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EFFECTS OF PERFECT SAMPLING DISTURBANCE ON UNDRAINED SHEAR PROPERTIES OF NORMALLY CONSOLIDATED AND OVERCONSOLIDATED DHAKA CLAY

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ABSTRACT: This paper presents the influence of perfect sampling disturbance on the undrained shear characteristics of reconstituted samples of normally consolidated and overconsolidated (OCR values of 2, 5 and 10) Dhaka clay. Reconstituted samples of the soil were prepared in the laboratory by K_0-consolidation of slurries. Undrained triaxial compression tests were performed on "in situ" and "perfect" samples of normally consolidated and overconsolidated Dhaka clay. The experimental indicated that, compared with "in situ" sample, undrained shear strength (s_u) and Skempton's pore pressure parameter, A at peak deviator stress (A_p) of "perfect" samples decreased. Axial strain at peak deviator stress (ε_p), initial tangent modulus (E_i) and secant modulus at half the peak deviator stress (E_{50}), however increased because of disturbance due to "perfect" sampling. It has found that the decrease in the values of s_u increased with increasing OCR values, while the reduction in the values of A_p decreased with increasing values of OCR. Increase in the values of ε_p increased with increasing OCR values, while the increase in the values of E_i and E_{50} reduced with increasing OCR values of the "perfect" samples. The nature of the effective stress path of the normally consolidated "perfect" sample was markedly different from that of the "in situ" sample. Effective stress paths of the overconsolidated "in situ" and "perfect" samples, however, were similar in nature

KEYWORDS: Clay, triaxial test, sample disturbance, shear strength, stiffness, overconsolidation ratio, pore pressure

INTRODUCTION

The engineering properties of soils needed for geotechnical analyses and designs are estimated either from results of laboratory or in-situ testing. In situ testing suffers from a number of disadvantages, so that it is not entirely a satisfactory procedure. These disadvantages include poorly defined boundary conditions in terms of stresses and deformations and uncertain drainage condition of the soil under investigation (Jamiolkowski et al., 1985). Laboratory testing is carried out on soil samples having previously retrieved it from the ground using form of sampling procedure. In the laboratory the stresses, deformations and boundary conditions can be more readily and precisely controlled and observed (Jamiokowshi et al., 1985). Sampling approach is therefore widely adopted.

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However, the inherent problem with the sampling approach is that the process disturbs the soil sample. This disturbance can be significant such that the behaviour of the laboratory differs markedly from its in situ behaviour. The significance of the soil depends on many factors including the type of soil, the method of sampling, sealing, storage and specimen preparation and testing procedure. During sampling process, soil is disturbed in two major ways. Firstly, mechanical disturbance is caused by inserting sample tubes into the soil which produces shear distortion and subsequent compression of soil close to the inside wall of the tubes (Schjetne, 1971). This disturbance is termed as tube penetration disturbance. The source of this disturbance is directly associated with sampler design and can be controlled to certain extent. Secondly, the disturbance can be experienced as a result of stress relief due to removal from the field to zero total stress state in the laboratory. This disturbance is termed as stress relief disturbance or perfect sampling disturbance. However disturbance due to stress relief is unavoidable even though its effects may be different depending on the depth of sampling and soil properties and present states. In order to understand the effects of perfect sampling on the undrained shear characteristics of clay, a number of researchers (Skempton and Sowa, 1963; Ladd and Lambe, 1963; Hight et al., 1985) have idealized the process of stress relief in the laboratory either by undrained release of the total deviator stress to zero from an "in situ" anisotropic condition, but maintaining an isotropic total stress state. Others, however, simulated relief by unloading both the deviator stress and isotropic stress to zero, i. e., by reducing the total stresses to zero (Noorany and Seed, 1965; Adams and Radakishna, 1971; Kirkpatrick and Khan, 1984; Hight et al., 1985; Kirkpatrick et al., 1986; Graham and Lau, 1988, Siddique and Farooq, 1996; Bashar et al., 1997; Siddique and Sarker, 1998). A summary of the effect perfect sampling on some engineering properties of some is presented in Table 1. In Table 1, all ratios referred to results from "in situ" samples. It can be seen from Table 1 that, in general, the effects of "perfect" sampling include reduction in undrained strength and an increase in strain at peak deviator stress.

This paper presents the results of further investigation into the effects of perfect sampling disturbance on the undrained stress-strain-strength, stiffness and pore pressure characteristics of normally consolidated and overconsolidated Dhaka clay at different overconsolidation ratios.

