Modelling the stress-strain response of coastal clay of Anwara

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ABSTRACT

An experimental investigation was conducted to study the undrained triaxial behaviour of some coastal clays of Bangladesh. The critical state parameters for these clays were computed and the undrained triaxial behaviour such as stress-strain, stress path and pore pressure responses for different overconsolidation ratios and various cell pressures were studied. The Modified Cam Clay (MCC) model was used to numerically predict the undrained stress-strain, stress path and excess pore pressure responses of a typical coastal clay from Anwara for various cell pressures and overconsolidation ratios. The numerical predictions were compared with the experimental behaviour. Reasonably good agreement was obtained between the experimental results and numerical predictions.

1 INTRODUCTION

The coastal region of Bangladesh comprises of the Chittagong coastal zone and the deltaic arcs of Khulna, Patuakhali and Noakhali. Flood protection embankments and cyclone shelters are needed in these regions. A proper understanding of the stress-strain characteristics of coastal clays in this region may help to design safe and economic foundations for such structures.

An experimental and numerical study of the coastal clays of three locations of the Chittagong coastal area of Bangladesh was carried out. Coastal clays of Chittagong were collected, remolded and then consolidated in the laboratory. This paper presents the results obtained from that study.

2 STRESS-STRAIN BEHAVIOUR OF COASTAL CLAYS

Experimental investigation of coastal clays of Bangladesh during isotropic consolidation and shearing, both under drained and undrained conditions, have been carried out by several researchers (Amin et al. 1987, Bashar 2002 & Siddique 2006). Some classic studies of marine clays have also been carried out by various researchers in the past. However, carefully controlled stress-strain tests of Bangladesh coastal clays under undrained conditions using the triaxial apparatus was first carried out by (Bashar 2002). The authors of this paper have used the Modified Cam Clay (MCC) model to numerically simulate the experimentally obtained triaxial stress-strain response of the remolded coastal clays of Bangladesh experimentally obtained by Bashar (2002).

3 MODIFIED CAM CLAY (MCC) MODEL

The MCC model was proposed by Roscoe and Burland (1968). The model has been used with relative success to predict the stress-strain behaviour of remolded and normally consolidated and lightly overconsolidated clays. Thus it was thought appropriate to use the MCC model to predict the stress-strain response of remoulded Bangladesh coastal clays. The MCC model is a volumetric strain hardening model within the critical state framework. The model assumes an elliptic yield locus at $p' - q$ space, where p' is the mean effective normal stress and q is the deviator stress. The model follows an associated flow rule. Thus the yield and the plastic potential function for the MCC model are identical and they are described by the equation as given below:

$$\left(\frac{q}{Mp'}\right)^2 = \frac{p'_o}{p'} - 1 \tag{1}$$

In equation (1), p'_o is the preconsolidation pressure of the soil and M is the slope of the critical state line (CSL) on $q - p'$ plane. The CSL represents the locus of possible ultimate stress states of the soil.

Stress states within the region of yield surface are assumed to be elastic. When a stress state is on the yield surface and an increment of applied stress is directed to the outward region of that surface, plastic incremental compressive and shear strains are assumed to occur. In the MCC model, as the soil compresses plastically, it's void ratio decreases, the soil hardens and the value of the preconsolidation pressure p'_o increases. p'_o is called the hardening parameter. p'_o is a monotonically increasing function of plastic volumetric strain. Hardening results in the expansion of the yield function such that the current stress state lies on the new expanded yield surface. The plastic hardening function may be derived from the $e - \ln p'$ curve of the soil as follows:

$$\frac{dp'_o}{d\varepsilon_v^p} = \frac{p'_o(1+e)}{(\lambda - \kappa)} \tag{2}$$

In the above equation, p'_o is the preconsolidation pressure, dp'_o is the increase of the preconsolidation pressure due to hardening, e is the current void ratio of the soil and $d\varepsilon_v^p$ is the incremental plastic volumetric strain. λ and κ are respectively the slope of the normal consolidation line and elastic rebound line of the $e - \ln p'$ curve.

The elastic stress-strain response of the soil in the MCC model is described by the elastic bulk modulus K and elastic shear modulus G. K is obtained from the unload-reload portion of the $e - \ln p'$ curve as follows :

$$K = \frac{dp'}{d\varepsilon_v^e} = \frac{p'(1+e)}{\kappa} \tag{3}$$

In equation (3), $d\varepsilon_v^e$ is the elastic part of the incremental volumetric strain. The elastic shear modulus G may be computed from the bulk modulus K and elastic Poisson's ratio μ as follows:

$$G = \frac{3(1-2\mu)}{2(1+\mu)}K \tag{4}$$

In the MCC model, both the elastic shear modulus G and elastic bulk modulus K are nonlinear and varies directly with the mean effective stress p' and current void ratio e.

