Modelling the stress-strain response of a cemented regional clay

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ABSTRACT

A regional clay was stabilized with ordinary Portland cement using various cement contents. Critical state parameters of the clay with and without cement were evaluated experimentally. Undrained triaxial stress-strain and excess pore pressure response were predicted for remoulded and normally consolidated untreated and cemented clays. The Modified Cam Clay (MCC) model and its modified form incorporating cementation effects were used for the numerical predictions. A more advanced model that takes into account various rates of cementation breakdown was also used. The numerical predictions of the various models are presented and also compared with one another.

1 INTRODUCTION

The Dhaka city and its surrounding zones are undergoing rapid development. Low lying areas, marshy land, fill areas etc. are increasingly being utilized for building structures and other civic amenities. Due to the critical sub-soil conditions, it is becoming increasingly important to consider the safety of the foundation for structures to be built in these soils. Thus it has become essential to study the stress-strain characteristics of the sub-soil of Dhaka city and its surrounding suburbs.

An experimental and numerical study of Savar area clay cemented to various degrees was carried out. The experimental part is concerned with the determination of the engineering properties of remoulded Savar clay with various degrees of cementation. Numerical simulation of the remoulded Savar area clay with and without cement using the Modified Cam Clay (MCC) model, Modified Modified Cam Clay (MMCC) model (Khalil Ullah 2007) and an extended MMCC or EMMCC model (Khalil Ullah 2007) incorporating cementation break down assumptions was carried out. The numerical predictions of the various models were compared and analysed. The results of the numerical study are presented in this paper.

2 CRITICAL STATE PARAMETERS

For the present study, disturbed soil samples were collected from the area of Savar, a suburb of Dhaka city, the capital of Bangladesh. Reconstituted Savar clay was prepared in the laboratory, finally reconsolidated with a selected overburden pressure of 150 kPa under K_0 condition in a consolidation cell. Some of the reconstituted Savar clay was cemented with 7% and 14% ordinary Portland cement, and cured for 7 days under K_0 conditions at water contents significantly higher than the liquid limit of the clay following procedures suggested by Uddin (2004). Test samples were then prepared from block samples extruded from the uncemented and cemented consolidated clay specimens. The critical state parameters of the remoulded Savar clay, with and without cement, were then determined. The critical state parameters obtained for the remoulded Savar clay without cement and with 7% and 14% cementation are presented in Table 1 below.

Table 1: Critical state parameters for Savar area clay

Parameters	0% cement	7% cement	14% cement
λ	0. 29	0.197	0.1
κ	0.033	0.03	0.01
M	1.16	1.25	1.3
p'_o (kPa)	133	375	400
N	1.37	1.29	1.45

In Table 1, λ and κ are respectively the slopes of the normal consolidation line and elastic rebound line of the e-lnp´ curve, M is the slope of the critical line in q-p´ plane, p'_o is the preconsolidation pressure of the soil and N is the void ratio at unit pressure of the e-lnp´ curve. A value of the Poisson's ratio μ was assumed in the models appropriate for undrained analysis.

3 CONSTITUTIVE MODELS

The MCC model (Roscoe & Burland 1968) and two of it's proposed variants, the MMCC and EMMCC model, were used in this paper to predict the stress-strain behaviour of remoulded Savar area clays with and without cement. The MCC model assumes an elliptic yield locus at $p' - q$ space. p' is the mean effective stress and q is the deviator stress. The yield and the plastic potential functions for the MCC model are identical. They are described by the equation as given below:

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

Cement treatment of clays gives it cementation strength, which in turn allows it to resist tensile forces. The tensile strength of clay due to cementation may be incorporated in the MCC yield locus in a manner similar to that suggested by Lagioia and Nova (1993) as follows

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

The model incorporating equation (2) as the yield locus is termed in this paper as the Modified Modified Cam Clay (MMCC) model. In equation (2), p_t is the tensile or cementation strength of the clay. The MMCC model reduces to the MCC model when the tensile strength is zero. This model was used to simulate the stress-strain response of cemented Savar clays. It was assumed that the unconfined compression strength q_u of clay is the deviator stress at zero mean effective pressure. Using this assumption, the tensile strength p_t of cemented clay was obtained from its unconfined compression strength q_u using equation (2) as follows (Khalil Ullah 2007):

$$p_t = \frac{{q_u}^2}{M^2 p'_o} \tag{3}$$

The consolidation component of cementation strength and cementation breakdown effect of the tensile strength component was incorporated in the MMCC model in a way suggested by Lagioia and Nova (1993). This model has been termed here as the extended MMCC or EMMCC model. The yield locus of the EMMCC model is given as follows:

$$\left\{\frac{q}{M(p' + p_t)}\right\}^2 = \frac{p'_o + p_t + p'_{mo}}{p' + p_t} - 1 \tag{4}$$

