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Potential of Portland pozzolana cement in the stabilization of an expansive soil subjected to alternate cycles of wetting and drying

Jijo James[*1)], Anupriya Natesan[1)], Aswini Manohar[1)], Vishvaa Subramanian[1)]

[1)] *Sri Sivasubramaniya Nadar College of Engineering, Rajiv Gandhi Salai, Kalavakkam – 603 110, Tamil Nadu, India*

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ABSTRACT
Cement/lime stabilization of soils is one of the common techniques adopted for improving its geotechnical properties. Lately, the focus of investigation has shifted to blended stabilization with industrial wastes as auxiliary additives. However, the role of blended cement in stabilization of soil has been studied insufficiently despite the fact that it is manufactured under controlled conditions. This investigation deals with the use of Portland pozzolana cement (PPC) instead of ordinary Portland cement (OPC) in the stabilization of an expansive soil subjected to alternate cycles of wetting and drying. Unconfined compression strength (UCS) test specimens of dimensions 38mm x 76mm were cast and cured for periods of 7, 14 and 21 days. Then, the specimens were subjected to 1, 2 and 3 cycles of wetting and drying and the UCS of the specimens were determined. Based on the results of the investigation, it was found that OPC performed significantly better than PPC under normal conditions. However, under conditions of wetting and drying, PPC stabilized soil performed much better than OPC stabilized soil when sufficient binder content was available.

1 Introduction

Expansive soils are well known for their detrimental volume change behaviour and the resulting effects on structures built on them. They are especially dangerous to lightly loaded structures due to the immense swell pressure generated by such soils when they imbibe moisture. Stabilization of such soils have been practiced for quite a while now to mitigate their devastating effects on the structures built on them. The most commonly adopted stabilization technique for such soils is chemical stabilization using either lime or cement. Cement stabilization, however, is not that effective in the case of extremely plastic swelling clays [1]. The use of industrial wastes as auxiliary additives to cement for improving its potential is well documented [2]. But it is a well-known fact that manufacture of cement has a very heavy carbon footprint. There has been extensive research in reducing this carbon footprint of cement use in the construction industry and soil engineering with no exception. The potential ways available are (1) Development of an alternative binder to cement (2) Partial replacement of cement with supplementary cementitious materials/pozzolans. There has been few studies going in the development of an alternative binder [3]–[6]. But the mainstream popularity of ordinary Portland cement (OPC) is yet to be challenged. On the other hand, partial replacement of cement seems to be rather successful with several materials identified for replacement. This partial replacement can be achieved at two levels. One, at the manufacturing stage where the part of the raw materials is replaced to develop blended cements. Two, at the application stage, when a part of the cement content for the required application is replaced with supplementary materials. In the area of soil stabilization, the latter method of partial replacement of cement with supplementary materials especially solid wastes is quite popular. The former technique of blended cements like Portland pozzolana cement and Portland slag cement have slowly started to gain acceptance, especially in the area of concrete technology. However, in the field of soil stabilization, use of blended cements in stabilization has not become as popular as the use of Portland cement. This, despite the fact that partial replacement of cement with supplementary materials at the field level has been as successful as in soil stabilization. A sift through literature reveals the fact that there have not been that many investigations involving use of Portland pozzolana cement (PPC) in the stabilization of soil. Patowary et al. [7] investigated the use of PPC in the development of

[*] Corresponding author:
E-mail address: jijothegreat@gmail.com

stabilized soil blocks. Patel et al. [8] investigated the bearing performance of PPC stabilized soil. Barman and Das [9] investigated the performance of two different types of soils stabilized with PPC. Cassiophea [10] investigated the combination of PPC and dolomite in stabilization of a clayey subgrade. Patel et al. [11] investigated the effects of variable dynamic compaction on the PPC stabilization of clayey soil. The available literature on stabilization of soils predominantly focusses on OPC rather than PPC. The few investigations carried out on PPC look into the fundamental properties of the stabilized soils. There exists a need to investigate the potential of PPC in soil stabilization for varying conditions of durability which are encountered in the field. Thus, this investigation attempts to evaluate the potential of PPC in stabilization of an expansive soil and compare it with the performance of OPC under normal conditions as well as conditions of alternate wetting and drying.

2 Materials

Soil deposited near a lake in Thaiyur in Kalavakkam, Tamil Nadu, was collected and characterized in the laboratory for its geotechnical properties. Table 1 shows the various properties of the soil as determined in the laboratory based on various codes of the Bureau of Indian Standards (BIS). The maximum size of the soil particles was not greater than 2 mm. In fact, 97% of the soil was finer than 75-micron sieve as seen from Table 1. The cements used in this investigation where commercially available OPC and PPC.

Table 1. Properties of the soil

Property	Value
Liquid limit [12]	67%
Plastic limit [12]	20.7%
Plasticity index	40.7%
Sand Content [13]	3%
Silt Content [13]	28%
Clay Content [13]	69%
Specific gravity [14]	2.67
Optimum moisture content [15]	18%
Maximum dry density [15]	16.30 kN/m^3
Unconfined compressive strength (UCS) [16]	103 kpa
Classification [17]	CH

3 Methods

The experimental methodology adopted in this investigation consisted of the following stages.

3.1 Preparation and characterization of soil

The soil sample collected from near the lake was brought to the lab and prepared for experimentation based on the procedure stated in BIS code [18]. This was followed by the geotechnical characterization of the soil in the laboratory for determination of its various properties and classification of the soil.

