Effect of pyrophyllite on behavioural strength of clayey soil

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Abstract. The clay soil consists of minerals like montmorillonite which shrink and swell when the moisture content is altered because of which the bearing capacity of soil get decreased, which causes differential shrinkage of soil can leads to failure of super-structure. These weak soils can be stabilized by adding chemical minerals to improve its properties. The probability of stabilizing the clay soil using pyrophyllite in different proportions like 5%, 10%, 15% and 20%. Initially the compaction characteristic on adding pyrophyllite was done by standard proctor compaction test and the strength character were done based on unconfined compression test at various curing periods such as 0, 3, 7, 14 and 28th days and California bearing ratio test done on 4 and 7thdays. Compaction character test shows that on addition of pyrophyllite content, OMC increase whereas MDD decreased. UCC strength was noted after a curing period of 28 days the strength gain was maximum, the rate of development in the strength however decreased in 20% of pyrophyllite content with the soil showed the maximum strength when compared to the other percentages. Also, on adding admixture the CBR value increases, but not beyond 15% for soil sample 1 whereas CBR value increased till 20% for soil sample 2. From the results, the admixture of 15% can be selected as a nominal percentage which can be used in soil to enhance the soil character. In addition to strength parameter, these admixtures are also an eco-friendly and economical additive in soil stabilization process.

1. Introduction
Due to alternate weathering process, rock fragments break down to form clayey soil. These clayey soils generally consist of Montmorillonite mineral which expands and shrinks when moisture content is altered. In addition to this, clayey soils exhibit very soft nature in the wet-side of the optimum, which is another important drawback to be noted. In India, these clayey soils conceal nearly 20% of the total area. So, presence of these soils in the urban places and during the construction of roads becomes a serious issue and those lands cannot just be abandoned for construction activities. If it is not considered, it results in excessive damage to the structures constructed over them. In order to utilize them effectively, proper remedial measures have to be taken prior to the construction of the super structure such as deep foundation techniques, moisture control techniques, soil replacement technique, pre-wetting, surcharge loading, soil stabilization, etc, can be used. Out of these, every method has their own pros and cons. But soil stabilization is one of the techniques which alter the parameters of the soil. Therefore, any further swell and shrink in the structure of the soil can be controlled and the performance of the soil which has been stabilized could be excellent under different loading conditions. Due to this, soil stabilization is mostly adopted method to improve the characteristics of weak soil.
Several researches have been conducted on the soil with various additives and their results increased soil strength, fatigue strength and decreased swell potential etc., irrespective of clay minerals. Lime is the most commonly used and also traditional stabilizer employed to enhance the various geo-technical properties of these expansive soils. [1-3] But production of lime from Limestone involves calcinations process which occur at high temperature of about 900 to 1100 °C, with release of CO2, lime is formed [4]. This released carbon di-oxide would have a considerable impact on the environment with energy loss for heating them [5]. Also, the major problem faced is lack of calcium-based minerals and over usage of particular deposits could lead to depletion of the resources.

In order to overcome this, various other materials were introduced to soil partially with lime such as Fly-ash, GGBS, RHA [6-8], Phospho-Gypsum etc, to strength it and to decrease their swell shrink behaviour. Several studies confirmed their strength increases on addition of these materials. Several combinations of these effluents with lime and cement usage of Fly-ash with RHA with cement and fly-ash, on adding marble dust with Rice Husk Ash, [9-12] Class-F Pond ash alone with Lime and Phospho-Gypsum, etc., have been studied by many authors. But there are in adequate number of studies available which considered the environmental effects of using these effluents and, those studies were only concentrated on a particular heavy metal [13-14].So, in order to utilize these additives effectively, their interaction with the environmental becomes a serious concern such as depletion of ground water, soil contamination etc, because of their presence of toxic heavy metals.

From all the previous studies these chemicals either contaminate the ground water table or their carbon dioxide emission levels are high. It is a major issue for the engineers to adopt a method which is both economical and eco-friendly. These shortfalls could be overcome by the usage of non-calcium-based minerals in stabilizing the soil. These non-calcium-based minerals are cheaply available when compared to primitive additives and the availability of these minerals would overpower the calcium based minerals. Summations to this, these minerals are also eco-friendly which doesn’t pollute the ground water table. So, to utilize the natural mineral deposits effectively, a study is conducted using pyrophylite for their effective usage in the fields to strengthen the clayey soil. Here in this study, compaction characteristics and strength properties are studied in soil treated with pyrophylite to examine the optimum percentage of the additive with the soil.