In equation (4), p'_{mo} is the increase in consolidation strength of remoulded clay as a result of cementation (Lagioa & Nova 1993). Additionally, in the EMMCC model, the tensile strength of clay was assumed to breakdown in a way similar to that proposed by Lagioia and Nova (1993) as follows:

$$p_t = p_{to} \exp\left[-\rho_t\left(\varepsilon^d\right)\right] \tag{5}$$

$$\varepsilon^d = \int \left|d{\varepsilon_v}^p\right| \tag{6}$$

In above equations (5) and (6), ε^d is the accumulated absolute plastic volumetric strains and ρ_t is the degradation parameter for tensile strength. p_{to} is the value of the tensile strength of the cemented clay before the onset of cementation breakdown. A large positive number may be used for ρ_t to simulate rapid cementation breakdown effects, while smaller values may be used for ρ_t to simulate slower rates of cementation breakdown (Lagioia & Nova 1993). A zero value may be assumed for ρ_t in case it is assumed that no breakdown of cementation occurs as a result of accumulated plastic volumetric strains. In the EMMCC model, no breakdown was assumed to occur for p'_{mo}, the consolidation component of cementation strength. The EMMCC model was used to simulate the stress-strain response of remoulded cemented Savar clays incorporating various rates of breakdown for the tensile strength component of cementation strength. This was done to study the effect of breakdown of the tensile strength component of cementation on the stress-strain response of the cemented Savar clay.

The plastic flow rule of the MMCC and EMMCC model are identical to that of the plastic flow rule of MCC model and is given is as below:

$$\frac{d\varepsilon_v^p}{d\varepsilon_q^p} = \frac{M^2 - \eta^2}{2\eta} \tag{7}$$

However, the term η in the above equation is defined in the MMCC and EMMCC models as follows:

$$\eta = \frac{q}{p' + p_t} \tag{8}$$

In equations (7) and (8), $d\varepsilon_v^p$ and $d\varepsilon_v^q$ are respectively the incremental plastic volumetric and incremental plastic deviatoric strains and η is the modified stress-ratio incorporating tensile strength (Lagioia & Nova 1993).

In all other aspects, the conceptual framework for the MMCC and EMMCC model are identical to that of the MCC model.

4 NUMERICAL PREDICTIONS OF CIU RESPONSE OF REMOULDED SAVAR CLAYS

Figure 1 and 2 shows the stress-strain and excess pore pressure predictions of the MCC model for uncemented and 7% and 14% cemented Savar area clays. It is observed from Figure 1 and 2 that the predicted initial shear strength, undrained shear strength and excess pore pressure increases with the increase of the degree of cementation.

Figure 3 shows the comparison of MCC and MMCC model predictions for the stress-strain response of 7% cemented remoulded Savar clay. It is observed from Figure 3 that the MMCC model predicts a significantly higher shear strength response than the MCC model, as would be expected for a model incorporating cementation strength effects. This is most likely because of the shift of the origin of the MMCC model yield locus to the left as a result of incorporating cementation strength p_t in equation (2). This makes the effective size of the MMCC yield locus significantly larger than the MCC yield locus as a result of the net increase of the effective preconsolidation pressure p'_o by an amount equal to p_t. It is interesting to note from Figure 4 that the MCC and MMCC model excess pore pressure predictions for 7% cemented clay are almost identical. Figure 5 shows the EMMCC model stress-strain predictions for a 7% cemented clay for very low to very high rates of simulated cementation breakdown. It is observed that the EMMCC model predictions of the undrained stress-strain response of normally consolidated cemented clay are relatively unresponsive to change of value of the cementation strength breakdown parameter ρ_t, identified by the term RHO in the legend in Figure 5. A more sensitive and physically meaningful parameter, which at the same time will be numerically stable when simulating practical boundary value problems, possibly needs to be devised to simulate cementation breakdown effects of artificially or naturally cemented soils.

