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On the determination of modified cam clay model parameters

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ABSTRACT: Numerical analysis of any boundary value problems requires a constitutive model to be used. Depending on the type of the problem to be solved and the material characteristics involved in the analysis, the constitutive model to be used in the analysis should be selected properly, so that the results close to the real behavior of the analyzed problems. Again, numerical prediction of any constitutive model depends highly on the correct selection of the model parameters. These model parameters for a given material are generally determined from different experimental data. Therefore, selection of a constitutive model and determination of its parameters for a given material are must in any numerical analysis.

It can be seen from literature that modified cam clay model is mostly used in numerical analysis of geomechanics problems requiring realistic soil models. To use this model for analyzing any problems in a given soil, the different model parameters for that soil are to be determined carefully. In the present study, selection and determination of the modified cam clay model parameters for some soils is done. The soils used in the study are collected from inside the NERIST campus, which is situated in Papumpare district of Arunachal Pradesh.

Key words: Numerical analysis, constitutive model, modified cam clay.

I. INTRODUCTION

The successful use of any numerical analysis in solving any engineering problems depends on the constitutive model chosen to represent the material behavior. The constitutive model associated with a specific material has to describe the material evolution under external actions. Soil is a very complex material and constitutive models required to describe the behavior of different types of soils are also complex and they are continuously developed and improved. However, more complex is the model, more difficult to estimate the defining parameters and to implement in a numerical analysis. Therefore, selection of a constitutive model for an analysis depends on its simplicity and easiness of determining the defining parameters (Popa and Batali, 2010). The model should be such that its parameters can be determined from simple laboratory tests with its easy numerical treatment. However, the results obtained from the analysis should be as close as possible to the real behavior of the analyzed problems.

It is reported in the literature that the most widely used soil constitutive models in numerical analysis of boundary value problems in soil mechanics are the cam clay group of models (Devi, 2011). These are elasto-plastic models developed based on the critical state concept and out of these models the modified cam clay (MCC) model has been mostly used in practice for computational applications (Gens and Potts, 1988; Wood, 1994). This model has proven to be simple with a few input parameters, which can be determined from standard laboratory tests and at the same time it appears to be sufficiently accurate for most applications (Mita at el., 2004).

The following paragraphs are describing the MCC model and its defining parameters. The model can be easily implemented in any numerical analysis like finite element method (FEM) and simple laboratory tests are required to estimate the defining model parameters. The results and analysis of various laboratory tests performed to estimate the parameters of MCC model are presented in the subsequent paragraphs.

II. MODIFIED CAM CLAY MODEL

Modified cam clay model is an elasto-plastic model based on few and simple postulates that predicts the stress-strain behavior of soils. The model was developed initially from triaxial tests data and later on extended for three-dimensional stress space. It is also important to note that the model is simple with a few input parameters, which

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can be determined from standard laboratory tests and still sufficiently accurate for most applications. Even though the name of the model seems to work only for clayey soils, it may also be applied to analyze other types of soils.

2.1 The State variables

The various state variables associated with the MCC model are given below:

p′ = general volumetric effective stress = mean effective stress = $(\square'_a+2\square'_r)/3$ for triaxial conditions

q = general deviator stress = deviator stress = $(\square'_a-\square'_r)$ for triaxial conditions

□= stress ratio = q/p′

v = specific volume = 1 + e, where e is the void ratio

Here $\square'_a$ = effective axial stress and $\square'_r$ = effective radial stress.

2.2 The model parameters

Model parameters for the MCC model are as given below:

□ = slope of the isotropic normal compression line in ln(p′) versus v plot

□= slope of the isotropic unload-reload line in ln(p′) versus v plot

M = slope of the critical state line in p′ versus v plot

N = value of v on the isotropic normal consolidation line at a value of p′=1

□= value of v on the critical state line at a value of p′=1. The values of N and □ are dependent on the units used. Either the value of N or the value of □ is to be specified as they are related through the equation □=Ñ□.□̃

p_c'=pre-consolidation pressure and determines the initial size of the yield curve

μ =Poisson's ratio.

In the following section the procedure of calculation of MCC model parameters are explained in brief.

III. PROCEDURE OF CALCULATION OF MCC MODEL PARAMETERS

The parameters κ and λ are determined either from the isotropic consolidation tests or from the one-dimensional consolidation tests. If isotropic consolidation tests are performed, then κ and λ are the slope of the unload-reload line and the isotropic normal compression line respectively, which are assumed to be linear in the graph of ln(p') versus v. If one-dimensional consolidation tests are performed, they can be related to the swelling index and compression index of the soil. The parameter κ defines the elastic behavior of the soil and it is related to the swelling index (C_s) through the equation $\square=C_s/2.3$ and the parameter λ is related to the compression index (C_c) through $\square=C_c/2.3$. The parameter M is the slope of the critical state line in p′-q space and it can be related to the effective angle of shearing resistance (□) through the relation: M = 6*sin□/(3-sin□). The value of □ can be determined from the laboratory p′ versus v plot, which is the value of the v corresponding to the value p'=1.

