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EFFECT OF STRESS RELIEF DISTURBANCE ON UNDRAINED SHEAR PROPERTIES OF CHITTAGONG COASTAL SOILS

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ABSTRACT : This paper discusss the influence of stress relief disturbance on the undrained shear characteristics of three reconstituted K_0-normally consolidated soils of Chittagong coastal region. Reconstituted samples of the soils were prepared in the laboratory by Ko-consolidation of slurries. Undrained triaxial compression tests, with pore pressure measurements, were performed on "in situ" samples and samples which expreience stress relief disturbance, i.e., "perfect" samples. The experimental results on the three soils showed that, in each soil compared with the "in situ" sample, "perfet" sample suffered loss in undrained shear strength (s_u) and Skempton's pore pressure parameter, A at peak deviator stress (A_p). Disturbance due to "perfect" sampling also produced significant reduction in the mean effective stresses (p'). It has been found that the reductions in the values of s_u, A_p and p' increased with decreasing plasticity of the soils. Axial strain at peak deviator stress (ε_p), initial tangent modulus (E_i), secant modulus (E_{50}) and secant stiffness (E_u) at varuous small strain levels, however, increased for the "perfect" samples because of the disturbance caused by stress relief. Compared with the "in situ" samples the "perfect" samples produced appreciably different effective stress paths to failure.

KEY WORDS : Clay, triaxial test, sample disturbance, strength, stiffness, 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 conditions of the soil under investigation (Jamiolkowski, Ladd, Germaine and Lancellotta, 1985). Laboratory testing is carried out on soil samples having previously retrieved it from the ground using some form of sampling procedure. In the laboratory the stresses, deformations, and boundary conditions can be more readily and precisely controlled and observed (Jamiolkowshi 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 disburbs the soil sample. This distubrance can be significant such that the behaviour of the soil in the laboratory differs markedly from its in situ behaviour. The significance of the disturbance 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 of the sample 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. In order to understand the effects of "perfect" sampling on the undrained shear characteristics of clays, a number of researchers (Skempton and Sowa, 1963; Ladd and Lambe, 1963; Hight Gens and Jardine, 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 stess state. Others, however, simulated stress 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; Davis and Poulos, 1967; Kirkpatrick and Khan, 1984; Graham and Lau, 1988; Sarker, 1994; Siddique and Farooq, 1996). A summary of the effects of "perfect" sampling on some engineering properties of a few regional soils of Bangladesh is presented in Table 1. It can be seen from Table 1 that, in general, the effects include reduction in undrained strength, and an increase in strain at peak deviator stress and stiffness.

Table 1. Summary of the Effects of "Perfect" Sampling on Some Engineering Properties of a Few Regional Soils of Bangladesh

Soil	Index values	Ratio of s_u	Ratio of ε_p	Ratio of E_i	Reference
Dhaka clay	w_L=45,I_p=23	0.97	1.16	1.67	Sarker (1994)
Patenga soil+	w_L=44,I_p=18	0.87	1.32	1.40	Siddique and Farooq (1996)
Kumira soil+	w_L=57,I_p=33	0.93	1.24	1.47	Siddique and Farooq (1996)

All ratios referred to results from "in situ" samples.
\+ coastal soils

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 three soils collected from the chittagong coastal region.

SOILS USED

The Chittagong Coastal Plain comprises the generally narrow strip of land between the Chittagong hills and the sea, together with the Halda, the Karnafully and the Sangu floodplains and the offshore islands. This is known to be occupied by gently sloping piedmont alluvial fans with mainly loamy soils. Tidal clay plains occupy most of the offshore island. The fan deposits from the Chittagong hills and deposits of coastal currents are mixed in a complicated manner in the Chittagong coastal area. The geological formations and soil characteristics of this area are very complicated due to the multifold shallow bedrock of the above hills. For the present study disturbed soils were collected from Banskhali, Anwara and Chandanaish areas of the coastal belt of Chittagong. The soils were taken by excavating up to depth of about 2.5 m to 3 m using hand shovels. All samples were packed in large polythene bags and were eventually transported to the Laboratory. Index properties of the soils were determined in order to characterize the soil. Table 2 shows the index properties and classification of the soils investigated. It can be seen from Table 2 that specific gravity, liquid limit and plasticity index of the soils from Banskhali, Anwara and Chandanaish varied from 2.69 to 2.72 from 34 to 45 and from 10 to 20 respectively. The soils were also classified according to Unified Soil Classification System (USCS). The soils from Anwara and Chandanaish are clays of low to medium plasticity having group symbol CL while the soil from Banskhali is a clayey silt of low plasticity having group symbol ML.