3.2 Selection of stabilizer content

Two trial cement contents for stabilization of the soil were fixed. The cement contents fixed were the same for both OPC and PPC for a one-to-one comparison of the results. Soil cement usually contains less than 5% cement content [1]. Thus, two contents, one below and the other above 5% were selected for the investigation. In this investigation, the contents selected were 2.5% and 7.5%.

3.3 Determination of compaction characteristics

The soil stabilized with 2.5% and 7.5% contents of OPC and PPC separately were subjected to compaction tests using the mini compaction apparatus [15], in accordance with the procedure laid down in BIS code [19] for stabilized soils.The mini compaction mould is a circular mould of 3.81 cm internal diameter and height of 10 cm with a 3.50 cm removable collar. The total volume of the mould is 114 cm^3. The hammer has a height of 3.5 cm, weighs 1 kg and falls freely over a foot in contact with the soil over a height of 16 cm. 200 g of soil finer than 2 mm was taken for the test and compacted in three layers with 36 blows per layer to replicate the standard proctor test. The test was repeated for different water contents to identify the maximum dry density (MDD) and optimum moisture content (OMC) for achieving the MDD. This was done to determine the MDD and OMC values of the stabilized samples for preparing UCS specimens. BIS code [19] recommends that in the case of compaction tests for stabilized soils, separate soil samples mixed with the stabilizer with increasing water content be used for each of the trials of the compaction test instead of increasing the water content in the same soil sample as done conventionally.

3.4 Preparation and curing of specimens

UCS specimens of dimensions 38 mm x 76 mm were prepared at their MDD and OMC values by static compaction. Then, the specimens were demoulded and immediately packed in a sealable polythene cover for curing for a period of 0 (2 hours), 7, 14 and 21 days. Three samples were cast for each combination. At the end of the period of curing, the samples were strained at a rate of 0.625mm/min until shear failure to evaluate the UCS.

3.5 Simulation of wetting and drying

Separate samples were cast for simulation of wetting and drying. The samples were cured for a period of 21 days before subjecting them to cycles of wetting and drying. The samples were placed in a bed of soaking wet cotton and then covered by another layer of soaking wet cotton to simulate the wetting cycle for a period of 24 hours. Care was taken to ensure that the bed of cotton stayed wet throughout the duration of the wetting cycle. This was followed by 24 hours in open air at room temperature which constituted one cycle of drying. Similar procedure has already been reported in literature [20], [21]. The samples were subjected to 1, 2 and

3 cycles of wetting and drying. This was followed by UCS testing to evaluate the effect of wetting and drying cycles on the strength.

4 Results and discussion

The results of the investigation involving the stabilization of an expansive soil under normal as well extreme conditions using OPC and PPC is discussed in the following sub sections.The compaction characteristics of the stabilized soil were determined to prepare the UCS samples. Table 2 gives the compaction characteristics of the OPC and PPC stabilized soil specimens.

Table 2. Compaction characteristics of the stabilized specimens

Combination	MDD (kN/m^3)	OMC (%)
2.5% OPC	15.59	25.5
2.5% PPC	15.62	29.5
7.5% OPC	16.43	21
7.5% PPC	15.44	27.5

4.1 Strength of OPC and PPC stabilized soil

Figure 1 shows the development of the strength of OPC and PPC stabilized soil with increase in curing period. From the figure, it can be seen that the strength of 2.5% PPC stabilized soil after 21 days of curing was 186 kPa, up from 103 kPa for pure expansive soil. However, on stabilization using 7.5% PPC, the achieved strength was 700 kPa, which was a significant improvement. When the expansive soil was stabilized with 2.5% OPC, the strength was 386 kPa after 21 days of curing, which is more than half of what was obtained using 7.5% PPC. When the soil was stabilized using 7.5% OPC, the achieved strength after 21 days of curing was 1652 kPa, which was more than double of what was achieved by the same content of PPC. Barman and Das [9] reported a strength of 119.54 kPa and 209.85 kPa for 2% and 8% PPC stabilized clayey soil after 28 days of curing whereas James and Pandian [22] report very high early strengths of more than 2000 kPa for 2% and 3% OPC stabilization. Thus, it is clear that the strength of the stabilized soil is the lowest for 2.5% PPC stabilization and rises with the increase in the binder content to 7.5% PPC. Comparing OPC and PPC stabilization, the strengths developed by OPC was more than twice that of PPC for both the stabilizer contents. Thus, it is obvious that under normal conditions, OPC stabilization of expansive soil is much better when compared to PPC stabilization, irrespective of the binder content

