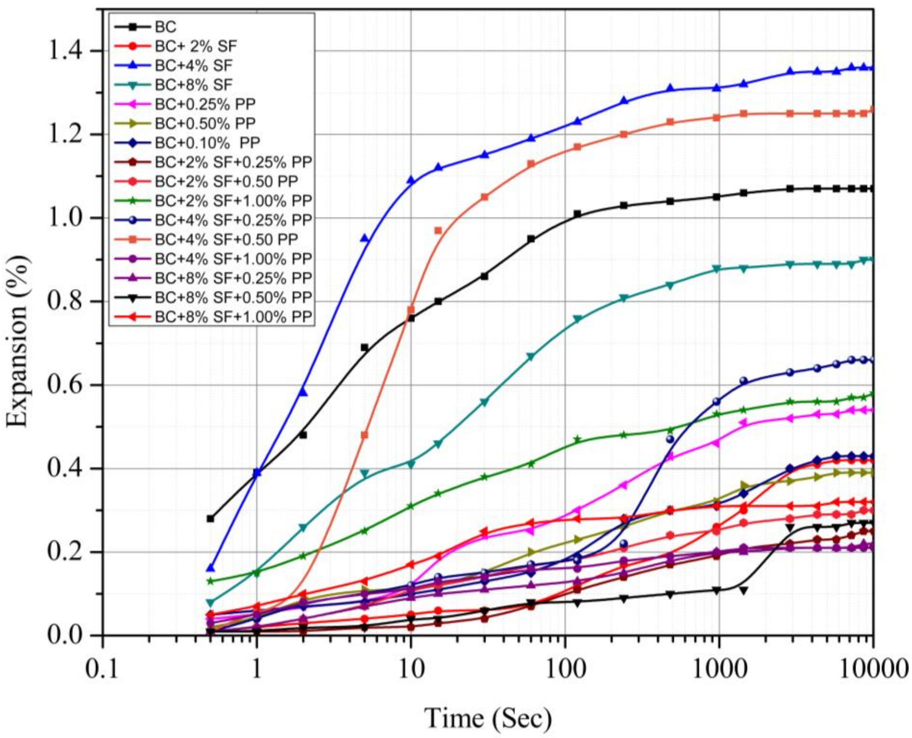

Figure. 3 Combined expansion curves of with and without reinforced expansive soil

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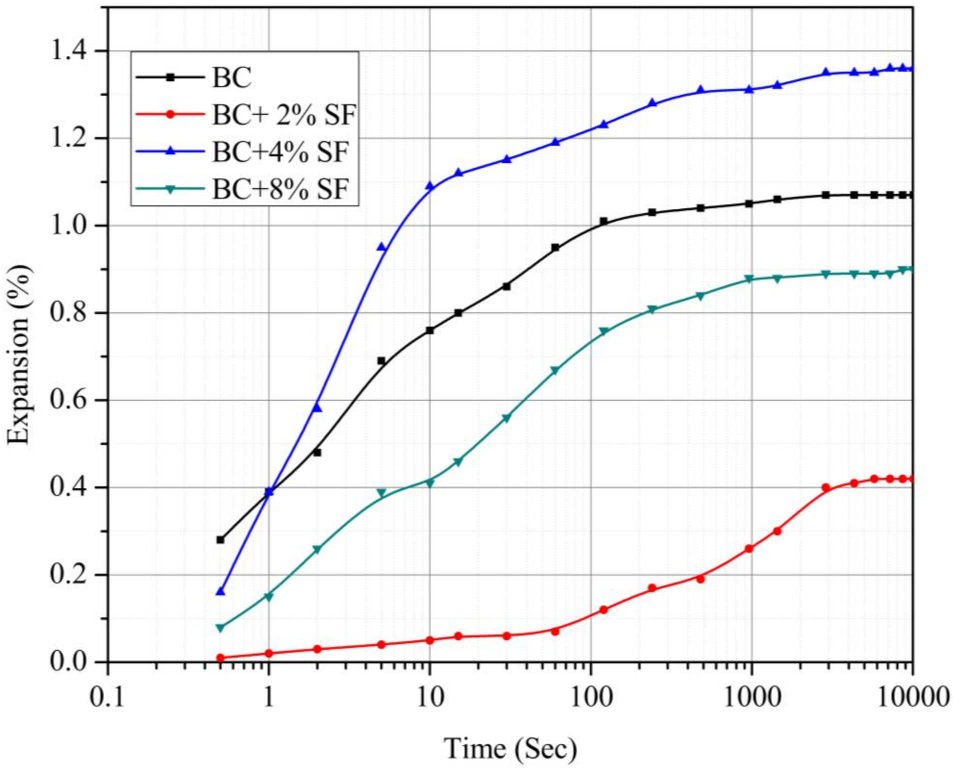

