BEHAVIOUR OF UNSATURATED AGGREGATED SOIL IN OEDOMETRIC CONDITION

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ABSTRACT

Natural and agricultural soils usually possess an aggregated structure; in the sense that they are composed of aggregates and large inter-aggregate pores. Under the natural condition, these soils are usually unsaturated and the large pores are easily drained. The present paper looks at the combined effects of soil structure and partial saturation on the mechanical behaviour of aggregated soils. Conventional and suction-controlled oedometer testing are used to evaluate the soil response at different combinations of saturation and the initial soil structure. The soil structure effects are assessed by comparing the behaviour of aggregated to that of the corresponding reconstituted soil. The effects of suction in reconstituted and aggregated soils are evaluated by testing at different levels of suction.

Key words: aggregation, apparent preconsolidation, oedometer, soil structure, suction (IGC: D3/D5)

INTRODUCTION

Aggregation of particles is a commonly observed phenomenon in natural and agricultural soils (Horn, 2003) as well as in compacted clays at dry side of optimum water (Barden and Sides, 1970; Sridharan et al., 1971; Collins and McGown, 1974) and compacted expansive clays (Lloret et al., 2003). However, size of aggregates in expansive and compacted clays are of some orders of magnitude smaller than aggregates in natural or agricultural soils. Structure of aggregated soils, in general sense, is composed of aggregates which are often separated by large inter-aggregate pores. The morphological characteristics of these pore space depend on the size, distribution and shape of aggregates and on their history of formation and compaction. Under natural conditions, these pores easily drain, and come into a partially saturated state. The combined effects of soil structure aggregation and partial saturation require experimental investigations as they may strongly influence the mechanical behaviour of the material.

The experimental evidence of the soil structure effects on the stress-strain response of soils have been reported for a wide variety of natural structured soils, including soft rocks (Tavenas and Leroueil, 1990; Smith et al., 1992), stiff clays and clay shales (Calabresi and Scarpelli, 1985; Anagnostopoulos et al., 1991; Burland et al., 1996), granular soils (Mitchell and Solymar, 1984; Coop and Atkinson, 1993) and residual soils (Vaughan et al., 1988). The extra features arising from soil structure are often identified in comparison with reconstituted soil of the same mineralogy as a reference state with intrinsic properties (Burland, 1990). The major influence of soil

structure in natural structured soil is reported to be on the yield limit and yielding behaviour. Leroueil and Vaughan (1990) reported that naturally occurring sedimentary and residual soils often have components of strength which cannot be accounted for by porosity and stress history alone. They showed that the void ratio for both residual and sedimentary structured soils is greater than can be sustained by the same soil from which structure has been removed by remolding. Similar evidences have been reported by Burland (1990) and Smith et al. (1992). Interpreting their results, Leroueil and Vaughan (1990) stated that while bonded structure in these materials might arise from different causes, its consequences on the material behaviour is similar and corresponds to a stiff behaviour followed by yield. Accordingly, they described this yield in a similar way to that occurring due to overconsolidation, although it is a different phenomenon. As for yielding behaviour, natural soils often exhibit a brittle behaviour with the post-yield compression index being much greater than that of reconstituted soils (Burland, 1990; Smith et al., 1992). It has been commonly reported that the compression curve of structured clay tends to converge to that of reconstituted clay, as the applied stress increases (Burland, 1990; Callisto and Calabresi, 1998). As expressed by Graham et al. (1988), during yielding, the material experiences the major disturbance; thus, the influence of soil structure becomes less important and the response of the materials becomes closer to that of the reconstituted.

Study of natural structured soil has been mainly focused on the saturated state and only few works have considered the partial saturation effects (Alonso and Gens, 1994; Leroueil and Barbosa, 2000). It has been shown

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that the increase in yield stress resulting from the combined effects of partial saturation and inter-particle bonding is larger than the sum of the contribution of the two factors. As such, suction in bonded soils has two effects corresponding to capillary effects on soil matrix and strengthening of inter-particle bonds which should be taken into account when dealing with these materials at unsaturated states.

The present paper looks at the combined effect of soil structure and partial saturation on the mechanical behaviour of aggregated soils. Although different in nature, aggregated soils are similar to bonded soils in the sense that their mechanical behaviour is predominantly influenced by soil structure. Aggregation is, indeed, a special type of inter-particle bonding phenomenon forming particle assemblages with a definite physical boundary and large pores between them. To figure out the influence of this structure on the mechanical behaviour, aggregated soil is compared with reconstituted soil of the same mineralogy in oedometric testing. The oedometric behaviour of both materials is evaluated and compared at different states of water saturation under controlled suction.