SOIL USED

Reddish brown Dhaka clay collected from Rupnagor Housing Project, Mirpur-11, Dhaka has been used in this investigation. Sampling was carried out according to standard procedure. Approximately 1 m by 1 m area was excavated to a depth of 1.5 m to 2

m. Disturbed samples were collected from the bottom of the borrow pit through excavation by hand shovels. The index properties and classification of the clay are according to Unified Soil Classification System (USCS) are listed below:

Specific Gravity	Liquid limit	Plasticity index	Clay fraction	Activity	USCS symbol
					2.
69	47	26	27%	0.81	CL

Table 1. Summary of the Effects of Stress Relief Disturbance on Some Engineering Properties of Clays at different OCR values

Soil	Index Values	OCR	Ratio of s_u	Ratio of ε_p	Ratio of E_i	Ratio of E_{50}	Ratio of A_p	Reference
Weald Clay	LL = 46 PI = 24	1.0	0.98	1.29	-	-	-	Skempton and Sowa (1963)
		2.0	1.03	0.88	-	-	-	
		14.0	1.08	-	-	-	-	
Soft Clay	LL = 88 PI = 45	1.0	0.95	1.05	0.9	-	-	Noorany and Seed (1965)
Boston Blue Clay	LL = 33 PI = 15	1.0	0.93	2.5	-	-	-	Ladd and Varallyay (1965)
Kaolin	PI = 30	1.0	0.44	2.75	0.76	-	-	Kirkpatrick and Khan (1984)
Illite	PI = 40	1.0	0.58	3.50	0.78	-	-	
North Sea Clay	LL = 32 PI = 17	1.0	0.72	8.00	1.19	-	-	Hight et al. (1985)
		7.4	0.96	1.00	0.47	-	-	
Kaolin	PI = 30	2.0	0.54	1.75	0.46	-	-	Kirkpatirick et al. (1986)
Illite	PI = 40	2.7	0.62	2.50	0.52	-	-	
Illite	PI = 40	5.0	0.86	1.10	0.94	-	-	
Paten-gha Clay	LL =44 PI = 18	1.0	0.87	1.32	1.40	-	0.32	Siddique and Farooq (1996)
Kumira Clay	LL = 57 PI = 33	1.0	0.93	1.24	1.47	-	0.17	
Bans-khali Clay	LL = 34 PI = 10	1.0	0.89	1.27	1.06	1.10	0.54	Bashar et al. (1997)
Anwara Clay	LL = 40 PI = 16	1.0	0.92	1.21	1.08	1.07	0.50	
Chan-danaish Clay	LL = 45 PI = 20	1.0	0.96	1.17	1.09	1.08	0.44	
Dhaka Clay	LL = 45 PI = 23	1.0	0.97	1.16	1.67	1.40	0.36	Siddique and Sarker (1998)

PREPARATION OF RECONSTITUTED SAMPLES

Reconstituted samples are those which are prepared by breaking down natural soils, sieving by No. 40 sieve, mixing them as slurry and reconsolidating them. Reconstituted samples enable to establish a general pattern of behaviour (Jardine, 1985). The major advantages of using data from reconstituted samples are the ambiguous and substantial effects of inhomogeneity can be eliminated, while the essential stress history and composition of in situ soils can be represented. In order to comparative study between "in situ" and "perfect" reconstituted samples have, therefore, been used to study the stress-strain-strength, stiffness and pore pressure characteristics of normally consolidated (OCR = 1) and overconsolidated Dhaka clays having OCR values of 2, 5 and 10 in triaxial compression test machine.

Reconstituted normally consolidated (OCR = 1) samples of Dhaka clays were prepared in the laboratory by K_0-consolidation of a uniform slurry of the clay in a cylindrical consolidation cell of 260 mm diameter and 305 mm in height. The slurry had water content of approximately 1.5 times the liquid limits of the soil. The slurry was allowed to consolidate by the self-weight of the sample and then gradually increased to 150 kN/m^2 over a period of nine to ten days. The reconstituted normally consolidated soil cake or block thus prepared, was extruded from the consolidation cell. The average water content and bulk density of soil block were determined. The values of moisture content and bulk density of the normally consolidated samples were 28 ± 0.5% and 19.5 ± 0.2 kN/m^3, respectively.