Table 2. Index Properties and Classification of the Coastal Soils Used

Index Properties and Classification	Location		
	Banskhali	Anwara	Chandanaish
Specific Gravity	2.69	2.70	2.72
Liquid Limit, w_L	34	40	45
Plasticity Index, I_p	10	16	20
% Sand	4.2	2.7	1.5
% Silt	80.3	75.3	66.5
% Clay	15.5	22	32
Activity	0.65	0.73	0.63
USCS Symbol	ML	CL	CL

USCS: Unified Soil Classification System

PREPARATION OF RECONSTITUTED SAMPLES

Reconstituted samples are those which are prepared by breaking down natural soils, 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 that 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" samples reconstituted samples have, therefore, been used to study the stress-strain-strength, stiffness and pore pressure characteristics of the three soils. Reconstituted samples of three coastal soil were prepared in the laboratory by K_o-consolidation from slurry which had a water content of approximately 1.5 times the liquid limits of the soils. Initially the slurry was allowed to consolidate by the self weight of the sample and then gradually increassed to150 kN/m^2 over a period of seven to eight days. The reconstituted soil cake or block thus prepared, was extruded from the consolidation cell. The average water content and bulk density of each soil block were determined. Water contents of the reconstituted samples collected from Banskhali, Anwara and Chandanaish were 30.5 $\pm$ 0.5%, 31.2 $\pm$ 0.5% and 32 $\pm$ 0.75% respectively and the respective values of bulk density were 19.4 $\pm$ 0.07 kN/m^3, 19.7 $\pm$ 0.15 kN/m^3 and 19.5$\pm$ 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 range of 0 to 1700 kN/m^2. Back pressure was applied using dash pot and control cylinder system. For measuring axial derformation, a strain gauge with a resolution of 0.0254 mm was used. A Bell and Howell pore water pressure transducer of operating range of 0-1034kN/m^2 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

After extruding the reconstituted soil block from consolidation cell, the large soil block was sliced into small blocks by wire and knife and stored in dessicator. Before testing each small block was trimmed by using piano wire, soil lathe and a split mould to prepare a sample of nominal dimensions of 38 mm diameter by 76 mm high. These trimmed samples were consolidated under K_o-conditions (K_o = 0.47, 0.49 and 0.50

for the three soils from Banskhali, Anwara and Chandanaish respectively) in the triaxial cell to its "in situ" vertical effective stress, σ'_{vc} (i.e., 150kN/m^2). A back pressure of 270 kN/m^2 has been used during K_o-consolidation of the samples. These samples have been termed as "in situ" samples. The "in situ" samples prepared from the soils from Banskhali, Anwara and Chandanaish have been designated as BI, AI and CI repectively.

"Perfect" Samples

This type of sample was prepared from "in situ" sample 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 allround isotropic stress (i.e., cell pressure) . The cell pressure was than reduced to zero and thereby the sample was subjected to zero total stress. This sample has been termed as "perfect" sample obtained from the complete release of the total "in situ" stresses. The "perfect" samples prepared from soils from Banskhali, Anwara and Chandanaish, have been designated as BP, AP and CP respectively.

LABORATORY TESTING PROGRAMME

The test programme consisted of carrying out the following two types of tests on coastal soils :

(1) Firstly, undrained trixial compression tests on the three "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_o-consolidation, each sample was sheared up to failure at a deformation rate of 0.025 mm/minute. A back presure 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 three "perfect" samples. In these tests, soon after simulation of the undrained release of the total "in situ" stress, each sample was subjected to a total isotropic stress (i.e., allround cell pressure) equal to "in situ" vertical effective stress under undrained condition. When the pore water pressure became steady, each sample was sheared up to failure at a deformation rate of 0.025 mm/min.