METHOD, MATERIAL AND PROGRAM

The conventional oedometer and a newly developed suction-controlled oedometer apparatus were used in this study. The new cell uses the osmotic method to control suction. The layout of the new oedometer system is depicted in Fig. 1(a). It consists of a special oedometer

cell placed in a loading frame, a peristaltic pump which operates with continuous flexible tubing, a reservoir for polyethylene glycol ethylene (PEG) solution, and a balance to monitor the water exchange. In the cell, shown in Fig. 1(b), water moves without input of energy across a semi-permeable membrane separating the soil sample and the aqueous solution PEG (*see e.g.*, Kassif and Ben-Shalom, 1971; Dineen and Burland, 1995). The imposed suction is in correlation with the PEG concentration through empirical relationships (Williams and Shaykewich, 1969; Money, 1989; Delage et al., 1998). Deformation of the sample and the balance values are continuously recorded using data loggers and computers.

The tested material, Bioley soil, is a clay with low plasticity (CL) from the western part of Switzerland. The plasticity index of the soil is 13.4%, its liquid limit 28.9 %, and the specific weight of the soil particles 2.70 kNm⁻³. Percentage of particles smaller than 0.02 mm and 0.06 mm is 63.8 and 85 respectively. The soil was available in reconstituted form; however, it has been tested under both reconstituted and aggregated form in this study. To ensure an identical initial soil structure, soil aggregates were obtained from compacted reconstituted soil through a controlled procedure as it follows. After compacting at dry side of the optimum water content, the soil was gently crushed. The crushed soil was sieved to obtain the aggregates between 2 and 4 mm. At the end of this process, aggregates were dried in the oven for 48 hours at a temperature of 105°C. Since the aggregates are all prepared following the same procedure, any possible influence of drying temperature on the initial soil structure is not considered here.

The aggregates obtained in this way were found to easily disaggregate in direct contact with water. Hence, aggregated samples could not be tested at the saturated state. However, for humid aggregates of unsaturated samples, aggregate were wetted by water spraying using a vaporizer in different steps and providing enough time intervals in order to ensure the humidity equilibrium in soil.

Four types of experiments have been carried out at different combinations of saturation and the initial soil structure, as illustrated in Fig. 2: (i) dry oedometer tests (DR, RC), (ii) soaking tests (SKS, SKR) of dry samples under constant vertical stress, (iii) saturated oedometer tests (SAT) and, (iv) unsaturated oedometer tests (USR, USS). For each type of experiment with the exception of

Fig. 1. Schematic representation of the osmotic oedometer system: (a) general layout and (b) oedometric cell (lengths in mm)

Saturation	Soil structure			
	reconstituted		aggregated	
	dry		unsat.	
	RC	SKR	SKS	DR
sat.	USR			USS
	SAT			

Fig. 2. Classification of the tests

saturated oedometric one, the tests were carried out on samples of aggregated and reconstituted soils.

Dry samples of both reconstituted and aggregated soil were prepared by free placement of the soil directly in the cell without any major compaction. This method of preparation for aggregated samples results in a relatively large inter-aggregate pores and consequently a high initial void ratio. Hence, it allows starting the test from a loose normally consolidated state.

Samples of unsaturated aggregated soils (USS) were prepared in the same way as dry samples with the exception that dry aggregates were first wetted up to the gravimetric water content of about 13% which is slightly at dry side of optimum water content. Unlike the aggregated samples, tests on unsaturated reconstituted samples (USR) started from a saturated state. Saturated samples of reconstituted soil were prepared, directly in the cell, from a mixture of high water content of 25% in order to ensure the saturation. The samples were consolidated before testing.

The so-called generalized vertical effective stress σ'_v , which is the Bishop's effective stress with the Bishop's coefficient being the degree of saturation, is used for analysis of the results (Bishop, 1959; Nuth and Laloui, 2008)

$$\sigma'_v = \sigma_{vnet} + S_r s \quad (1)$$

In the above equation, S_r is the degree of saturation, s is the matric suction and, σ_{vnet} is the vertical net external stress.