EQUIPMENT AND INSTRUMENTATION

For the determination of undrained shear properties of the samples a strain controlled triaxial apparatus together with volume change and pore pressure measuring devices were used. Soil lathe was used to trim the sample to the required dimension. The cell had the facility of drainage through both top and bottom of the sample. Cell pressure was applied using a standard pressure gauge of operating of 0 to 1700 kN/m^2. Back pressure was applied using dash pot and control cylinder system. For measuring axial deformation, a strain gauge with a resolution of 0.0254 mm was used. Mercury pore pressure null indicator has been used to monitor pore pressure. A burette system (Bishop and Donald, 1961) was used for measuring volume change during consolidation.

TYPES OF TEST SAMPLES

"In situ" Samples

The soil cake prepared by K_0-consolidation was extruded from the consolidation cell. The cake was sliced by the wire knife into small blocks and samples of nominal dimensions of 38 mm diameter by 76 mm high was prepared by trimming a block sample using piano wire, a soil lathe and a split mould. These samples were consolidated under K_0-conditions (K_0 = 0.50) in the triaxial cell to its in situ vertical effective stress, σ'_{vc} i. e., 150 kN/m^2 to prepare normally consolidated (i, e., OCR = 1). The maximum vertical effective stress of 150 kN/m^2 was reduced to 75 kN/m^2, 30 kN/m^2 and 15 kN/m^2 to prepare overconsolidated samples of OCR values of 2, 5 and 10, respectively. A back pressure of 270 kN/m^2 has been used during K_0-consolidation and swelling of the samples. These samples have been termed as "in situ" samples. The "in situ" samples prepared from Dhaka clay for OCR values 1, 2, 5 and 10 have been designated OCR1-I, OCR2-I, OCR5-I and OCR10-I, respectively.

"Perfect" Samples

These types of samples were prepared from respective "in situ" samples in the triaxial cell. The in situ shear stress, i.e., deviator stress of the "in situ" sample was first released from its in situ anisotropic stress condition. At this stage, the sample was subjected to an all-round isotropic stress (i.e., cell pressure). The cell pressure was then reduced zero and thereby the sample was subjected to zero total stress. This sample has been termed as "perfect" sample, obtained by the complete relief of the total in situ stresses. The "perfect" samples prepared from Dhaka clay for OCR values 1, 2, 5 and 10 have been designated OCR1-P, OCR2-P, OCR5-P and OCR10-P, respectively.

LABORATORY TESTING PROGRAMME

The test programme consisted of carrying out the following tests on normally consolidated and overconsolidated Dhaka clay:

(1) Firstly undrained triaxial compression tests on the four "in situ" samples were carried out in order to determine the reference "undisturbed" behaviour of the clays. In these tests after the completion of K_0-consolidation (for normally consolidated sample) and K_0-consolidation and swelling (for overconsolidated samples of OCR values 2, 5 and 10), each sample was sheared in undrained condition up to failure at a deformation rate of 0.02 mm/minute. A back pressure of 270 kN/m^2 has been used during consolidation prior to undrained shearing.

(2) Secondly, unconsolidated undrained triaxial compression tests were carried out on the four "perfect" samples. In these, tests, soon after simulation of the undrained release of the total respective "in situ" stress. Each sample was subjected to total isotropic stress (i. e. all-round cell pressure) equal to respective "in situ" vertical stress under undrained condition. When the pore water pressure became steady, each sample was sheared up to failure at a deformation rate 0.02 mm/minute.

EFFECT OF PERFECT SAMPLING ON UNDRAINED SHEAR PROPERTIES

Changes in Effective Stress paths

A comparison of the effective stress paths in s'- t' [s'= $(\sigma'_a+\sigma'_r)$ / 2, t'= $(\sigma'_a- \sigma'_r)$ /2] space for "in situ" and "perfect" samples (which simulated total stress relief) at four OCR values is presented in Fig 1. It can be seen from Fig. 1 that for the normally consolidated "in situ" samples, complete relief of total stresses, produced appreciably different effective stress path for the "perfect" samples.