RESULTS AND DISCUSSIONS

EFFECT OF "PERFECT" SAMPLING ON UNDRAINED SHEAR CHARACTERISTICS

Effective Stress Paths and Mean Effective Stress

Fig. 1 shows the effective stress paths in p'-q' [$p' = (\sigma'_a + 2\sigma'_r)/3$, $q' = (\sigma'_a - \sigma'_r)$] space for undrained triaxial compression tests on "in situ" and "perfect" samples for the three coastal soils. It can be seen from Fig. 1 that

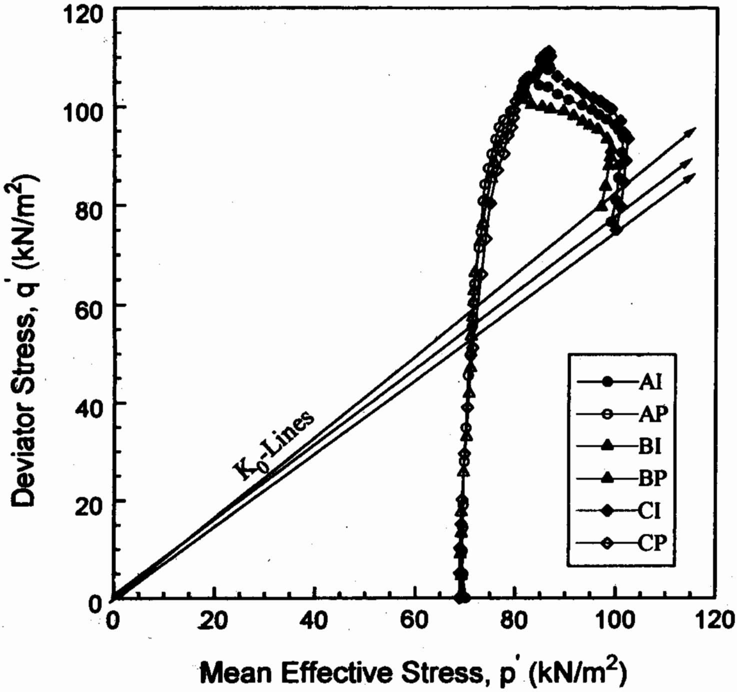

Fig 1. Comparison of Effective Stress Paths of "In Situ" and "Perfect" Samples for the Three Soils

for the "in situ" samples, initially mean effective stress (p') slightly increases with the increase in deviator stress (q') and then it decreases with further increase in q' and as failure approaches p' increases with the increase in q'. For the "perfect" samples, however, p' remains almost constant with the increase in q' during the most part of undrained shearing and as failure approaches p', however, slightly increases with the increase in q'. "Perfect" sampling, therefore, produced appreciably different effective stress paths. The effective stress paths for the "in situ" samples are typically similar to those of normally consolidated clays. However, although the "perfect" samples have been prepared from the normally consolidated "in situ" samples they adopt stress paths similar to those for overconsolidated samples. Marked difference in the effective stress paths between the "in situ" and "perfect" samples has also been reported by several investigators (Skempton and Sowa, 1963; Ladd and Lambe, 1963; Atkinson and Kubba, 1981; Sarker, 1994; Siddique and Farooq, 1996).

Another significant effect of "perfect" sampling is the reduction of mean effective stress, p' which is also evident from Fig. 1. Due to "perfect" sampling the mean effective stresses of the "in situ" samples of Banskhali, Anwara and Chandanaish reduced by 34.5%, 32.7% and 31% respectively. It is also evident that the reduction in p' due to "perfect" sampling disturbance increases with decreasing plasticity of the soils.

STRESS-STRAIN AND STIFFNESS PROPERTIES

A comparison of deviator stress (q') versus axial strain (ε) plots for the "in situ" and "perfect" samples of the three coastal soils is presented in Fig. 2. From the stress-strain data the undrained strength (s_u), axial