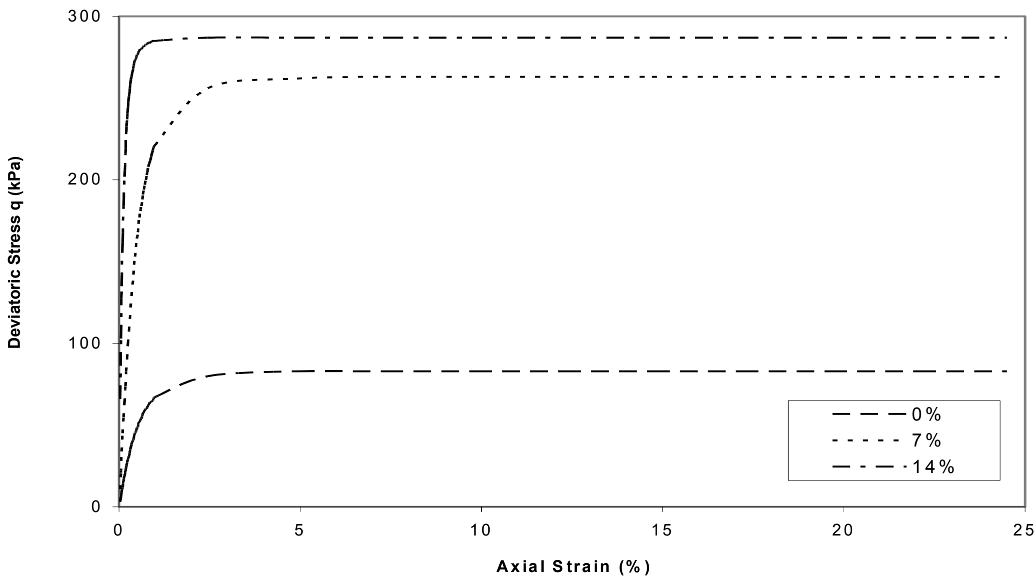

Figure 1: MCC prediction of undrained stress-strain response of normally consolidated reconstituted Savar clay for varying degrees of cementation

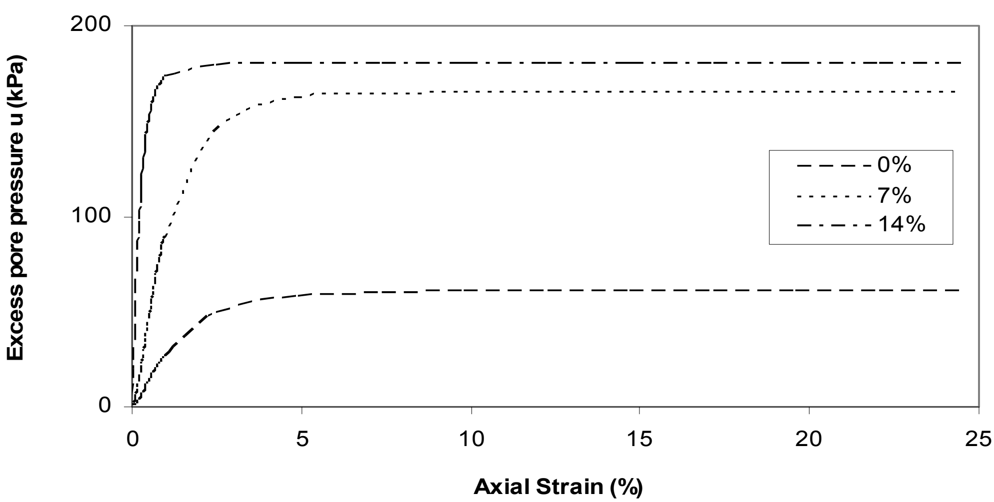

Figure 2: MCC prediction of excess pore pressure response of normally consolidated reconstitute Savar clay for varying degrees of cementation

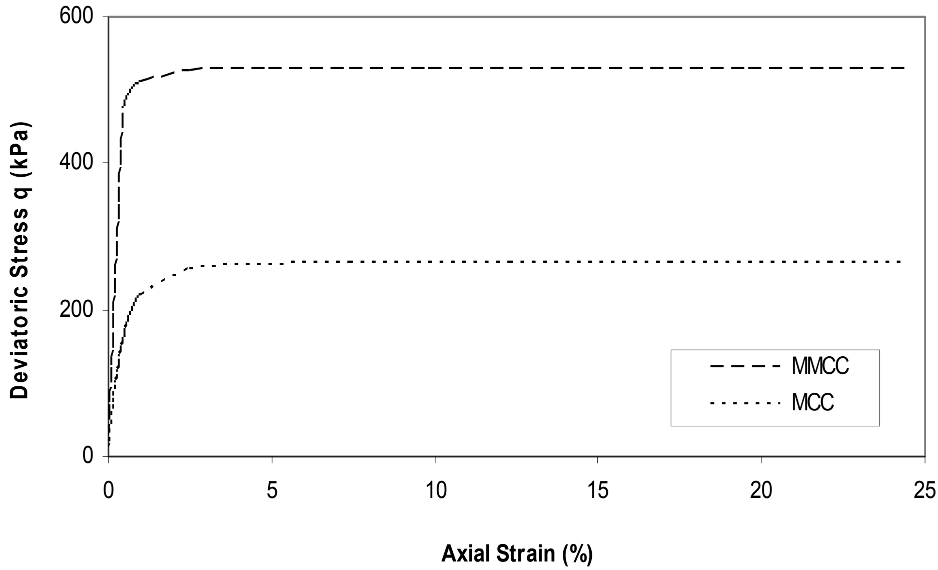

Figure 3: MCC and MMCC prediction of undrained stress-strain response for 7% cemented Savar clay (OCR=1)