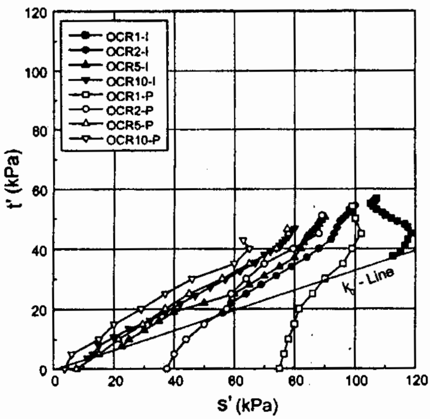

Fig 1. Comparison of effective stress paths of normally consolidated and overconsolidated "in situ" and "perfect" samples of Dhaka clay

Fig. 1 also shows that the nature of the effective stress paths of the overconsolidated "in situ" and "perfect" samples, are similar. Marked difference in the effective stress paths between the normally consolidated "in situ" and "perfect" samples have also been reported by several investigators (Skempton and Sowa, 1963; Ladd and Lambe, 1963; Atkinson and Kubba, 1981; Hight et al., 1985; Siddique and Farooq, 1996; Bashar et al., 1997; Siddique and Sarker, 1998).

Changes in Stress-Strain-Strength and Stiffness Properties

A comparison of the deviator stress versus axial strain plots for "in situ" and "perfect" samples at four OCR values is presented in Fig. 2. From the stress-strain data, the undrained strength (s_u), initial tangent modulus (E_i), secant modulus at half the peak deviator stress (E_{50}) and axial strain at peak deviator stress (ε_p) have been determined for both the "in situ" and "perfect" samples. A comparison the undrained shear parameters of the "in situ" and "perfect" samples is presented in Table 2. It can be seen from Table 2 that undrained shear strength of "perfect" samples reduced due to disturbance caused by the relief of total stress. Compared with "in situ" samples, the values of undrained shear strength of Dhaka clay decreased by about 4.4%, 5.9%, 7.9% and 8.2% for "perfect" samples of OCR values 1, 2, 5 and 10, respectively. Fig. 3 shows the plot of reduction in undrained shear strength with the increase in OCR. It can be seen from Fig. 3 that reduction in undrained shear strength increased with the increase in OCR for "perfect" samples of Dhaka clay. It has been found that value of ε_p increased by about 7.2%, 8.9%, 19.7% and 20.9% for "perfect" samples of OCR values 1, 2, 5 and 10, respectively. So, increase in ε_p increased with the increasing OCR for "perfect" samples of Dhaka clay. Reduction in undrained strength due to stress relief has been found for other normally consolidated clays by a number of researchers (Skempton and Sowa, 1963; Noorany and Seed 1965; Ladd and Varallyay, 1965; Atkinson and Kubba, 1981; Kirkpatrick and Khan, 1984; Hight et al., 1985; Graham et al., 1987, Siddique and Farooq, 1996; Bashar et al. 1997). Ladd and Varallyay (1965), Kirpatrick and Khan (1984), Graham et al. (1987), Siddique and Farooq (1996) and Bashar et al. (1997) also observed considerable increase in ε_p due to stress relief for reconstituted normally consolidated clays. Reduction in s_u and increase in ε_p due to stress relief has been also found by Hight et al. (1985) and Kirkpatrick et al. (1986) for reconstituted overconsolidated clays.

Plottings of secant stiffnesses (E_u) at small strain levels (up to 1%) for "in situ" and "perfect" samples of the reconstituted normally consolidated and overconsolidated Dhaka clay are shown in Fig. 4. It can be seen for Fig. 4 that, in general, secant stiffnesses of the "in situ" and "perfect" samples decreased with the increase in axial strain. It can also be seen from Fig. 4 that in each case, secant stiffness (at all strain levels) of the "perfect" sample is considerably higher than that for the "in situ" sample. For comparison, the values of secant stiffnesses (at 0.1% axial strain) of the "perfect" samples of OCR values 1, 2, 5 and 10 increased by 20%, 18.5%, 16% and 13.3%, respectively.

Table 2 also shows that because of disturbance due to stress relief, the initial tangent modulus (E_i) and secant modulus at half the peak deviator stress (E_{50}) increased. Fig. 5 shows that increase in E_i and E_{50} decreased with the increasing OCR for "perfect" samples of Dhaka clay. Compared with the "in situ" samples of the Dhaka clay, the values E_i increased by approximately 14%, 9.2%, 8.5% and 7.6% and E_{50} increased by approximately 19%, 10.9%, 10.8% and 9.9% for "perfect" samples of OCR values 1, 2, 5 and 10, respectively. Hight et al. (1985) and Kirkpatrick et al. (1986) found decrease in stiffness of overconsolidated clays while Bashar et al. (1997) and Siddique and Sarker (1998) found increase in stiffness of normally consolidated clays due to disturbance caused by stress relief.