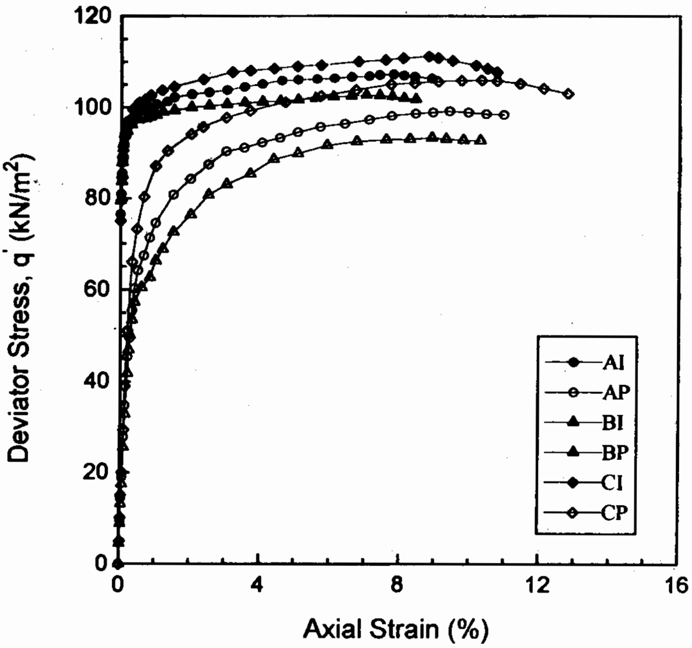

Fig 2. Deviator Stress vs. Axial Stain Plots for "In Situ" and "Perfect" Samples

strain at peak deviator stress (ε_p), initial tangent modulus (E_i), secant modulus at half the peak deviator stress (E_{50}), and secant stiffness (E_u) at small strain levels and have been determined for both the "in situ" and "perfect" samples. A comparison of the undrained soil parameters of the "in situ" and "perfect" samples is presented in Table 3. It can be seen from Table 3 that undrained shear strength of the "perfect" samples reduced due to disturbance caused by stress relief. The values of undrained strength of the "perfect" samples BP, AP and CP reduced by11.2%, 7.6% and 5.4% respectively.Values of Axial strainat peak deviator stress (ε_p), however, increased due to disturbance caused by stress relief. Values of ε_p

increased by 27.1% and 17% for the "perfect" samples BP, AP and CP respectively. Decrease in undrained strength due to stress relief has also been found for other normally consolidated clays by a number of researchers (Skemptonand Sowa, 1963; Noorany and Seed, 1965; Davis and Poulos,1967; Kirkpatrick and Khan, 1984; Sarker, 1994; Siddique and Farooq, 1996). Kirkpatrick and Khan (1984), Sarker (1994) and Siddique and Farooq (1996) also observed considerable increase in ε_p for normally consolidated kaolin (I_p = 30) and Illite (I_p = 40), reconstituted Dhaka clay (w_L = 45, I_p = 23) and two reconstituted coastal soils (w_L = 44 and I_p = 18; w_L = 57 and I_p = 33) respectively. It is also evident that the degree of reduction in undrained strength and increase in axial strain at peak deviator stress increases with decreasing plasticity of the soils. Kirkpatrick and Khan (1984) and Siddique and Farooq (1996) also found larger reduction in undrained strength in less plastic soils than in more plastic soils due to "perfect" sampling. A noticeable behaviour observed in these coastal soils, in that the values of ε_p for these samples (both "in situ" and "perfect") are considerably large. Similar results were also reported by Siddique and Farooq (1996) for other coastal soils of Bangladesh.

Table 3. Comparison of Undrained Shear Properties of "In Situ"and "Perfect" Samples of the Three Coastal Soils

Undrained Shear	Samples					
Parameters	BI	BP	AI	AP	CI	CP
s_u (kN/m^2)	51.0	45.3	53.6	49.5	55.5	52.5
ε_p (%)	7.0	8.9	7.8	9.4	8.8	10.3
E_i (kN/m^2)	24570	26118	26280	28350	27600	30150
E_{50} (kN/m^2)	18720	20685	19845	21300	22050	23850
A_p	0.76	0.41	0.74	0.37	0.71	0.31

Table 3 also shows that because of disturbance due to "perfect" sampling, both the initial tangent modulus (E_i) and secant modulus at half the peak deviator stress (E_{50}) increased. Compared with the "in situ" samples, the values of E_i of the "perfect" samples from Banskhali, Anwara and Chandanaish increased by 6.3%, 7.9% and 9.2% respectively while the values of E_{50} of the respective samples increased by 10.5%, 7.3% and 8.2% respectively. Hight, Gens and Jardine (1985), Sarker (1994) and Siddique and Farooq (1996) also found increase in initial stiffness in normally consolidated soils due to disturbance caused by stress relief.