Figure. 4(a) Expansion rate curves for silica fume reinforced expansive soil

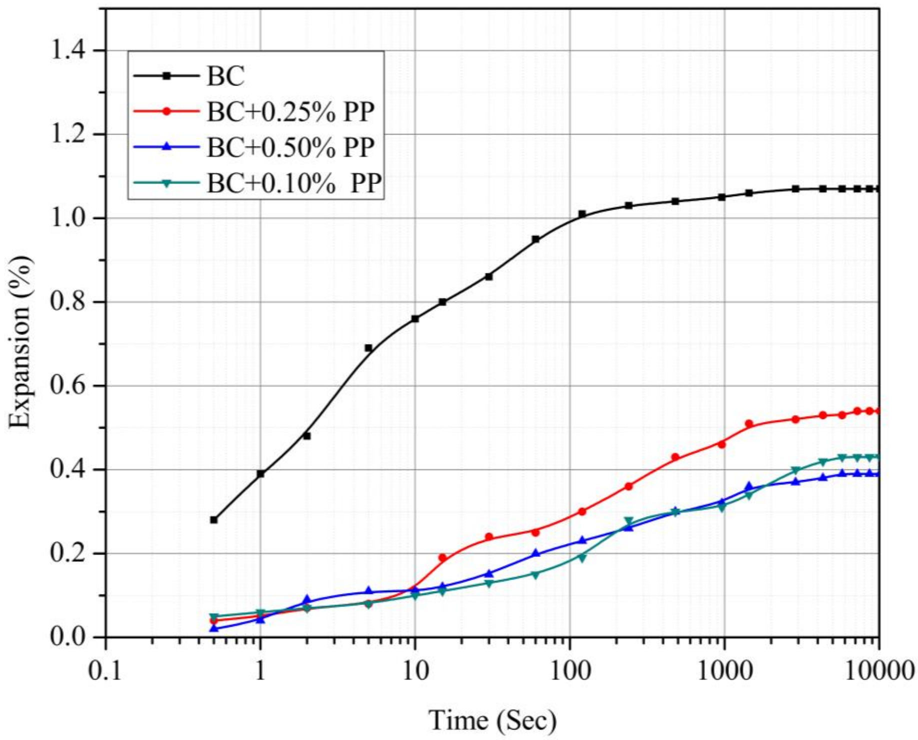

Figure 4(b) Expansion rate curve for polypropylene fiber reinforced expansive soil