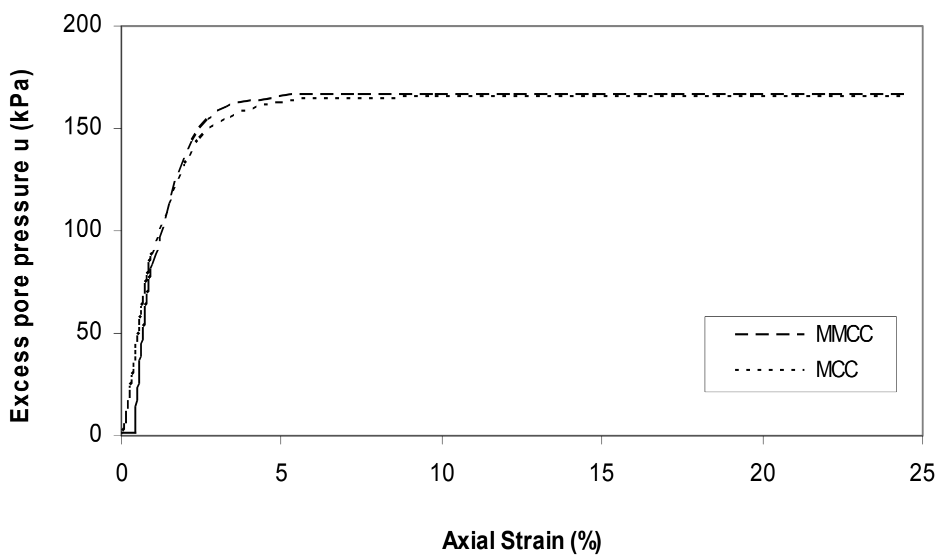

Figure 4: MCC and MMCC prediction of excess pore pressure response for 7% cemented Savar clay (OCR=1)

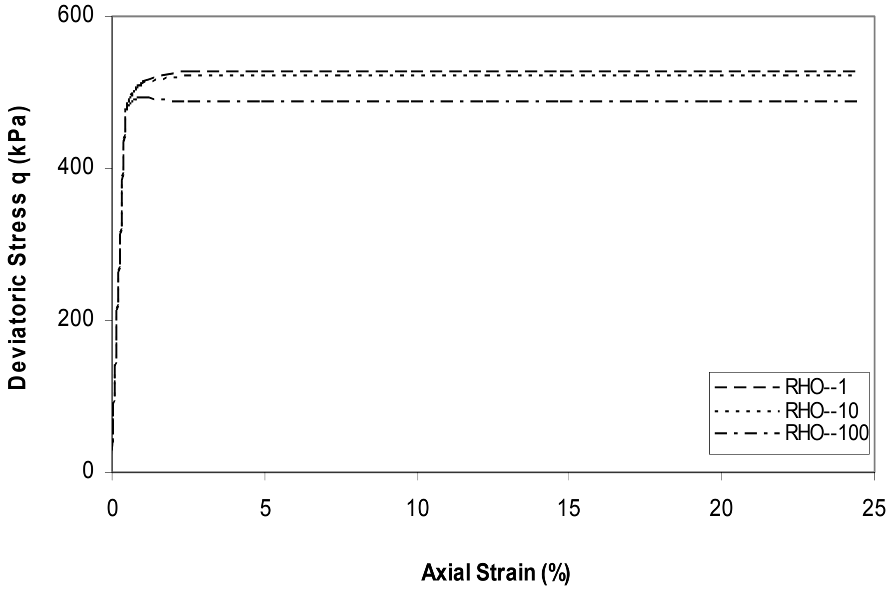

Figure 5: EMMCC model prediction of undrained stress-strain response of 7% cemented Savar clay (OCR=1); the legend RHO represents cementation breakdown parameter ρ_t

5 SUMMARY AND CONCLUSIONS

The MCC model and two of its variants incorporating cementation and cementation breakdown effects were used to numerically predict the undrained shear and excess pore pressure response of remoulded and normally consolidated clay from Bangladesh, with and without cementation. It was observed that the MCC model predicts higher strengths for cemented clays, but the rate of increase of the predicted shear strength decreases with the rate of increase of percentage of cementation. The Modified from of the MCC model, which incorporates tensile strength in the yield locus, predicts higher undrained shear strength for cemented clays than the corresponding MCC model. However, the results of the model simulating cementation breakdown effects appear to be relatively unresponsive to the value of the cementation breakdown parameter. Thus simply incorporating tensile strength component of cementation in the MCC model may result in reasonably realistic predictions of cemented clay behaviour. Additionally, new approaches need to be devised to realistically and more effectively simulate cementation breakdown effects of artificially or naturally cemented soils.

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