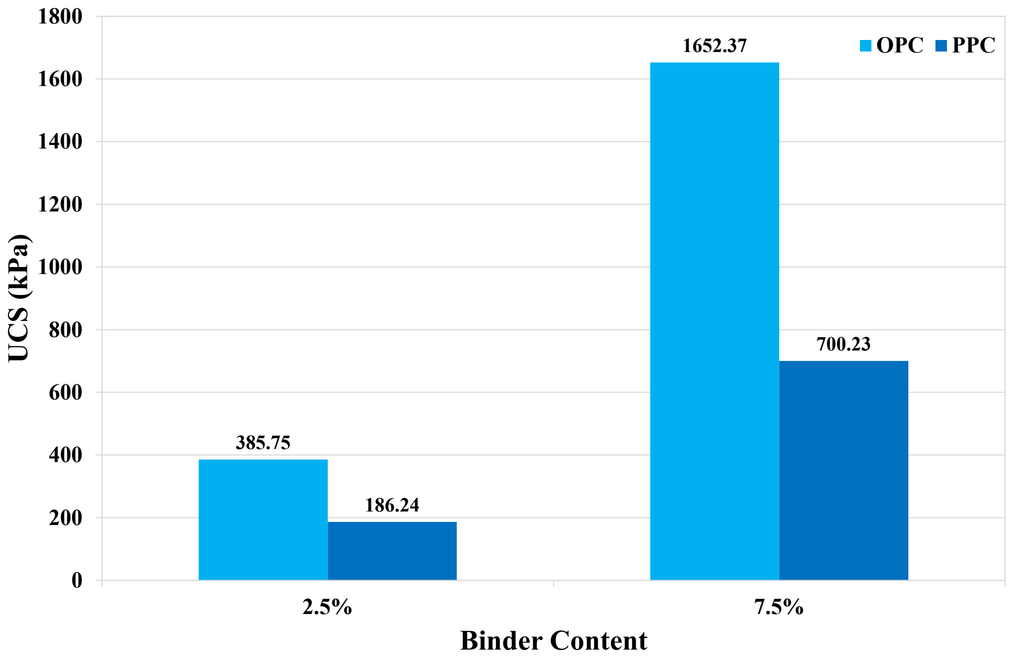

Figure 1. Strength of OPC and PPC stabilized soil at 21 days of curing

Figure 2 shows the development of the strength of the stabilized soil with curing period. From the figure, it can be seen that strength increases with curing which is a well-established fact. It can also be seen that the trends of development have good correlation with the actual data as seen from the R^2 values. However, it can be seen that development of the strength of PPC and OPC is significantly different at higher binder content. The strength development of OPC at higher binder content is significantly better when compared to PPC. At lower binder contents, the strength development seems to be similar superficially with strength gain being more or less flat when compared to stabilization at higher binder content. In order to understand this better, an analysis of the rate of strength gain of all the four combinations was done. The entire range of curing was divided into three stages viz. from 0 -7 days, 7 – 14 days and 14 – 21 days. The rate of strength gain was determined by obtaining the slope of the curve between the boundaries of each stage. A similar analysis was performed earlier by Naveena et al. [23].

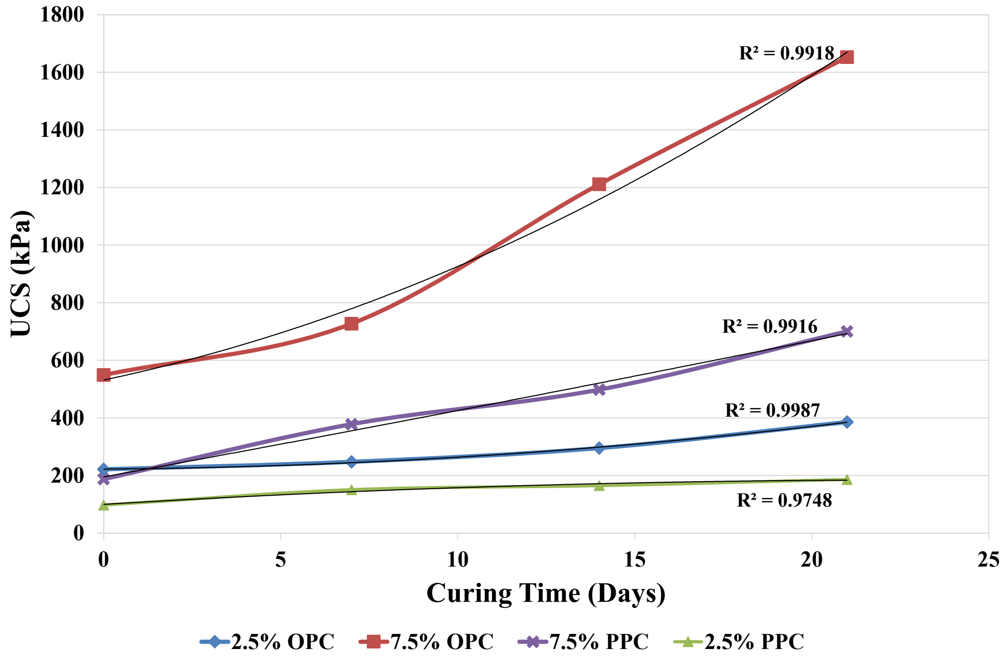

Figure 2. Development of the strength of OPC and PPC stabilized soil with curing

Figure 3 shows the rate of the strength gain for all the four combinations.To determine the strength rate gain of 7 days, the 0 day strength of all samples were determined at 2 hours of curing based on earlier literature [24], [25].