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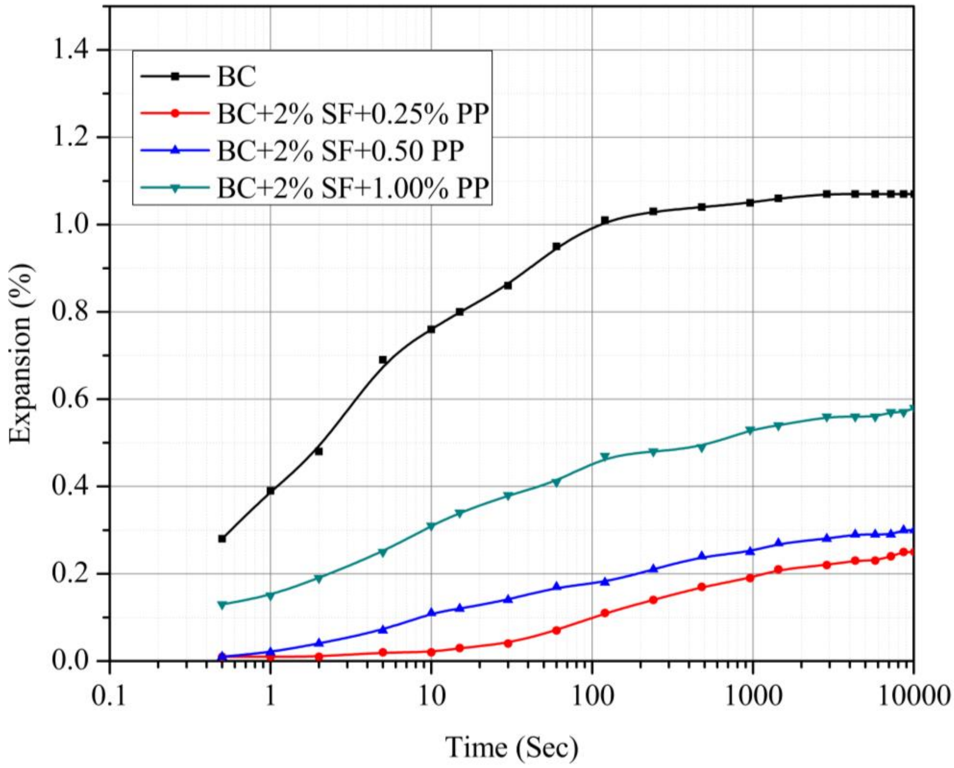

Figure. 4 (c) Expansion rate curve for polypropylene fiber reinforced with 2% silica fume expansive soil

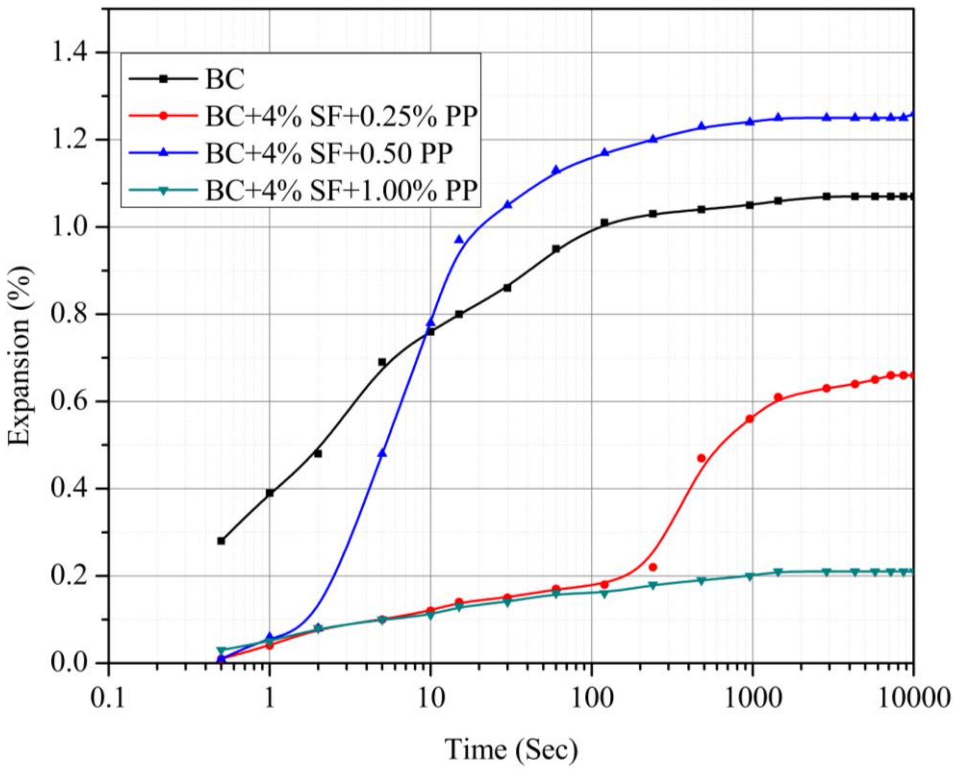

Figure. 4(d) Expansion rate curves for polypropylene fiber reinforced with 4% silica fume expansive soil.