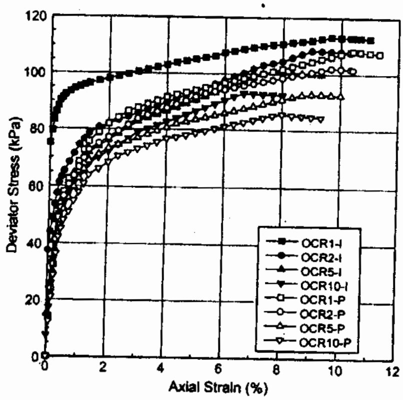

Fig 2. Deviator stress vs. axial strain plots for normally consolidated and overconsolidated "in situ" and "perfect" samples of Dhaka clay

Table 2. Undrained Shear Characteristics of "In Situ" and "Perfect" Samples

Sample Designation	S_u (kN/m²)	ε_p (%)	E_I (kN/m²)	E_{50} (kN/m²)	A_p
OCR1-P	54.1	10.4	32490	27300	0.043
OCR1-I	56.6	9.7	28500	22950	0.42
OCR2-P	51.0	9.8	28970	24120	0.039
OCR2-I	54.2	9.0	26530	21750	0.19
OCR5-P	46.4	9.1	26450	22650	0.035
OCR5-I	50.4	7.6	24380	20450	0.14
OCR10-P	42.8	8.1	23920	20830	0.036
OCR10-I	46.6	6.7	22230	18950	0.13

Changes in Pore Pressure Response

Fig. 6 shows a comparison of the changes in pore pressure during shearing between the "in situ" and "perfect" samples. It can be seen from Fig. 6 that compared with the "in situ" sample, the changes in pore pressure for the "perfect" sample is considerably less. From Fig. 6, it appears that for both "in situ" and "perfect" samples at small strains (up to 2.5%), the pore pressure increases rapidly with the increase in deviator stress and then pore pressure remains fairly with the increase in axial strain. Skempton's pore pressure parameters A at peak deviator stress (A_p) were determined from pore pressure data for the "in situ" and "perfect" samples which are also shown Table 2. It can also be seen from Table 2 that the value of A_p of about 89%, 79%, 75% and 72% are less than that of the "in situ" samples for "perfect" samples of OCR values 1, 2, 5 and 10, respectively. Therefore, decrease in the values of A_p reduced with the increasing OCR for "perfect" samples of Dhaka clay as shown in Fig. 7. Significant reduction in the values of A_p due to stress relief for reconstituted normally consolidated clays has also been reported by other investigators (Siddique and Farooq, 1996; Bashar et al. 1997 and Siddique and Sarker, 1998).

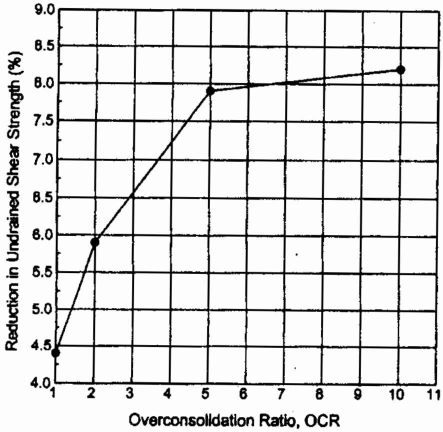

Fig 3. Variation of reduction in undrained shear strength with OCR for "perfect" samples of Dhaka clay

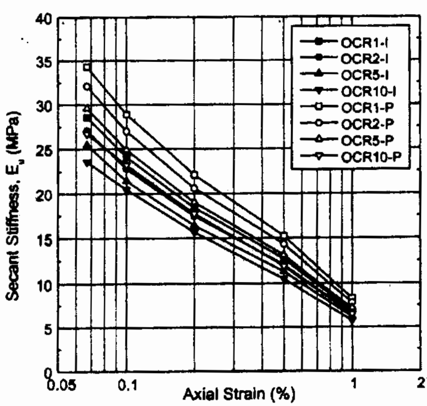

Fig 4. Secant stiffness vs. axial strain plots of normally consolidated and overconsolidated "in situ" and "perfect" samples of Dhaka clay