2. Materials and methods
The two soil samples were choosing to analyse the effect of admixture. The soil sample 1 (S1) in this research was collected around Uthiramerur, Kancheepuram at a depth of 1m where eight-way road from Chennai to Salem is proposed to be constructed. The soil sample 2 (S2) was collected at Chembarambakam near NH-48 where the growth of the city is more due to the increased rate of migration towards urban regions. These soil sample collected were dried, pulverized and then mixed thoroughly for the uniform mixture of soil [15-17]. The soil sample 1 and 2 consisted of about 94% and 97% silt and clay respectively. Specific gravity of the sample was tested in abidance with IS 2720-Part III [18]. Both the soil samples collected have been classified as clayey soil having High Compressibility (CH) derived from Atterberg’s Limit test results as per IS: 2720-Part V [19-20]. Free Swell Index, standard proctor compaction characteristics tests, unconfined compressive strength of the soil, CBR of the soil were tested in accordance with IS: 2720 – Part XL, IS:2720 (Part-VII), IS:2720 (Part-X) and IS: 2720 (Part–XVII) [21-24] correspondingly and the outcomes are revealed in the Table 1. To enhance the various properties of clayey soil, the admixture used here is pyrophylite (P). This mineral is naturally occurring deposits and count about 23.27 million tonnes in India [25].

3. Test methods
The light weight standard proctor compaction characteristics test was done in accordance with BIS[21]. Various percentage of pyrophylite such as 5, 10, 15 and 20% were added with the soil, mixed thoroughly with the water. To measure the water content, minimum of 100 grams were weighed in order to minimize the errors. The maximum dry density achieved and their corresponding optimum moisture content during this compaction test was used to prepare both UCC and CBR samples.
Based on the compaction characteristics test results UCC samples were prepared confirming to BIS [22]. In order to examine the effect of curing on the samples, these tests have been carried out at different curing periods such as 0, 3, 7, 14, 28, 60 days on varying percentage of pyrophyllite such as 5, 10, 15, and 20. Minimum of three samples were casted in order to minimize natural errors. The test setup consisted of a loading frame with a load cell of 5kN capacity and an LVDT of maximum tolerance 30mm to measure displacements occurred in the sample. Also, one of the most significant parameters for quantifying the strength of the Sub-Base soil is CBR Value. The soil samples were also casted based on the compaction characteristics test and proper care was taken while casting and curing the CBR samples as per the BIS[23]. A loading frame of 50kN capacity was used to measure the load applied with the penetration rate of 1.25 mm/min and an LVDT with maximum displacement capacity of 30 mm to measure the penetration of the plunger. Surcharge pressure of 2.5 kPa (i.e., 0.36 psi) was applied on the samples while curing and testing the samples are given in Table 1.

| Property          | S1   | S2   |
|-------------------|------|------|
| SG                | 2.53 | 2.58 |
| FSI (%)           | 61.50| 83.33|
| Liquid Limit (%)  | 54.60| 61.00|
| Plastic Limit (%) | 29.30| 33.33|
| Shrinkage Limit (%)| 8.70 | 8.05 |
| MDD (g/cc)        | 1.47 | 1.44 |
| OMC (%)           | 21.20| 22.8 |
| UCC Strength (kPa)| 93.10| 81.29|
| CBR Value (%)     | 2.16 | 3.20 |

4. Experimental methods

4.1. Standard Proctor compaction test

| Percentage of admixture | Compaction characteristics test |
|-------------------------|---------------------------------|
|                         | Soil sample 1 | Soil sample 2 |
|                         | OMC (%)       | MDD (g/cc)    | OMC (%)       | MDD (g/cc)    |
| S+ 0% P                 | 21.2          | 1.47          | 22.8          | 1.44          |
| S + 5% P                | 21.5          | 1.45          | 23             | 1.432         |
| S + 10% P               | 22            | 1.439         | 23.4           | 1.422         |
| S + 15% P               | 22.75         | 1.43          | 24             | 1.41          |
| S + 20% P               | 23.3          | 1.412         | 24.5           | 1.39          |

From the compaction characteristics tests the proctor compaction curves were plotted for S1 and S2 as represented in the Figure 1 and 2and it was inferred that addition of pyrophyllite content increases the OMC, but decreases the MDD and the results is as shown in the Table 2. In the view of compaction test results, the increase in the OMC can possibly be due to the reaction of the admixture with the soil.
and the decrease in the MDD can probably be due to the exchange process between the admixture and the clayey soil, which reduces the diffuse double layer thickness leading to decrease in MDD 26.

Figure 1. Compaction characteristics curve of pyrophyllite treated soil sample 1.

Figure 2. Compaction characteristics curve of pyrophyllite treated soil sample 2.

4.2. Unconfined Compressive Strength Test
The stress-strain relationships from unconfined strength test are graphically represented in the Figure3 and 4 for the soil sample 1 and 2 respectively. From the test results, it is inferred that the increase in the pyrophyllite content with soil increases the unconfined compressive strength and the soil attains maximum strength when adding 20% of pyrophyllite with the soil. Curing the samples played a noteworthy role in intensifying the UCC strength.
Figure 3. Stress - Strain characteristics of soil sample 1 treated by means of pyrophyllite at 28 days curing periods.

Figure 4. Stress - Strain characteristics of soil sample 2 treated with pyrophyllite at 28 days curing periods.

