EFFECT OF PORE SIZE DISTRIBUTION ON UNCONFINED COMPRESSIVE SHEAR STRENGTH

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ABSTRACT: The unconfined compressive strength is one of the influencing parameter that is used for determining the in-situ strength of soft, fine-grained soil deposits. Since many previous research works have highlighted the influence of pore fluid type, electrolyte concentration, pH and valence of the pore fluid on unconfined compressive shear strength. The present study has inferred the effect of pore size distribution (PSD) on unconfined compressive shear strength (UCS) of bentonite and kaolinite minerals. It is observed that the pore size distribution of bentonite is a bimodal distribution representing both inter pore and intra pore, whereas the kaolinite mineral exhibits a unimodal distribution representing only the inter pore. The inter pore represents the water molecules bounded between soil aggregates whereas the intra pore represents the water molecules bounded within the soil aggregated and on the clay surface. From the obtained UCS value of bentonite and kaolinite minerals it can be inferred that the UCS strength variation of bentonite mineral is strongly influenced by the water molecules bounded on the clay surface or diffused double layer water, whereas the UCS strength of kaolinite minerals is controlled by the net attractive force between the clay particles. The present study demonstrated that the pore size distribution is also one of the parameter that strongly influences the unconfined compressive strength of the soil.

1 INTRODUCTION

The unconfined compressive strength is a simple and time independent test which is generally carried out to characterize the in-situ strength of soft, fine grained soil deposits. In view of this many research works were carried out to infer the influencing parameters that control the unconfined compressive strength variation. Du *et al*. (1999) analyzed the effect of dry unit weight, soil mineralogy and soil fabric arrangement on the swelling-shrinkage and unconfined compressive strength characteristics. In addition Sridharan and Prakash (1999) highlighted the reason behind the distinct undrained shear strength behavior of kaolinite and montmorillonite minerals. From the obtained results it was concluded that the undrained shear strength of kaolinite minerals was strongly influenced by the net attractive force between the particles whereas in case of montmorillonite minerals the undrained shear strength was controlled by the viscous shear resistance of the diffused double layer (DDL) water.

Umesh *et al*. (2011) highlighted the effect of acid contamination on geotechnical properties of black cotton soil, it has been concluded that the observed change in behavior of black cotton soil was mainly attributed by the reduction in double layer thickness, as well as the reduction in its moisture holding capacity and loss of cohesion with increase in acid concentration. Heeralal *et al.* (2012) and Lin and Cerato (2012) inferred the effect of microstructural change on macrostructure behavior of clay minerals in a detailed way. Further Sasanian and Newson (2013) characterized the effect of moisture content on soil fabric using mercury intrusion porosimetry (MIP) analysis, from the obtained pore size distribution curve the peaks associated with larger pore diameters were termed as inter-cluster pores, representing the water molecules bounded between soil aggregates. On the other hand the peaks associated with smaller peaks were termed as intra-cluster pore which quantifies the water molecules bounded within the soil aggregate and on the clay surface.

From the literature review it can be observed that all the macro-level behavior of clay minerals was strongly influenced by the corresponding change that occurs at its micro-level. Further not many efforts were made to correlate the micro-level behavior with its macro-level changes, keeping this in view attempt was made to establish the relationship between the change in pore size distribution of clay minerals compacted at different moisture content with the corresponding change in its unconfined compressive strength value.

2 EXPERIMENTAL INVESTIGATION

The experimental investigation includes the selection of different clay minerals, characterising them for physical, chemical, mineralogical and compaction characteristics. Further the unconfined compressive strength of soils compacted at different water content was established, in addition the pore size distribution of clay minerals was obtained using mercury intrusion porosimetry.

2.1 Material Selection and Characterisation

The present study has selected sodium bentonite (denoted as Na-BT) and kaolinite (denoted as KT) as a representative samples for testing. The collected geomaterials were processed and characterised for their physical, mineralogical and geotechnical properties by following the guidelines presented in the Indian standards. The obtained results are presented in Table 1

Table 1 Basic Characteristic of Geomaterials

Properties	**Na-BT**	**KT**
Physical Characteristics		
Specific gravity (G)	2.72	2.67
Specific surface area (m^2/g)	338	47
Plasticity Properties		
Liquid limit (%)	287	40
Plastic limit (%)	62	25
Particle Size Characteristics (percent by weight)		
Gravel size	0	0
Sand size	2	39
Silt size	40	28
Clay size	58	33
Classification of soil (As per IS: 1498-1970)	CH	CI
Mineralogical Characteristics		
Minerals Present	Kaolinite, Montmorillonite, Quartz	Kaolinite, Quartz
Compaction Characteristics		
$\gamma_{d\ max}$ (kN/m^3)	13.86	16.35
OMC (%)	29.1	20.35

2.2 Mineralogical Characteristics

The mineralogical compositions of selected geomaterials were obtained using X-Ray Diffraction (XRD) technique. From the established XRD pattern the minerals present in the geomaterials were quantified using international centre for diffraction data base (ICDD, 1978), and the same is detailed in Table 1.