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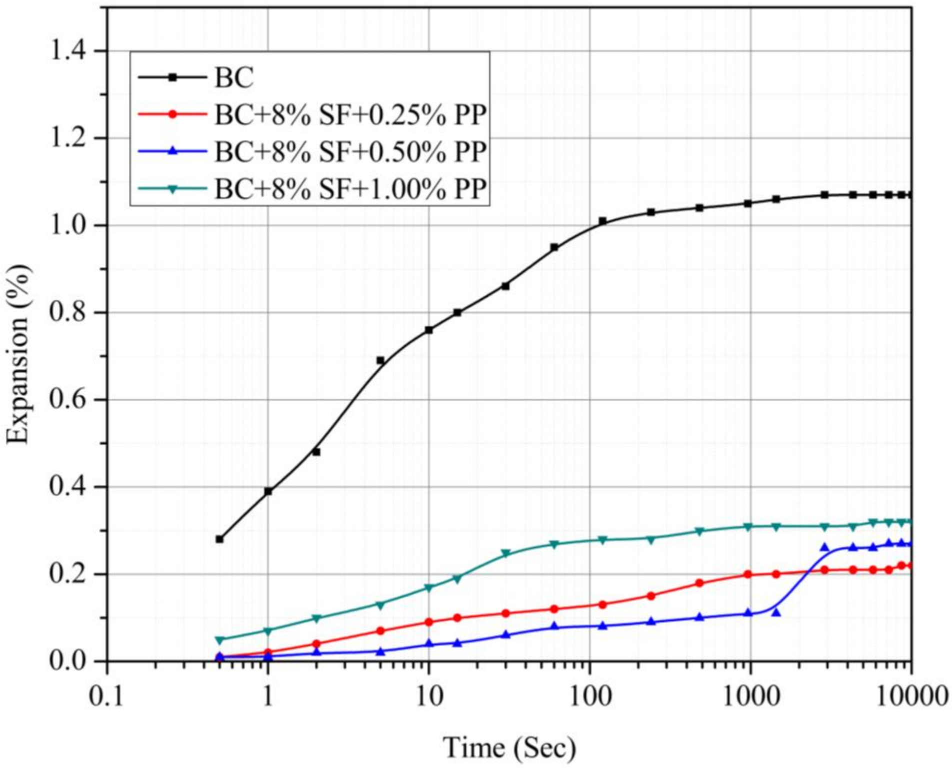

Figure. 4(e) Expansion rate curves for polypropylene fiber reinforced with 4% silica fume expansive soil.

V. CONCLUSION

The results of the study on the potential use of polypropylene fiber and silica fume to improve the behavior of expansive soil and reduce upward swelling pressure. The inclusion of silica fume and polypropylene fiber reduces the plastic index (PI) and liquid limit (LL) of expansive soil and increase the plastic limit. Due to this alteration in the property of expansive clayey soil, the soil changed its UCSC classification form high-plastic clays (CH) to low-plastic clays (OH).

A significant improvement in swelling pressure was obtained with the inclusion of silica fume content as swelling pressure decreased for all the test samples. Low swelling pressure was calculated at the 8% silica fume content with a reduction of approximately 59%. The investigation shows that the silica fume is a valuable material to modify the property of expansive clayey soil. The inclusion if silica fume content in pavement expansive soil subgrade reduces the upward swelling pressure.

The use of PP fiber shows significant improvement in the engineering properties of expansive clay soil. The reinforced soils of different percentages of PP content can be used for controlling the swelling pressure of the expansive soil subgrade. It has been observed that 0. 50% PP fiber mix exhibited an exponential reduction in the upward swelling pressure and heave. 0.50 % PPSC mix shows a 42% reduction in the swelling pressure and 73% reduction in the expansion/min, which should be used as the optimum percentage in the PP fiber for the field applications.

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