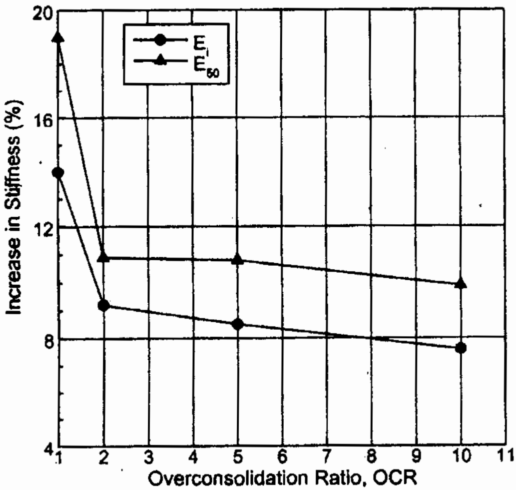

Fig. 5. Variation of percentage increase in E_i and E_{50} with OCR for "perfect" samples of Dhaka clay

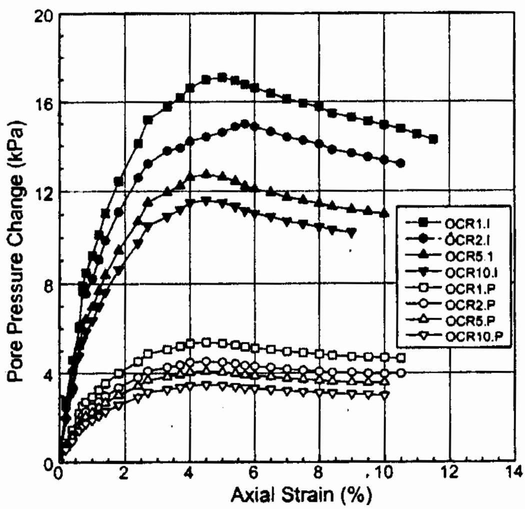

Fig 6. Pore pressure change vs. axial strain plots of normally consolidated and overconsolidated "in situ" and "perfect" samples of Dhaka clay

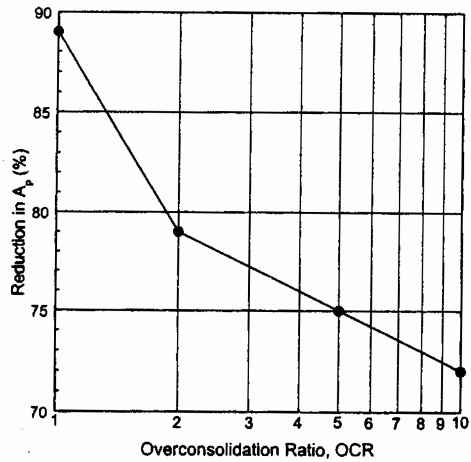

Fig 7. Variation of percentage reduction in A_p with OCR for "perfect" samples of Dhaka clay

CONCLUSIONS

Influences of perfect sampling disturbance on undrained stress-strain-strength, stiffness and pore pressure characteristics of reconstituted normally consolidated and overconsolidated Dhaka clay have been investigated. The major findings and conclusions can be summarised as follows:

- The nature of the effective stress path of the normally consolidated (OCR = 1) "perfect" sample was markedly different from that of the "in situ" sample. The nature of the effective stress paths of the overconsolidated (OCR = 2, 5 and 10) "in situ" and "perfect" samples, however were similar.
- Disturbance due to perfect sampling led to reduction in the values of s_u while the values of E_i, E_{50} and ε_p increased because of disturbance due to total stress relief.
- Compared with "in situ" samples, the pore pressure changes of the "perfect" samples are very small, resulting in much lower values of A_p for the "perfect" samples.
- The reduction in s_u increased with the increase in OCR-values.
- The increase in value of ε_p increased with increasing OCR-values. The increase in the values of E_i and E_{50} decreased with the increase in OCR-values.
- The reduction in value of A_p decreased with increasing OCR-values.

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NOTATION

A	Skempton's pore pressure parameter
A_p	Skempton's pore pressure parameter A at peak deviator stress
E_i	undrained initial tangent modulus
E_u	undrained secant stiffness
E_{50}	undrained secant stiffness at half the maximum deviator stress
K_0	coefficient of earth pressure at rest
OCR	overconsolidation ratio
LL	liquid limit
PL	plastic limit
PI	plasticity index
s_u	undrained shear strength
s'	$(\sigma'_a + \sigma'_r)/2$
t'	$(\sigma'_a - \sigma'_r)/2$
ε_p	axial strain at peak deviator stress
σ'_{vc}	"in situ" vertical effective consolidation stress
σ'_a	axial effective stress
σ'_r	radial effective stress

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