SATURATED AND DRY BEHAVIOUR

The behaviour of the soil at two extreme cases of dry and fully saturated are evaluated here; while, the effects of suction variation in the intermediate unsaturated cases are investigated in the next sections.

Oedometric response of two saturated reconstituted samples, tested in conventional and osmotic cells, are shown in Fig. 3. In one hand, similarity of these results

validates the performance of the new osmotic oedometer cell; and in the other hand, they represent the saturated reference behaviour of the soil in the absence of suction and structure effects.

The oedometric curves for dry reconstituted and aggregated samples are shown in Fig. 4(a). Although tested in a normally consolidated state, the aggregated samples show an initial stiff behaviour followed by yielding. The initial stiff behaviour is due to the strength of the aggregates.

Although stemming from a different phenomenon, this stiff behaviour in aggregated soils can be described in the same way as induced over consolidation. Therefore, the limit that separates the initial stiff behaviour from the subsequent yielding is called the initial *apparent preconsolidation stress*. The apparent preconsolidation pressure depends on the soil structure and it is identical for samples of the same structure at the similar stress state and stress history.

It is observed that the aggregated samples exhibit

Fig. 3. Saturated oedometric curves of reconstituted samples standard and osmotic cell

Fig. 4. Oedometric response of dry aggregated and reconstituted samples

higher initial void ratio in comparison with the reconstituted soils. The difference in void ratio is due to the initial open structure of the aggregated soils with inter-aggregate pores. This difference decreases at higher values of applied stress where the aggregated structure is remolded and the inter-aggregate pores tend to close.

The reversible deformations could be assessed during the unloading-reloading parts of the test. The slope of the stiff part and the unloading (swelling) line is almost the same in aggregated and reconstituted samples. However, unloading was performed at the stress level for which the aggregated structure has been already obliterated significantly, as indicated by the convergence of two curves.

The major difference in the observed behaviour of aggregated and reconstituted soils lies in their slope of the virgin compression at the stress values above the apparent preconsolidation stress. Figure 4(b) illustrates results of tests on the dry aggregated sample (DR), and the dry reconstituted sample (RC), where the loading has been continued up to the maximum applied stress of 3000 kPa. The dotted line in this figure represents the virgin oedometric compression line of reconstituted soil. The two curves tend to converge at high values of applied stress. It is observed that the virgin compression line of the reconstituted soil is an asymptote to the compression curve of aggregated soil intersecting at its very beginning. This latter one exhibits a non-linear part at high value of stress in the logarithmic scale.

In further evaluations, soaking tests were carried out to evaluate the wetting effects. The test includes an oedometer test in a conventional cell where the sample is initially dry. At a given loading step, water is slowly added and the sample is soaked under the constant vertical stress. After reaching the equilibrium, the oedometric test is then continued under saturated condition.

Two aggregated samples (SKS01, SKS02) and two reconstituted samples (SKR01, SKR02) have been tested for soaking under two vertical stress values of 1.1 kPa and 125 kPa. The samples were prepared in the same way as for the dry tests: and similarly, the aggregated samples

exhibited a higher initial void ratio than the reconstituted samples.

Figure 5 shows the results of the soaking tests in terms of void ratio versus the vertical stress. The vertical drop represents the wetting-induced deformation under the constant vertical stress. After the drop, the samples undergo normal consolidation compression during the rest of oedometric compression. The wetting-induced deformation for both aggregated and reconstituted samples is more significant when soaked under the higher vertical stress. However, this deformation in aggregated samples is almost twice the corresponding value in reconstituted samples. After soaking, the curves coincide and the samples show an identical normal consolidation line (NCL) under the saturated condition. Even if the compression curve of the sample is initially well above this curve, the wetting-induced deformation brings the state of the soil down to the saturated normal consolidation curve. In other words, the saturated virgin compression curve (and unloading curve) is an intrinsic characteristic of the material which is independent of the initial structure of the soil. When consolidated under saturated condition, the aggregated structure of the soil is removed and the soil behaves similarly to a reconstituted soil.

UNSATURATED BEHAVIOUR

The unsaturated tests were carried out by controlling matric suction and vertical net stress. The tests were completed in two phases: *phase i* in which the suction increases prior to the main compression, and *phase ii* where the main oedometric compression (and swelling) is performed under constant suction.