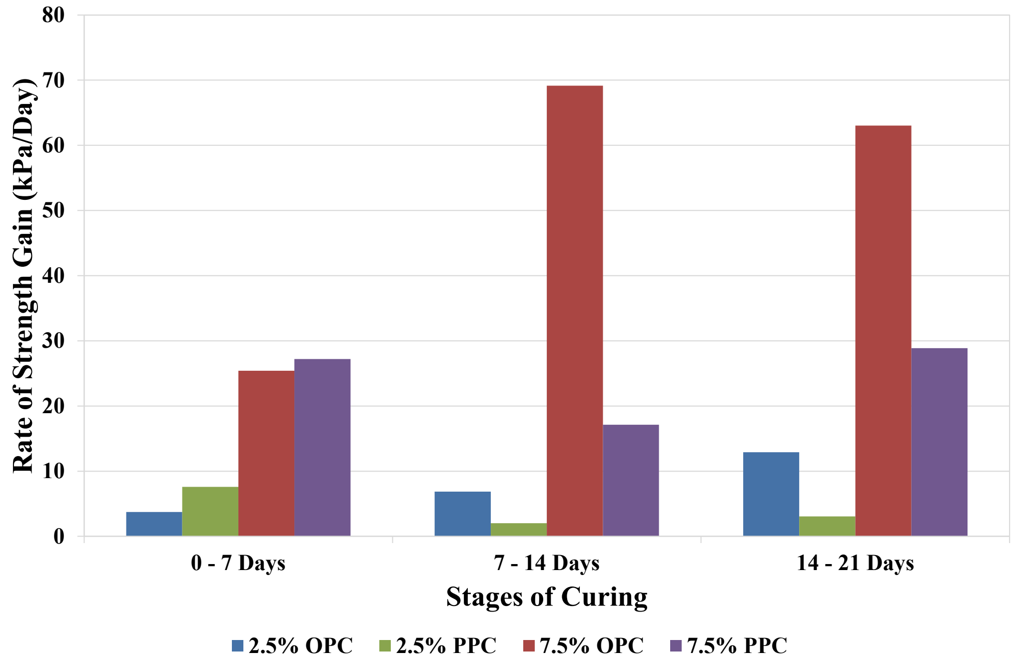

Figure 3. Rate of strength gain with curing period for OPC and PPC stabilized soil

Comparing the binder content, the rate of strength gain of PPC at lower binder content of 2.5% is 7.6 kPa/day which is double that of 2.5% OPC stabilized soil at 3.73 kPa/day. It can be seen that PPC performs better in early curing period when compared to OPC, however, it should be noted that the absolute strength of OPC stabilized soil is still higher than PPC stabilized soil at 7 days. This may be due to the higher strength developed by OPC stabilized soil at 2 hours curing when compared to PPC stabilized soil. Despite the slower rate of strength gain in the early stage, the higher starting strength of OPC stabilized soil results in the strength of OPC stabilized soil staying higher than PPC stabilized soil. However, when the binder content is increased to 7.5%, the strength gain rate of PPC and OPC stabilized soils are 27.22 and 25.42 kPa/day, respectively. Thus, at higher binder content, there is only a small difference in the strength gain rate, with the absolute strength values of OPC stabilized soil significantly higher than PPC stabilized soil. When curing time is increased, the strength development of OPC stabilized soil is significantly better than PPC stabilized soil during the second and third stage of curing, making up for the slow rate of strength gain in early curing. A similar trend was reported by Naveena et al. [23] where the rate of strength gain was 7.94 kPa/day during the first seven days when the cement content was 3%. However, when cement content was increased to 9%, the rate of strength gain increased to 93.4 kPa/day in the first seven days. The trends of strength gain rates of PPC and OPC stabilization are quite the opposite. The strength gain rates of OPC stabilization is maximum in stage 2 whereas in the case of PPC stabilization it is the lowest of the three stages. Table 3 gives the results of UCS of all combinations of stabilized soil specimens.

Table 3. Average UCS of all combinations for different curing periods and cycles

Curing	UCS (kPa)			
	2.5% OPC	2.5% PPC	7.5% OPC	7.5% PPC
0 Days	221.41	97.54	548.99	187.59
7 Days	247.51	150.71	726.97	378.17
14 Days	295.43	164.79	1211.07	498.11
21 Days + No Cycle	385.75	186.24	1652.37	700.23
21 Days + 1 Cycle	402.76	176.82	2330.34	1104
21 Days + 2 Cycles	446.9	291.43	1579.16	1664.34
21 Days + 3 Cycles	451	300.13	1590.95	1839.18

4.2 Durability of OPC and PPC stabilized soil

The durability of OPC and PPC stabilized soil was determined by subjecting the samples to alternate cycles of wetting and drying. Figure 4 shows the durability of OPC and PPC stabilized soil subjected to 1, 2 and 3 cycles of wetting and drying. From the figure, it can be seen that the performance of both OPC and PPC stabilized soil is similar at lower binder content of 2.5%. The increase in number of cycles result in a marginal increase in the strength of both the OPC and PPC stabilized specimens. The increase in strength can be attributed to the increase in time of chemical reactions with wetting and drying cycles as well as the increase in cementitious compounds during wetting and drying cycles [26]. Similar increase in the strength with the increase in number of cycles have been reported by several other researchers as well [21], [27], [28]. In the case of 2.5% OPC stabilized soil, the strength of the specimens increases from 385 kPa to 451 kPa when the number of cycles increases from 0 to 3. PPC stabilized soil also performs similarly with the strength of 2.5% binder content stabilized soil increasing in strength from 186 kPa to 300 kPa. OPC is still better than PPC at this quantum of stabilizer irrespective of no. of cycles of wetting and drying. However, the durability performance completely changes at higher contents of binder. The strength of 7.5% OPC stabilized soil increases from 1652 kPa to 2330 kPa for the first cycle of wetting and drying. On further increase in the wetting and drying cycles, the strength drops to 1579 kPa for two cycles and then stabilizes at 1591 kPa for three cycles. On the other hand, the strength of 7.5% PPC stabilized soil steadily increases from 700 kPa to 1104 kPa and 1664 kPa for one and two cycles of wetting and drying. The strength gain then flattens to 1839 kPa for three cycles of wetting and drying. Thus, at 7.5% binder content, OPC performs better than PPC but only for the first cycle of wetting and drying. A further increase in number of cycles results in the OPC stabilized soil losing its strength whereas PPC stabilized soil keeps on gaining strength. A possible reason for the loss in strength of the 7.5% OPC stabilized soil after the first cycle of wetting and drying may be due to the higher heat of hydration of OPC. After the first cycle of wetting and drying, the moisture supplied by the wetting process may have induced better hydration of the OPC. OPC hydrates faster and generates more heat of hydration compared to PPC. This may have led to shrinkage cracks during the drying cycle resulting in a compromised microstructure of the OPC stabilized soil. Cuisinier et al. [31] state that some investigations have revealed that imposition of the first cycle of wetting and drying could induce a significant change in the microstructure of the soil. As a result, the strength of OPC stabilized soil decreases after the first cycle of wetting and drying. Introduction of pozzolanic materials like flyash in blended cements reduces the rate of hydration when compared to OPC [29], [30]. Thus, PPC hydrates slower than OPC and has comparatively lesser heat of hydration.This may have resulted in the steady increase in the strength of PPC stabilized soil with increase in number of wetting and drying cycles. However, microstructural investigations need to be carried out in future investigations to confirm the veracity of this possible mechanism. The gain in strength of PPC treated soil stabilizes for the third cycle of wetting and drying. But the strength of PPC stabilized soil after three cycles of wetting and drying is clearly higher than OPC stabilized soil. Thus, it can be stated that PPC stabilization of soil will perform better than OPC stabilization of soil under conditions of alternate wetting and drying, provided that the PPC content adopted for stabilization is sufficient enough. However, the determination of sufficient content of PPC in stabilization still needs to be evaluated as this study adopted only trial contents of PPC.