An increase of UCS values were observed in the soil sample 1 from 113.61 kPa to 154.55 kPa for soil with 20% admixture and an increase from 104.1 kPa to 144.26 kPa when adding 15% of admixture with the soil with an increase of 0 to 28 days curing as represented in the Figure 5. Similarly, with the increase in pyrophyllite content with soil sample 2 increased the UCS value from 140.8 kPa to 253 kPa when adding 20%, 133.93kPa to 231kPa after adding 15% of pyrophyllite from curing the samples from day 0 to day 28 as represented in the Figure 6. The overall UCS value obtained for the soil samples treated with pyrophyllite is tabulated in the Table 3.
Table 3. UCS value of pyrophyllite treated S1 and S2 at diverse curing periods.

| Percentage of admixture | Unconfined Compressive Strength (kPa) |
|-------------------------|--------------------------------------|
|                         | Curing Periods (days)                |
|                         | 0 days | 3 days | 7 days | 14 days | 28 days |
| S1+0%P                  | 93     | -      | -      | -       | -       |
| S1+5%P                  | 95     | 98     | 106    | 113     | 122     |
| S1+10%P                 | 99     | 112    | 116    | 128     | 133     |
| S1+15%P                 | 104    | 116    | 130    | 141     | 144     |
| S1+20%P                 | 113    | 135    | 143    | 149     | 154     |
| S2+0%P                  | 81     | -      | -      | -       | -       |
| S2+5%P                  | 108    | 115    | 125    | 135     | 142     |
| S2+10%P                 | 114    | 133    | 152    | 178     | 189     |
| S2+15%P                 | 133    | 154    | 179    | 219     | 231     |
| S2+20%P                 | 140    | 169    | 202    | 234     | 253     |

Figure 5. UCC values of soil sample 1 by means of varying percentages of pyrophyllite at diverse curing periods.
Figure 6. UCC values of soil sample 2 by means of variable percentages of pyrophyllite at diverse curing periods.

4.3. California Bearing Ratio Test
Load vs. Penetration results after curing of 7 days is shown in the Figure 7 and 8 for soil sample 1 and 2 respectively. The results showed that with upsurge in the pyrophyllite content in the soil increased CBR value up to 15% pyrophyllite, then the value started to decrease for soil with 20% pyrophyllite for the soil sample 1. And as the soil sample 2 is concerned, the CBR value keeps increasing up to 20% but the rate of increase in the value decreased. Curing had a substantial impact on the CBR values of treated soils and it is shown in the Table 4.

Figure 7. Load – Penetration characteristics for soil sample 1 with pyrophyllite of variable percentages at 7-day curing.
Figure 8. Load – Penetration characteristics for soil sample 2 with pyrophyllite of variable percentages at 7-day curing.

Table 4. CBR values of treated soil samples.

| Percentage of admixture     | California Bearing Ratio (CBR) % |
|-----------------------------|----------------------------------|
|                             | Sample 1                          | Sample 2                          |
|                             | 4 days  | 7 days  | 4 days  | 7 days  |
| Soil + 5% Pyrophyllite      | 2.2     | 4.8     | 3.72    | 4.24    |
| Soil + 10% Pyrophyllite     | 2.40    | 5.21    | 4.17    | 4.84    |
| Soil + 15% Pyrophyllite     | 4.20    | 6.03    | 5.36    | 6.85    |
| Soil + 20% Pyrophyllite     | 4.10    | 5.44    | 6.69    | 8.56    |
Influence of the Admixture on CBR values of treated sample with un-treated CBR values were calculated as influence factor as per the following relationship 1 given below. The variation of Influence factor for the soil samples S1 and S2 are represented in the Figure 9 and 10 respectively.

\[
\text{Influence of Admixture} = \frac{\text{CBR Value of Treated Soil}}{\text{CBR Value of Untreated Soil}} \quad (1)
\]

These results reveal the effectiveness of upsurge in the strength on adding the pyrophyllite with the soil. On the addition of the pyrophyllite with different soil sample shown an increase in strength and it was inferred that 15% of the admixture resulted the maximum rate of gain.

5. Conclusion

From the above results as discussed earlier the following conclusions were drawn and are as follows. With the pyrophyllite content with the soil, the MDD of the soil declines whereas the OMC rises irrespective of the soil samples collected. Even though being decreased in the MDD, studies shows that this particular property would possibly contribute to the upsurges in the strength of the soil because of the decreased DDL thickness and the increase in the cat-ion exchange capacity between the soil and pyrophyllite added. On adding the pyrophyllite with soil, unconfined compressive strength increases nearly 253.1kPa from 83kPa when compared to the virgin soil sample 2, given that the soil samples are cured at the proper intervals. Similarly, a marginal increase was encountered on the soil sample 1. CBR value increased approximately 2 to 3-fold by adding pyrophyllite with the soil samples collected. It to be noted that at 20% of pyrophyllite with the soil the value started to decrease, but not less than the virgin soil in soil sample 1, where as the soil sample 2 the rate at which CBR value started to increase decreased. Thus, from the above observations it can be concluded that pyrophyllite can also be used as an effective stabilizer to stabilize soil instead of Calcium based admixtures. Also, this would be cost effective and eco-friendly technique additive for enhancing the behaviour of the soil.

6. References
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