2.3 Compaction Characteristics

The relationship between the moisture content and dry unit weight of the selected geomaterials were obtained using miniature proctor compaction apparatus. The selected geomaterials were mixed with different proportion of distilled water and it was compacted in the miniature compaction mould.

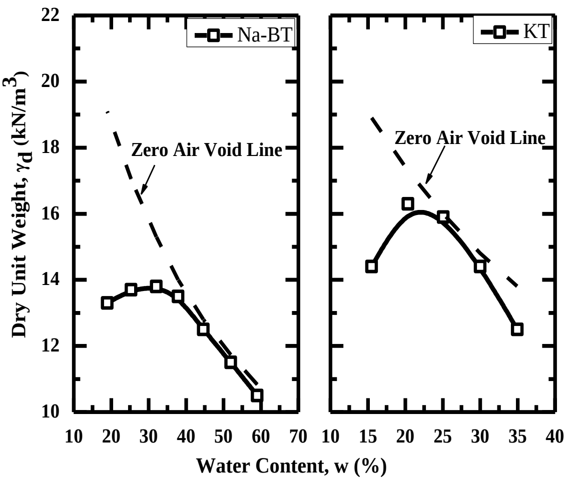

Fig. 1 Compaction curve of geomaterials

From the compacted soil mass and moisture content the relationship between dry unit weight, γ_d and water content, w, has been established and the same is shown in Fig. 1. The compaction characteristics such as the maximum dry unit weight and optimum moisture content value for the selected geomaterials were calculated and the same is shown in Table 1.

From the obtained compaction characteristic curve the sample compacted at different moisture content was selected for further testing. The details of molding moisture content and dry unit weight selected for unconfined compressive strength test and pore size distribution is detailed in Table 2.

Table 2 Sample Details for UCS and MIP Analysis

Compaction State	Na-BT		KT	
	γ_d, kN/m^3	**w (%)**	**γ_d, kN/m^3**	**w (%)**
Dry of Optimum	13.5	21.35	14.5	10.93
OMC	13.86	29.1	16.35	20.35
Wet of Optimum	13.5	36.86	14.5	29.75

2.4 Unconfined Compressive Strength

To obtain the unconfined compressive strength value, the geomaterials were initially mixed with desired quantity of distilled water and stored in an airtight bag for 48 hours to ensure uniform maturation of the soil. The prepared soil mass was compacted to the desired density and it was tested in the triaxial test setup for its UCS value. The obtained stress-strain behavior of selected geomaterials is illustrated in Fig. 2. From the obtained stress-strain relationship, the unconfined compressive strength values were measured and the same is depicted in Table 3.

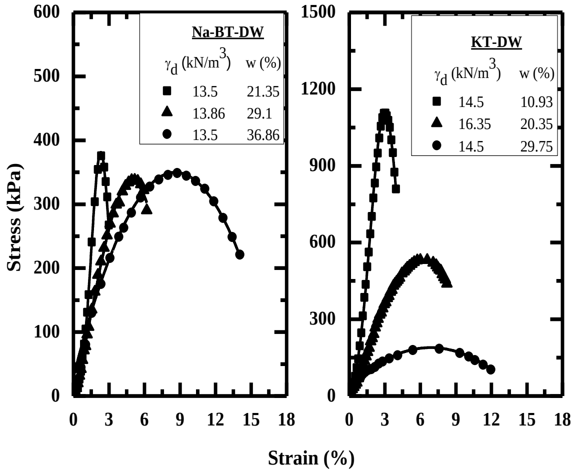

Fig. 2 Stress-strain variations of geomaterials

Table 3 UCS Values of Geomaterials

Geomaterial	γd, (kN/m3)	w (%)	UCS (kPa)
	13.5	21.35	376
Na-BT	13.86	29.1	338
	13.5	36.86	349
	14.5	10.9	1107
KT	16.35	20.35	531
	14.5	29.75	184

2.5 Pore Size Distribution Characteristics

The pore size distribution (PSD) is one of the main influencing factors that control the engineering properties of geomaterials to a great extent. In view of this, the pore size distribution characteristic of the compacted geomaterials has been established using MIP technique. The geomaterials compacted for the desired density and water content was freeze dried and tested in MIP for their pore size distribution characteristics and the same is presented in the form of Fig. 3 and 4. Further the log-differential curve of Na-BT shown in Fig. 3 exhibits a bimodal pattern, which explains the type of the pores present in the soil i.e. the pore size distribution of Na-BT is mainly contributed by two types of pores. The peak associated with large diameter pores (inter pores) represents the water molecules bounded between soil aggregates whereas the peak associated with smaller diameter pores (intra pores) are related to the water molecules bounded within the soil aggregated and on the clay surface (Romero *et al*., 1999). From the obtained pore size distribution and log-differential curve of KT mineral shown in Fig. 4, it was inferred that the KT mineral exhibits a unimodal pattern i.e. the pore size distribution of KT mineral is mainly influenced by the inter pore volume rather than the intra pore volume. As kaolinite mineral is 1:1 mineral having hydrogen bonding between the successive clay layers, the interlayer swelling of kaolinite mineral is significantly less (Mitchell 1976) due to which the formation of intra pores in kaolinite mineral is significantly very low when compared to that of sodium bentonite. The measured inter and intra pore volumes of selected geomaterials are shown in Table 4.