4 MODIFIED CAM CLAY PARAMETERS FOR COASTAL CLAYS

The MCC model parameters for Bangladesh coastal clays were obtained from conventional laboratory tests by Bashar (2002) and Siddiquee (2006). The consolidation curve for the coastal clays were obtained in the laboratory from which the slope of the elastic rebound curve κ, the slope of the normal consolidation curve λ, the void ratio N at unit pressure on the normal consolidation line and the initial preconsolidation pressure p'_o was determined. The critical state line and the slope of the critical state line M was determined from staged CU tests with pore pressure measurements. An appropriate value for elastic Poisson's ratio μ for undrained simulation of clays using the MCC model was assumed from the literature. The geotechnical parameters for Anwara clay located in the coastal region of Chittagong of Bangladesh are given in Table 1 below.

Table 1: Soil parameters for Anwara clay

Parameter	Value
λ	0.128
κ	0.023
M	1.32
p'_o (kPa)	150
N	1.37
LL(%)	40
PI(%)	16

5 CONSOLIDATED UNDRAINED SHEARING (CIU) OF COASTAL CLAYS

Clay slurry was prepared using coastal clay samples with initial water content close to the liquid limit of the soil. The slurry was poured in a cylindrical consolidation cell and consolidated under k_0 conditions. For the first 24 hours, the soil slurry consolidated on it's self weight. Subsequently, the required consolidation pressure of 150 kPa was gradually applied on the slurry sample using a loading frame and proving ring in 10 equal increments applied for 24 hours each. The final pressure was maintained until the load displacement curve indicated the end of primary consolidation.

Block samples of the coastal clay were obtained from the consolidation cell from which triaxial samples were prepared. The samples were first isotropically consolidated to a cell pressure of 150 kPa and then subjected to undrained shearing in a triaxial apparatus (Bashar 2002). A series of soil samples were sheared in this process. For other samples, after applying the consolidation pressure of 150 kPa, the cell pressure was first reduced to 100, 75, 30, 15, 7.5 and 5 kPa respectively and then sheared. Thus for these soil samples, isotropic overconsolidation ratios (OCRs) of 1, 1.5, 2, 5, 10, 20 and 30 respectively were achieved. For each of the sheared samples, the curves of deviator stress q by axial strain ε_a, the deviator stress q by mean effective pressure p' and excess pore pressure u by axial strain ε_a were plotted (Bashar 2002).

6 PREDICTION OF CIU RESPONSE OF COASTAL CLAYS

The consolidated undrained triaxial shearing of coastal clays at various OCR's were numerically simulated by a single element finite element model using the program AFENA (Carter & Balaam 1995). The MCC model was used as the constitutive model to simulate the stress-strain response of the element. As the triaxial test data at low cell pressures and high overconsolidation ratios may not have an adequate level of accuracy, experimental data and corresponding MCC model simulations for Anwara clay for overconsolidation ratios of only 1, 2 and 5 respectively are presented in this paper.

Figure 1 shows the predicted (continuous lines) and observed (symbols) undrained stress-strain response for Anwara clay in triaxial shear. It is seen that the MCC model predicts non-linear strain hardening response of the clay before the ultimate stress state is reached. Figure 2 shows the predicted (continuous lines) and observed (symbols) undrained stress paths for Anwara clay during undrained triaxial shear. It is observed that the both the stress-strain response and stress paths for normally consolidated and lightly overconsolidated Anwara clays are reasonably well predicted by the MCC model. Figure 3 shows the predicted (continuous lines) and observed (symbols) excess pore pressure response during undrained triaxial shear of normally consolidated Anwara clay. In this case predictions were obtained using the MCC model for overconsolidation ratios of 1, 2 and 5. However, the experimental data for excess pore pressure response for normally consolidated case only was available from Bashar (2002).

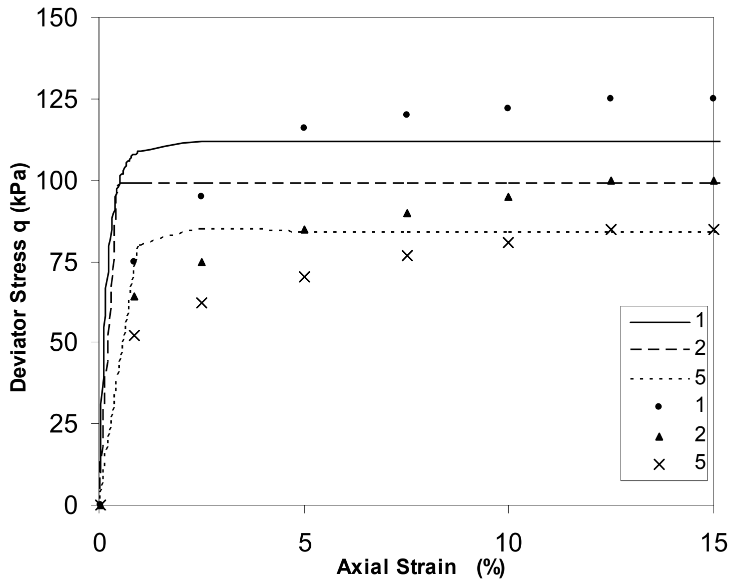

Figure 1: MCC prediction (continuous lines) and test data (symbols) of undrained stress-strain response of Anwara clay for OCR values of 1, 2 and 5