The stress path and the testing parameters are presented in Fig. 6 and Table 1. The reconstituted samples USR01, USR02, and USR03 were respectively consolidated to the vertical effective stress of 60, 90, and 200 kPa prior to testing. The listed values of initial water content and void ratio of reconstituted samples correspond to the state of the material after the primary consolidation

Fig. 5. Results of soaking tests on aggregated (SKS) and reconstituted (SKR) samples

Fig. 6. Followed stress path in unsaturated test (see Table 1 for details)

phase. As in dry tests, the aggregated samples were initially in the loose state.

In the following, prior to the comparison of results, selected results are separately presented for reconstituted and aggregated samples.

Unsaturated Reconstituted Sample

Results of the test on unsaturated reconstituted sample USR03 are presented in Figs. 7 and 8. Starting from the saturated state, the maximum suction of circa 3000 kPa is

applied in different suction steps. The dotted line represents the *phase i* corresponding to the suction increase and the bold line corresponds to the *phase ii* during which the net stress varies under constant suction.

The increase of suction in *phase i* provokes a significant drop of water content (Fig. 7(a)), so that the soil loses the main part of its water. This yields a suction-induced volume change, or shrinkage, which is reflected in the stress-strain response, namely the oedometric compression curve.

The oedometric compression curves of the sample in terms of effective stress and net stress are shown in Fig. 7(b). The two curves exhibit a horizontal separation due to the term $S_r s$ in the expression of effective stress. The apparent effective preconsolidation stress is about 2100 kPa. The increase of suction causes a volume change drop in the beginning of the net stress curve. While, the suction variation steps lie on the initial stiff part of the curve corresponding to the overconsolidated part in the effective stress interpretation.

Degree of saturation shows a significant drop in *phase i* which is first followed by a smooth increase during the

Fig. 7. Test results of the reconstituted sample USR03 (stress path: OBAKMJ): (a) variation of gravimetric water content, (b) oedometric curve, (c) variation of degree of saturation and (d) variation of degree of saturation at constant suction

Fig. 8. Water retention curves of reconstituted sample USR03, suction increase under constant vertical net stress: (a) water content-suction, (b) degree of saturation-suction and (c) suction-induced deformation

subsequent compression phase, and then, shows a decrease in the further successive unloadings steps (Fig. 7(c)). In other words, the degree of saturation varies with void ratio even at constant suction, as previously evidenced by some authors (Gallipoli et al., 2003; Wheeler et al., 2003; Cuisinier and Laloui, 2004). When expressed as a function of void ratio (Fig. 7(d)), the degree of saturation for all loading and unloading steps lies on a single curve. Hence, an appropriate evolution rule for the degree of saturation should take into account the void ratio in addition to the suction.

Figure 8 illustrates the water retention response of the sample. Below the matric suction of 250 kPa, the sample remains almost saturated. This suction, referred to as *air entry value suction*, represents the suction at which the air enters to the soil pores. Beyond this suction, the water content and the degree of saturation undergo major drops followed by insignificant decrease. Evolution of void ratio with suction (Fig. 8(c)) shows that the major suction-induced shrinkage of the sample occurs at suctions below the air entry value. These results are in agreement with the interpretation of suction-induced

volume change given by Geiser et al. (2006).

Unsaturated Aggregated Sample

The results of two aggregated samples USS03, and USS04, corresponding to matric suction of circa 500 kPa and 1500 kPa respectively, are presented here.

Figure 9 shows the experimental results for sample USS03. Due to an increase in suction, a major decrease of water content is observed which is then followed with a slight decrease associated with the subsequent compression (Fig. 9(a)). However during the final steps of compression and unloading, the water content increased.

Evolution of the void ratio as a function of net stress in Fig. 9(b) shows an insignificant suction-induced deformation during *phase i*. The effective and the net stress compression curves converge at higher values of stress where the influence of the term S_s becomes insignificant. The apparent effective preconsolidation stress is about 110 kPa. Beyond this limit, the effective stress compression curve exhibits a nonlinear behaviour.

As observed in Fig. 9(c), the degree of saturation decreases slightly in *phase i*. Because of the large empty

Fig. 9. Test results of the aggregated sample USS03 (stress path: O'CDG): (a) variation of gravimetric water content, (b) oedometric curve, (c) variation of degree of saturation and (d) variation of degree of saturation at constant suction

inter-aggregate pores, the degree of saturation at the beginning of compression in *phase ii* corresponds to the relatively low value of 0.21. The degree of saturation remains constant at the early steps of compression and then increases with loading. No significant change in degree of saturation is observed during the swelling steps. Plotted as a function of void ratio, the degree of saturation for both loading and unloadings lies on the same curve (Fig. 9(d)).