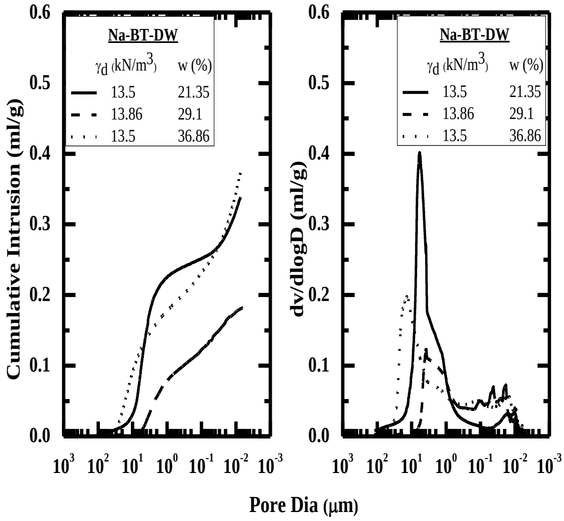

Fig. 3 PSD of Na-BT

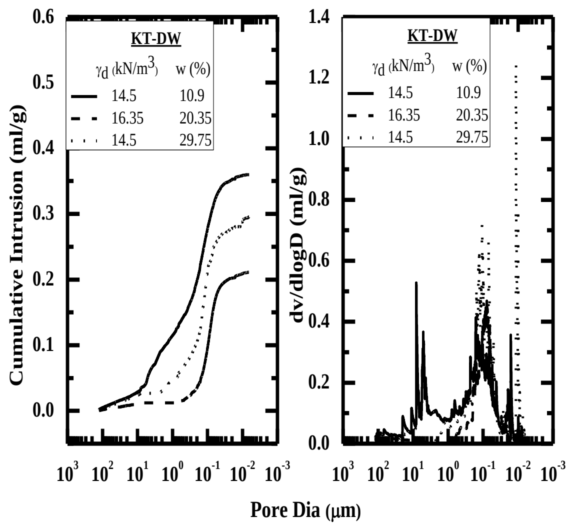

Fig.**4** PSD of KT

Table 4 Pore Volume Distribution of Geomaterials

Geomaterial	γ_d, kN/m^3	w (%)	Inter Pore Volume (ml/g)	Intra Pore Volume (ml/g)
Na-BT	13.5	21.35	0.25	0.088
	13.86	29.1	0.122	0.078

	13.5	36.86	0.231	0.142
	14.5	10.9	0.360	-
KT	16.35	20.35	0.211	-
	14.5	29.75	0.295	-

3 CONCLUSIONS

Based on the experimental results the following observation has been made.

- From the obtained pore size distribution curve of sodium bentonite it was observed that the increase in water content from dry of optimum to wet of optimum the inter pores have shifted to the left corresponding to larger diameter pores, the observed shift in the pore diameter is due to the volume and diameter expansion of free water held in between the soil aggregates (inter pores). Further the samples compacted at dry of optimum and optimum moisture content (OMC) exhibits similar particle size distribution pattern except that the samples compacted at optimum moisture content (OMC) have shown reduction in inter pores when compared with the samples compacted at dry of optimum
- The log-differential curve of sodium bentonite exhibits a bimodal pattern i.e. the pore size distribution of sodium bentonite is influenced by both inter and intra pore volume. In case of kaolinite mineral the pore size distribution is mainly contributed by the inter pore volume, which can be visualized from the its unimodal pattern
- From the measured inter and intra pore volume of sodium bentonite it was inferred that the sample compacted at wet side of optimum have higher intra pore volume when compared with sample compacted at other two compaction states. The obtained pore volume distribution dictates the increase in diffused double layer water formed around the clay surface when it is compacted at higher water content.
- In case of kaolinite mineral the formation of intra pore is negligible when compared with sodium bentonite, this is due to the fact that the hydrogen bonding between the successive clay layers of kaolinite mineral resist the interlayer swelling between the clay layers
- The UCS value of sodium bentonite compacted at wet side of optimum is higher when compared with soil compacted at optimum moisture content, whereas the UCS value of kaolinite mineral decreases with increase in water content. The observed change in UCS characteristics of sodium bentonite and kaolinite mineral is due to the fact that UCS strength variation of montmorillonite mineral is mainly contributed by the shear resistance offered by the diffused double layer water whereas the UCS strength of kaolinite mineral is controlled by the net attractive force between the clay minerals (Sridharan and Prakash, 1999).

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