Plottings of secant stiffnesses (E_u) at small strain levels (up to 1%) for "in situ" and "perfect" samples of the three coastal soils are shown in Fig. 3. It can be seen fro Fig. 3 that, in general, secant stiffnesses of the "in situ" and perfect" samples reduced with the increase in axial strain. It can also be seen from Fig. 3 that in each soil, secant stiffnesses (at all strain levels) of the "perfect" sample are considerably higher than those for the "in situ" sample. For comparison, the values of secant stiffnesses (at 0.1 % axial strain) of the "perfect " samples from Banskhali, Anwara and Chandanaish increased by about 19%, 18% and 21.7% respectively.

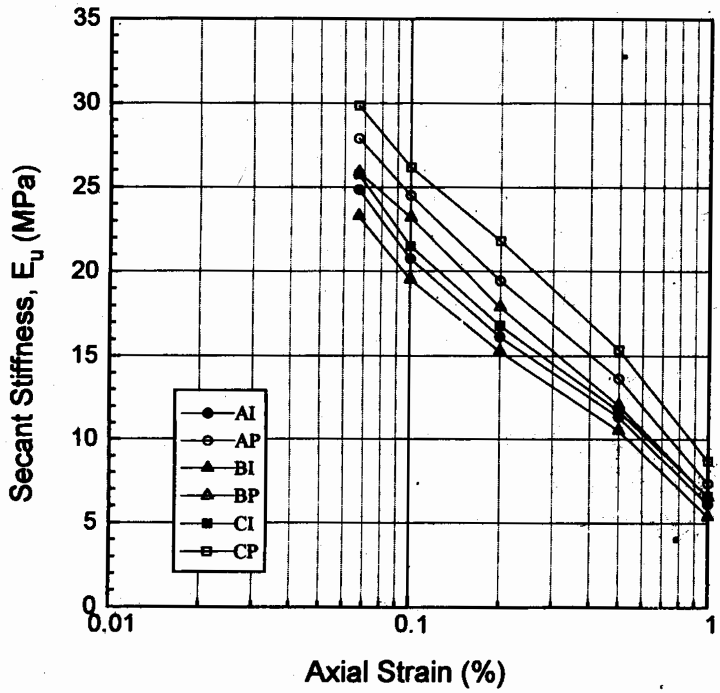

Fig 3. Secant Stiffness vs. Axial Strain Plots for "In Situ" and "Perfect" Samples of the Three Soils

PORE PRESSUR ERESPONSES

Fig. 4 shows the comparison of Skempton's pore pressure parameter A with axial strain between the"in situ" and "perfect" samples of the three coastal soils. It can be observed from Fig. 4 that, compared with the "in situ" samples the values of Skempton's pore pressure parameter A for the "perfect" samples are considerably less. Tha values of Skempton's pore pressure parameter A at peak deviator stress, A_p were also determined and have been shown in Table 3. It can be seen from Table 3 that for each soil, the values of A_p of the "perfect" sample are considerably less than