To get a better understanding of the performance of the OPC and PPC stabilized soil under conditions of wetting and drying, the strength index (I_{qu}) of the stabilized specimens were calculated for different cycles of wetting and drying. Muntohar and Khasanah [26] report strength index to be the ratio of strength of the stabilized specimen subjected to wetting-drying cycles to that of the strength of the specimens not exposed to wetting and drying. Figure 5 shows the strength index of the OPC and PPC stabilized specimens with number of wetting and drying cycles. The strength index of 7.5% PPC stabilized soil steadily increases from 1 to 2.63 for three cycles of wetting and drying. Even at lower binder content of 2.5%, the strength index increases from 1 to 1.61 for three cycles of wetting and drying, despite a marginal drop in index after the first cycle of wetting and drying at 0.95. On the other hand, the strength index of OPC stabilized soil only improves in the case of 2.5% OPC content. It increases from 1 to 1.17 for three cycles of wetting and drying. At higher content of 7.5%, the strength index increases only after the first cycle to 1.41, whereas on further increase in the number of cycles, the index drops and stabilizes to around 0.96. Thus, it can be stated that irrespective of binder content, PPC stabilized specimens perform better under conditions of wetting and drying compared to OPC stabilized soil. However, this statement has to be considered along with the absolute strength developed by the two different binders. The absolute strength of OPC stabilized soil is significantly higher even after the first cycle of exposure. However, after subsequent cycles of exposure, even the absolute strength of OPC stabilized soil specimens is reduced below that of PPC stabilized soil. The absolute strength of PPC stabilized soil increased with the increase in exposure cycles. However, this is true only for the higher binder content of 7.5%. In the case of low binder content of 2.5%, the absolute strength of PPC is less than OPC stabilized soil, though it steadily increases with the increase in number of cycles of wetting and drying.

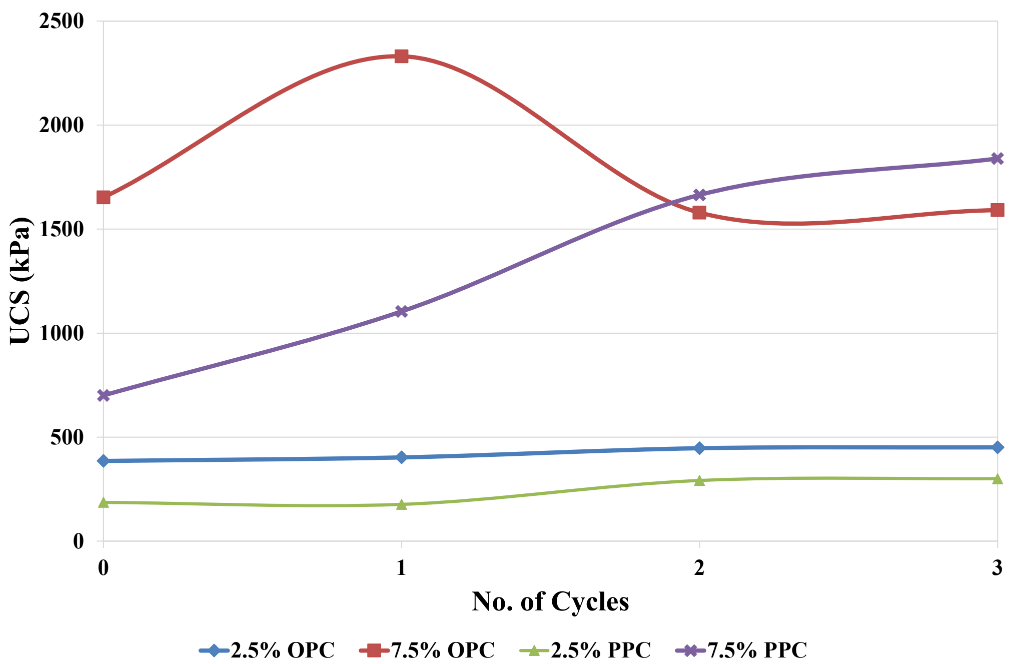

Figure 4. Strength of OPC and PPC stabilized soil subjected to wetting and drying cycles