Similar observations were made for sample USS04, as presented in Fig. 10. However, a slight increase of water content has been observed during *phase i* (Fig. 10(a)). This observation disagrees with the expected behaviour, i.e., the shrinkage of the sample as a result of suction increase.

The induced change of degree of saturation due to the slight initial increase of water content is insignificant in comparison with the rest of the test (Fig. 10(c)). The evolution of water content during the compression phase is similar to the one in test USS03, i.e., an initial decrease followed by final increase.

Changes in the void ratio as a function of both net and effective vertical stress are presented in Fig. 10(b). In this

figure, a clear non-linearity is observed for the compression curve plotted in both net and effective stress. However, the non-linearity is better observed in the effective stress curve. The apparent effective preconsolidation stress in this sample is about 410 kPa.

The evolution of the degree of saturation of the sample during compression in terms of vertical net stress and void ratio are illustrated in Figs. 10(c) and (d) respectively. The degree of saturation remains around the low value of 0.26 during the initial steps of compression, while it increases with the successive loading steps until reaching 0.66 at the maximum vertical net stress of 3000 kPa. Subsequent unloading brings the degree of saturation to 0.59 at the end of the test.

Analysis of the Results

The effects of soil structure on the behaviour of unsaturated material has been evaluated by comparing the results of tests on aggregated and the corresponding reconstituted soil at the same applied suction. Comparison of these results in terms of effective stress is presented for suction levels of circa 500, 1500 and 3000 kPa in Fig. 11.

Fig. 10. Test results of aggregated sample USS04 (stress path: O'GIG): (a) variation of gravimetric water content, (b) oedometric curve, (c) variation of degree of saturation and (d) variation of degree of saturation at constant suction

As for the dry samples, the unsaturated aggregated samples exhibit higher void ratio in comparison to the reconstituted soil. At the same suction, there is an insignificant difference between the swelling index of aggregated and reconstituted samples. However, the virgin compression parts of the curves differ significantly. In other words, the influence of the soil structure effects on the recoverable (elastic) deformations is insignificant; while it is more important for the irrecoverable (plastic) deformations.

The two compression curves converge at higher values of effective stress. This evidence is more remarkable in Fig. 11(b) where the effective stress has been increased up to about 4000 kPa. It is observed that the virgin compression line of the reconstituted soil (dotted line) is an asymptote to the oedometric curve of aggregated sample with an intersection at initial values of effective stress in the very beginning of the curve.

Effects of suction variation on the material behaviour are evaluated by comparing the results of tests on samples of the same material and soil structure at different suctions.

Depicted in terms of effective stress, the results of

reconstituted samples are compared in Fig. 12. The initial slope of the compression curve (due to suction increase) is bigger for samples USR01 and USR02 in comparison to USR03. However, the total deformation at the end of suction increase phase in the first two tests might be a combination of reversible and irreversible deformations which cannot be further distinguished due to the lack of intermediate suction steps.

Also observed in Fig. 12(a) is an increase of apparent effective preconsolidation stress with suction for reconstituted samples. This phenomenon is better illustrated in Fig. 12(b). The normal consolidation line of reconstituted soil shifts to the right due to suction increase. This is equivalent to the increase of the effective preconsolidation stress with suction for a soil sample of a given state. Quantitative comparison of the increase in the effective preconsolidation stress of these samples is not directly possible because of the difference in the initial states of the samples as well as the possible occurrence of irreversible deformations during the loading. Such a comparison needs postulation of yield limits.

Figure 12(b) illustrates a clear increase of the slope of the virgin compression line when the state of the sample is

Fig. 11. Comparison of unsaturated oedometer response of aggregated and reconstituted samples: (a) $s = 500$ kPa, (b) $s = 1500$ kPa and (c) $s = 3000$ kPa

Fig. 12. Comparison of unsaturated oedometer response of reconstituted samples at different suction levels: (a) apparent preconsolidation stress and (b) compressibility index

changed from saturated to unsaturated. It is, however, difficult to make a distinction between the slopes at two suctions of 500 and 1500 kPa.