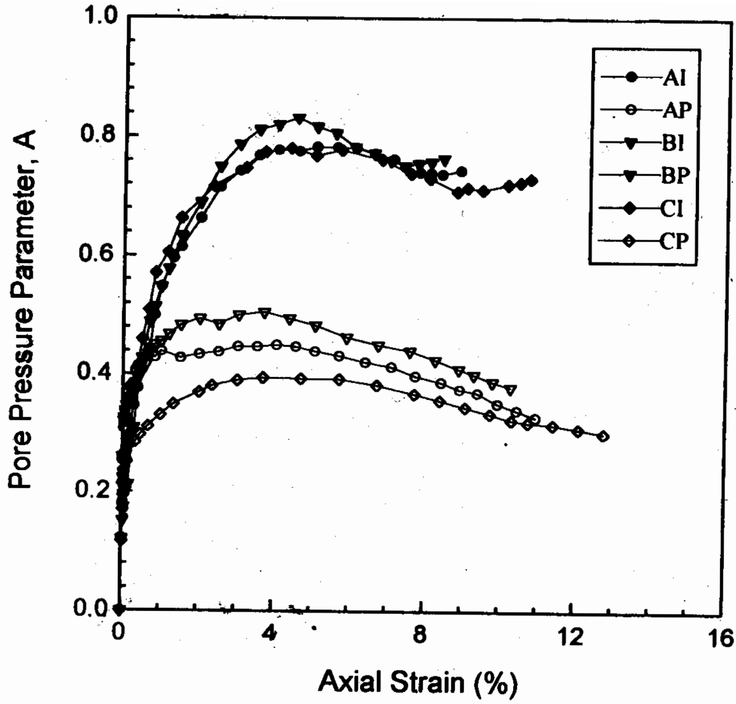

Fig 4. Comparison of Pore Pressure Parameter. A vs. Axial Strain Plots for "In Situ" and "Perfect" Samples

that for the "in situ" sample. The values of A_p reduced by 46.1%, 50% and 56.3% for "perfect" samples BP, AP and CP respectively because of disturbance caused by stress relife. These results also indicate that the reduction in the values of A_p increased with increasing plasticity of the soils. Similar findings were also reported by Siddique and Farooq (1996) for other coastal soils. Significant reduction in A_p due to stress relief has also been reported by a number of investigators (Noorany and Seed, 1965; Kirkpatrick and Khan, 1984; Sarker, 1994; Siddique and Farooq, 1996).

CONCLUSIONS

Effects of stress relief or "perfect" sampling disturbance on undrained stress-strain-strength, stiffness and pore pressure characteristics of the three coastal soils of Chittagong have been investigated. Compared with the "in situ" samples, "perfect" sampling produced appreciably different effective stress paths. Although the"perfect" samples have been prepared from normally consolidated "in situ" samples, they adopt stress paths similar to those of overconsolidated samples. Experimental results indicate that for each soil compared with the "in situ" sample, the values of s_u, A_p and p' of the "perfect" sample were reduced while the values of ε_p, E_i, and E_{50} and E_u (at small strains) of the "perfect" sample were increased due to distrubance caused by stress relief. For the three soils studied, compared with the "in situ" samples the values of s_u, A_p and p' of "perfect" samples were reduced up to 11.2%, 56.3% and 34.5% respectively and it has been found that the reductions in the values of s_u, A_p and p' increased with decreasing plasticity of the soils. However, the degree of increase in the values of ε_p increases with decreasing plasticity of the soils. Both the values of E_i and E_{50} increased up to 9.2% and 10.5% respectively while the value of E_u (at 0.1% axial strain) increased up to 21.7%. The values of A_p of the "perfect" samples reduced markedly up to 56.3% and it has been observed that the reduction in the values of A_p increased with increasing of plasticity of the soils.

From the aforementioned effects of "perfect" sampling disturbances in unaged Chittagong coastal soils, it is evident that sbustantial changes in the effective stress path and undrained soil parameters between the "in situ" and "perfect" samples occurred. Therefore, appropriate technique should be adopted to minimize the "perfect" sampling effects in these coastal soils. Although the effect of reconsolidation of "perfect" samples in order to restore the "in situ" behaviour for these unaged samples was not investigated, this suggests the need to minimize the "perfect" sampling disturbance by reconsolidating before being sheared using either the Bjerrum (1973) procedure (i.e., anisotropic reconsolidation to in situ stress under K_o-condition) or the SHANSEP (Ladd and Foott, 1974) procedures (i.e., anisotropic reconsolidation under K_o-condition to a pressure at least equal to 1.5 to 2 times the in situ vertical effective stress).

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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	initial tangent modulus
E_u	secant modulus at any stress level
E_{50}	secant modulus at half the peak deviator stress
I_p	Plasticity index
K_o	coefficient of earth pressure at rest
p'	mean effective stress = $(\sigma'_a+2\sigma'_r)/3$
q'	deviator stress = $\sigma'_a - \sigma'_r$
s_u	undrained shear strength
w_L	liquid limit
w_p	plastic limit
ε	axial strain
ε_p	axial strain at peak deviator stress
σ'_a	axial effective stress
σ'_r	radial effective stress
σ'_{vc}	in situ vertical effective stress