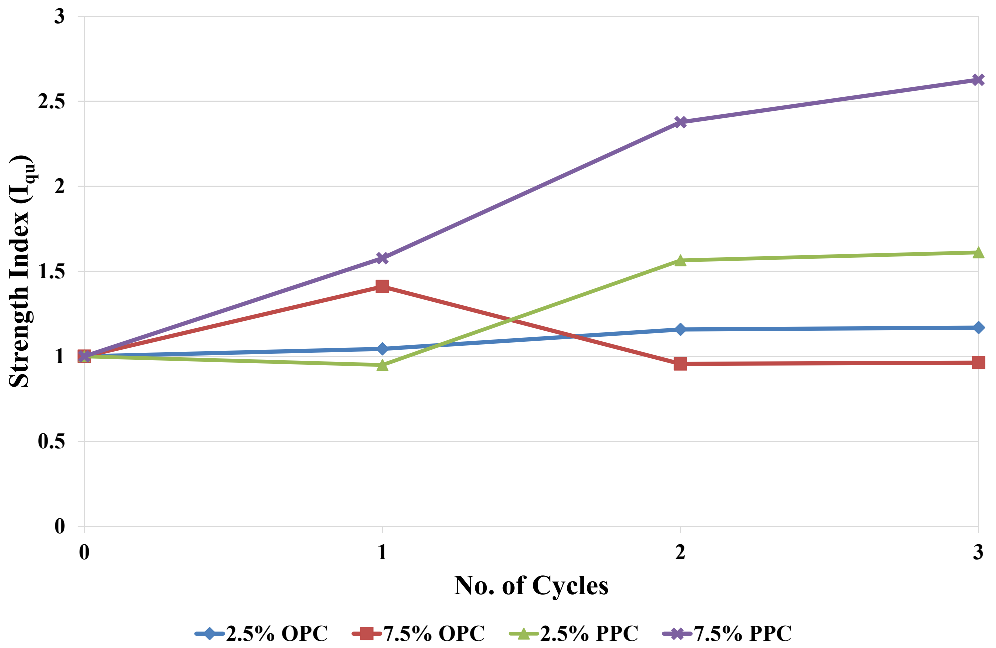

Figure 5. Strength index of OPC and PPC stabilized soil with wetting-drying cycles

4.3 Stress-strain characteristics of OPC and PPC stabilized soil

Figure 6 shows the stress-strain characteristics of the stabilized soil with 2.5% binder content. From the figure, it can be seen that 2.5% OPC stabilized soil behaves like a brittle material with the failure strain at 1.3%.

The first cycle of wetting and drying results in an increase in the failure strain to 4.5%. However, on further increase in wetting and drying cycles, the failure strains decrease to 2.9% and 1.6% respectively for 2 and 3 cycles of wetting and drying. Thus, in the case of OPC stabilized soil, it can be seen that the first cycle of wetting and drying has a major impact on the stiffness of the material. Subsequent cycles result in the material reverting to brittle behaviour.

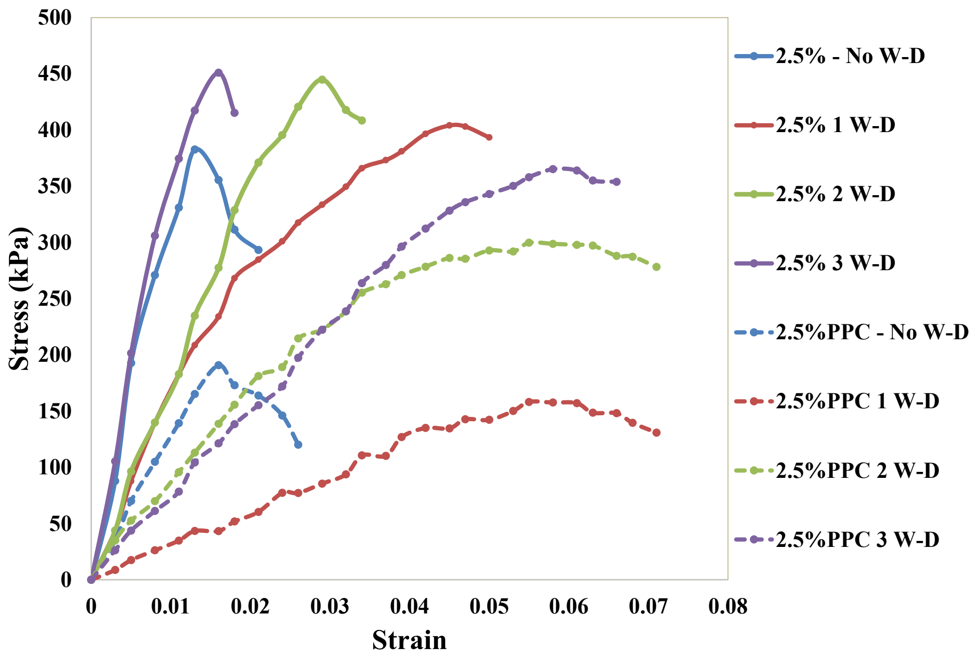

Figure 6. Stress-strain characteristics of 2.5% OPC and PPC stabilized soil

On the other hand, in the case of 2.5% PPC stabilized soil, the failure strain is 1.6%, indicating brittle behaviour. Similar to OPC stabilized soil, the first cycle of wetting and drying results in the material behaving more like a ductile material with failure strain as high as 5.5%. However, the effect of subsequent wetting and drying cycles is insignificant as PPC stabilized soil continues to behave as ductile material for all cycles with failure strains close to 5.5% for all cycles. Muntohar and Khasanah [26] report that the variation in moisture content of stabilized specimens is maximum during the first cycle of wetting and drying. This additional moisture content supplied during the first cycle of wetting and drying may have also resulted in further formation of cementitious products leading to a gain in strength after the first cycle. A similar response has been reported in literature by earlier investigators [26], [28], [32]. Thus, the resultant effect of increased moisture content and further formation of cementitious products may be a reason for the ductile behaviour of the stabilized specimens after the first cycle of wetting and drying in the present study. Thus, it can be concluded that the first cycle of wetting and drying reduces the stiffness of the stabilized specimen, irrespective of binder type. Multiple cycles of wetting and drying influences the ductility behaviour of OPC stabilized specimen whereas its effect on the ductility behaviour of PPC stabilized soil is insignificant at low binder content of 2.5%.