To elucidate the suction effects in aggregated samples, the oedometric curves of four unsaturated samples tested at different matric suction of 500 kPa (USS03), 1000 kPa

Fig. 13. Comparison of unsaturated oedometer response of aggregated sample at different suction levels

Fig. 14. Increase of apparent effective preconsolidation stress with suction in aggregated samples

(a)

(USS02), 1500 kPa (USS04), and 3000 kPa (USS01) are compared in Fig. 13. The evolution of the apparent effective preconsolidation stress with suction in these samples is depicted in Fig. 14. It is seen that this stress increases with suction; starting from 110 kPa in sample USS03 with suction of 500 kPa, the apparent effective preconsolidation stress reaches around 500 kPa in test USS01 where the applied suction is 3000 kPa.

As previously shown for reconstituted samples, suction also has an increasing effect on the apparent effective preconsolidation stress of these samples. The difference in the ascending rate of apparent preconsolidation stress in aggregated and reconstituted samples can be assessed by observing the horizontal separation of the two compression curves with suction (*see* Fig. 11).

For this purpose, the schematic representation of compression curve of aggregated (structured) and reconstituted samples of the same suction in Fig. 15(a) is employed. The intersection of the compression curve of aggregated soil with the NCL of reconstituted soil (point I in Fig. 15(a)) represents a possible state of the reconstituted soil which shares the initial state with the aggregated soil.

The ratio of the initial apparent preconsolidation of the aggregated soil over the effective stress corresponding to this point ($\sigma'_{vc}/\sigma'_{vc}^*$) are plotted versus the suction for the three pairs of aggregated and reconstituted samples in Fig. 15(b). Increase of this ratio with suction means that the increase rate of apparent effective preconsolidation with suction is higher in aggregated samples than in reconstituted ones.

This observation indicates the additional effects of suction in aggregated (structured) soil, and is of great importance for constitutive modeling.

SUMMARY AND CONCLUSION

The experimental results presented in this paper are classified in three main parts: merely related to soil structure effects at constant suction, related to the intrinsic

(b)

Fig. 15. Influence of suction on the apparent effective preconsolidation stress in structured (aggregated) and reconstituted samples: (a) schematic representation of compression curves and (b) evolution of the ratio $\sigma'_{vc}/\sigma'_{vc}^*$ with suction

suction effects in reconstituted soil regardless of the soil structure and, related to the combined effects of soil structure and suction on the material behaviour.

The soil structure effects are evaluated using the experimental results of aggregated (structured) samples and their comparison with reconstituted soils at the same suction. The main results are as follows. (i) There is an *apparent preconsolidation stress* in the aggregated soils, which is a function of not only stress state and stress history but also soil structure. (ii) The effects of soil structure on the elastic properties appears to be insignificant. However, this conclusion requires further investigations. (iii) The compression curve of aggregated soil is located to the right side of the reconstituted compression curve at the same suction. The higher void ratio at a given value of applied stress is due to the existence of large inter-aggregate pores. (iv) The compression curves of aggregated and reconstituted soils at the same suction tend to converge at higher values of applied effective stress where the aggregated structure is obliterated. (v) For a given matric suction, the virgin compression line of the reconstituted soil is an asymptote to the compression curve of aggregated soil intersecting the curve at the initial virgin state.

The intrinsic suction effects correspond to the effects of suction variation in reconstituted soils and are assessed based on the results of unsaturated tests of reconstituted samples. These effects can be summarized as follows. (i) Apparent effective preconsolidation stress in reconstituted samples increases with suction. (ii) Slope of normal consolidation line in the effective stress plane, namely compressibility index, increases from saturated to unsaturated samples while it remains almost constant for within the unsaturated samples. (iii) Suction effect on the swelling index is insignificant for reconstituted soil.

Finally, the combined effects of suction and soil structure are evaluated by comparing the results of aggregated and reconstituted samples at different suctions. (i) Suction effect on the swelling index is insignificant for aggregated soil. (ii) Initial apparent effective preconsolidation stress decreases as a result of wetting. In other words, samples with higher matric suction exhibit higher values of apparent effective preconsolidation stress. (iii) The increase rate of effective preconsolidation pressure with suction is higher for aggregated soils rather than reconstituted soil. The above set of experimental evidences figures out the main features arising from the combined effects of soil structure and partial saturation in the mechanical behaviour of aggregated soils.

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