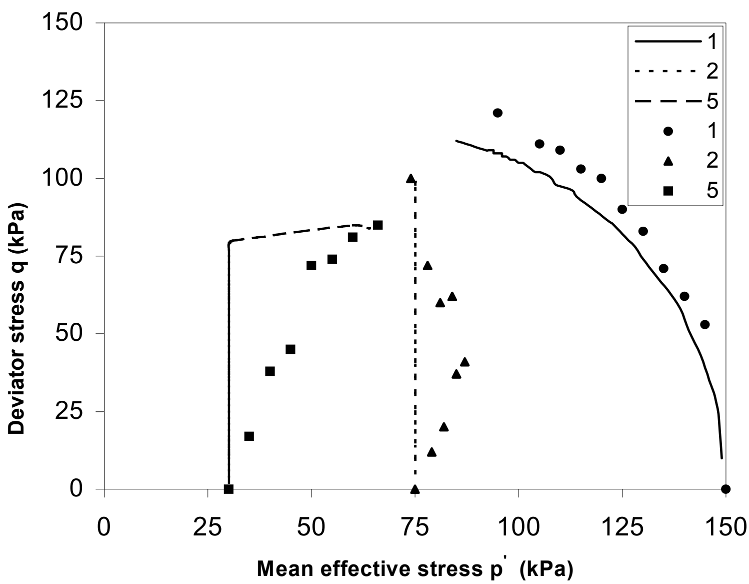

Figure 2: MCC prediction (continuous lines) and test data (symbols) of undrained triaxial stress path of Anwara clay for OCR values of 1, 2 and 5

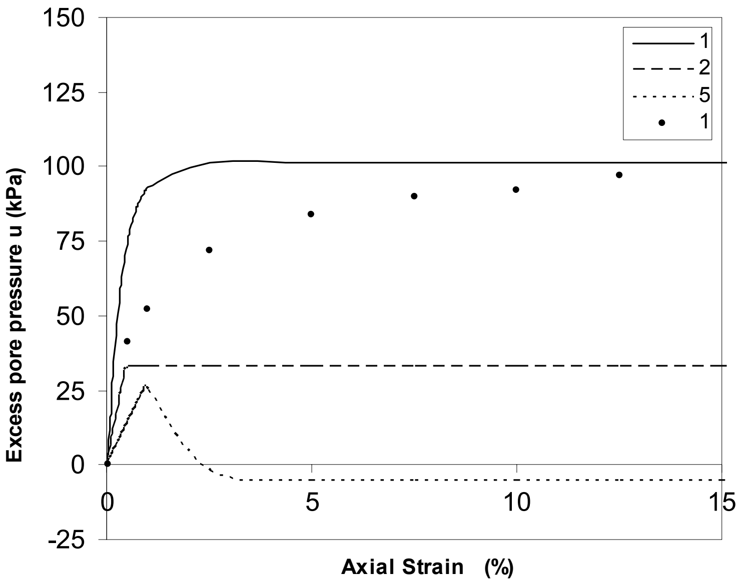

Figure 3: MCC prediction (continuous lines) of excess pore pressure response of Anwara clay for OCR values of 1, 2 and 5; test data (symbols) for OCR value of 1 only was available

7 SUMMARY AND CONCLUSIONS

The MCC model was used to predict the stress-strain, excess pore pressure and effective stress path of remolded Anwara clay obtained from a coastal region of Bangladesh. The remolded clay samples were sheared in a triaxial apparatus under undrained conditions. It was observed that the MCC model is a reasonable tool for prediction of the undrained shear response of a typical coastal clay of Bangladesh. It is capable of predicting the strain hardening response of the coastal clay as observed experimentally. The MCC model predicts an elastic response for light to moderately overconsolidated clays before the onset of yield. However, an observation of the effective stress path and stress-strain response of the coastal clay indicate some elasto-plastic behaviour for overconsolidated clays from the onset of load application. The inability of the MCC model to predict such response before the onset of yield is a limitation of this model. However, as a whole, the MCC model appears to be quite suitable to predict the observed response of coastal clay of Anwara during undrained triaxial shear.

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