Figure 7 shows the stress-strain characteristics of stabilized soil with 7.5% binder content. At higher binder content of 7.5%, OPC stabilized soil exhibits more brittle behaviour compared to PPC stabilized soil. However, in the case of 7.5% OPC stabilized soil, the soil exhibits increased ductile behaviour until 2 cycles of wetting and drying, which was not the case in 2.5% OPC stabilized soil. On further increase in wetting and drying cycles to 3, the soil started to exhibit brittle behaviour. The failure strains increased from 1.8% to 5.5% for 2 cycles of wetting and drying and then again reduced to 2.6%. In the case of 7.5% PPC stabilized soil, the failure strain increases from 2.9% to 5.8% for 2 cycles of wetting and drying and then reduces to 2.9% for the third cycle. Thus, it can be seen that at higher binder content of 7.5%, wetting and drying cycles render both OPC and PPC stabilized soil to behave like a more ductile material until two cycles of wetting and drying beyond which both tend to exhibit brittle behaviour once again. At higher binder content, the formation of cementitious gels would be more pronounced. This would have delayed the ingress of moisture, thereby rendering both the materials to behave in a ductile manner until two cycles of wetting and drying. Further increase in number of cycles, the formation of more cementitious products would have overshadowed the softening effect due to wetting and drying cycles resulting in exhibition of brittle behaviour. Aldaood et al. [33] report that the increase in number of wetting and drying cycles results in the formation of macropores. The loss in strength of OPC stabilized soil at higher number of wetting and drying cycles may also be due to the formation of such macropores. It can be clearly seen that the stress-strain behaviour of the stabilized specimen is influenced by binder content, binder type and cycles of wetting and drying. Overall, it can be stated that PPC performs better than OPC at higher binder content and higher number of wetting and drying cycles. However, the number of cycles considered in this investigation is too low for giving a generalized verdict on the performance of PPC in comparison with OPC in soil stabilization.

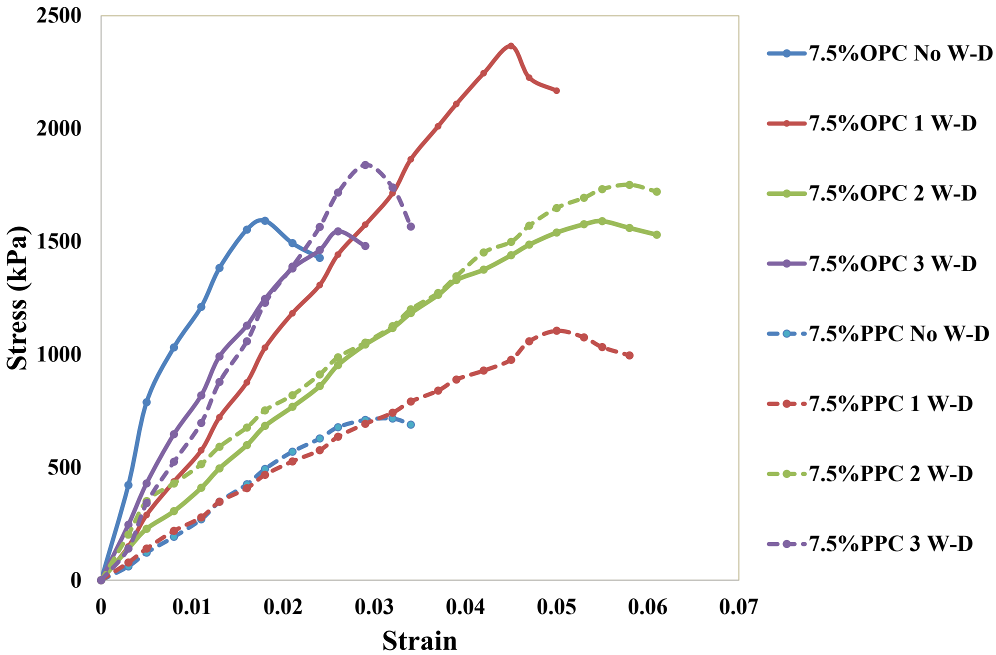

Figure 7. Stress-strain characteristics of 7.5% OPC and PPC stabilized soil

The behaviour of the stabilized soil can be further interpreted from the stress-strain characteristics using the secant modulus of elasticity [26]. The secant modulus of elasticity, E_{50} is defined as the ratio of half of peak stress to the corresponding axial strain [34]. Figure 8 shows the variation of secant modulus, E_{50}, for the various combinations of binders used in this investigation for different cycles of wetting and drying. It is evident from the figure that 7.5% OPC stabilized soil has the higher modulus when not subjected to any wetting and drying cycles. Increase in the number of cycles results in the modulus of OPC stabilized soil to reduce. This is true for both 2.5% and 7.5% binder content. However, after two cycles of wetting and drying there is an increase in the secant modulus of OPC stabilized soil for both 2.5% and 7.5% binder content. The secant modulus drops from 207.1 MPa and 36.53 MPa to 34.24 MPa and 18.13 MPa after two cycles for 7.5% and 2.5% OPC stabilized soil, respectively. On the other hand, the secant modulus of 2.5% PPC stabilized soil does not show a clear trend. It starts at around 10.3 MPa and wavers up and down to 5.74 MPa for three cycles of wetting and drying. However, 7.5% PPC stabilized soil, clearly shows an increase in secant modulus with increase in wetting and drying cycles. The modulus of 7.5% PPC stabilized soil increases from 24.33 MPa to 67.18 MPa, in comparison with the 76.77 MPa achieved by 7.5% OPC stabilized soil after three cycles of wetting and drying.

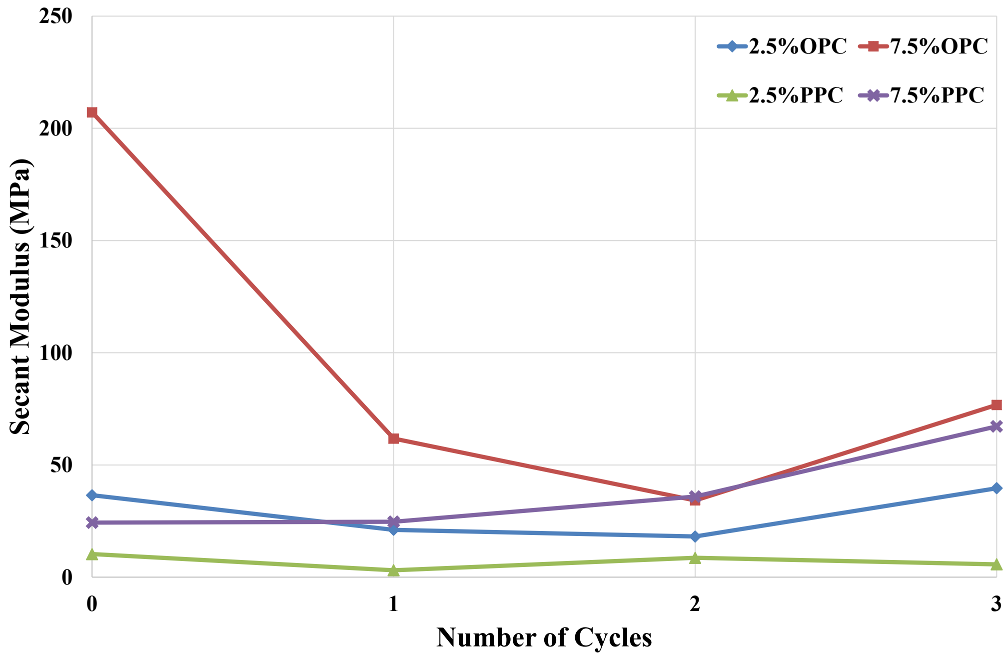

Figure 8. Secant modulus (E_{50}) of OPC and PPC stabilized soil

5 Conclusions

The present investigation aimed to study the efficacy of PPC in stabilization of soil under conditions of alternate cycles of wetting and drying. From the results of the investigation, the following points may be concluded.

i. The strength of OPC stabilized soil was much higher than that of PPC stabilized soil for both stabilizer contents investigated. In fact, the strengths developed by OPC was more than twice that of PPC for both the stabilizer contents. Thus, it can be concluded that under normal conditions of stabilization, OPC stabilization performs much better than PPC stabilization, irrespective of binder content.

ii. The durability performance of both OPC and PPC stabilized soils at low binder content of 2.5% resulted in a marginal increase in strength for both. However, at higher binder content of 7.5%, the durability performance of both OPC and PPC stabilized soil were different with strength loss for OPC stabilized soil against strength gain for PPC stabilized soil. Thus, it can be stated that the durability performance of the stabilized soil is influenced by binder type as well as its content.

iii. Under conditions of wetting and drying, the strength index of PPC stabilized soil increased with the increase in number of cycles of wetting and drying for both binder contents. For OPC stabilized soil, the strength index increased with the increase in number of cycles at low binder content and decreased with increase in number of cycles at higher binder content. The values of increase in strength index were also higher for PPC stabilized soil when compared to OPC stabilized soil. Thus, it can be postulated that PPC stabilization of expansive soil performs better under conditions of alternate wetting and drying when compared to OPC stabilization.

iv. The first cycle of wetting and drying results in the increase in failure strains of both OPC as well as PPC stabilized soils. Thus, it can be stated that irrespective of binder type or content, wetting and drying cycles can change the straining behaviour of the material.

v. At low binder content of 2.5%, with increase in wetting and drying cycles, OPC stabilized soil recovered back its brittle behaviour whereas up to three cycles of wetting and drying did not have any influence on the ductile behaviour of PPC stabilized soil. Thus, use of PPC stabilization at low binder content may not provide satisfactory performance.

vi. At higher binder content of 7.5%, the failure strains increase with the increase in wetting and drying cycles up to 2 cycles after which both OPC and PPC stabilized soils exhibit brittle behaviour but the PPC stabilized soil retains higher strength when compared to OPC stabilized soil, thus reinforcing the conclusion that PPC stabilized soil performs much better than OPC stabilized soil provided that sufficient binder content is available for satisfactory performance.

The number of cycles considered in this investigation, however, can only give initial indications and higher number of cycles of wetting and drying is essential for getting a clearer picture for more obvious conclusions as to its performance under wetting and drying conditions.

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Conflict of interest

The authors declare no conflict of interest in the publication of this manuscript.

Data availability

The data obtained during the course of this investigation is available on request from the authors.

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