In MCC model the bulk modulus (K) is a state variable, which varies with p'. A constant value of Poisson's ratio (μ) or shear modulus (G) is generally specified. It is theoretically preferable to consider a constant value of G. But experimental evidence shows the variation of G with stress level and hence difficult to estimate a constant value. Therefore, usually a constant value of μ is specified allowing G to vary in the same way as K. The value of μ can be estimated either from data of K_o (coefficient of earth pressure at rest) versus OCR (over-consolidation ratio) or from strain measurement in triaxial tests. It is reported that a value of μ about 0.3 is obtained for many soils from data of K_o versus OCR (Britto and Gunn, 1987). In the present study it was not possible to investigate the value of μ for the given soils and hence a value of 0.3 is assumed for all samples.

In an elasto-plastic analysis using MCC model, the in situ stresses in a given soil mass are required. The value of p_c', which determines the location of the initial yield surface, is determined from the in situ stresses. To determine these stresses the value of K_o is required. There are different approaches developed to estimate the value of K_o and available in the literature. An empirical relation between K_o and OCR is given by Parry (1982) as follows:

$K_o=K_{nc}*(OCR)^{\square}$, where □ is in radian.

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Here K_{nc} is the coefficient of earth pressure for normally consolidated soil and given as K_{nc}=1-sin(□). Knowing the value of in situ vertical stress (□$_{vo}$) and horizontal stress (□$_{ho}$) at a point within the soil mass, the corresponding value of p' and q can be determined. Putting these values of p' and q in the yield surface equation of MCC model, the corresponding value p_c' can be determined.

IV. LABORATORY TESTS RESULTS AND ESTIMATION OF MCC MODEL PARAMETERS

For estimating the MCC model parameters, a series of laboratory tests are to be performed. The tests which are required for this purpose are:

- Strain-controlled consolidated drained (CD) triaxial tests
- Or consolidated undrained triaxial tests (CU) with pore pressure measurements
- Load-unload-reload consolidation tests

In the present study series of strained controlled CD triaxial tests and one dimensional consolidation tests are performed. The required model parameters are estimated by analyzing these test results. Soil samples are collected from three different locations near hostel block-H in NERIST campus, which is located in Papumpare district of Arunachal Pradesh. These soil samples are named as Sample-1, Sample-2 and Sample-3. For each soil type representative samples are collected from a depth of about 0.5m from the ground surface. From the one-dimensional consolidation tests, the pre-consolidation pressures (σ_{rm}) for the samples are estimated to be in the range of 80-100 kN/m^2. Therefore, in case of CD triaxial tests, all the samples are consolidated to a minimum value of σ_r =100 kN/m^2 before testing.

In the following sections, the test results and estimation of MCC model parameters are explained in brief.

4.1 Test results

Results from CD triaxial tests for these three different soils are given in the Fig. 1 in the form of modified Mohr-Coulomb failure envelopes. The shear strength parameters for these soils are given in Table 1. The isotropic consolidation curves and swelling curves for Sample-1, Sample-2 and Sample-3 are shown in the Fig. 2, Fig. 3 and Fig. 4 respectively. The consolidation properties of the soils are given in the Table 2.

Soil Type	tan(ψ')	d'	□'=sin^{-1} (tan(ψ'))	c'=d/cos(f')
Sample-1	0.25	9	14.5	9.3
Sample-2	0.174	6	10.02	6.1
Sample-3	0.215	9	12.41	9.2

Table 1: Shear strength parameters

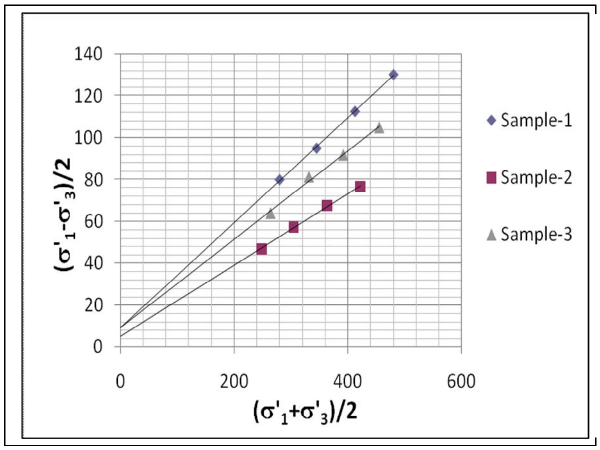

Fig. 1: Modified Mohr-Coulomb failure envelopes

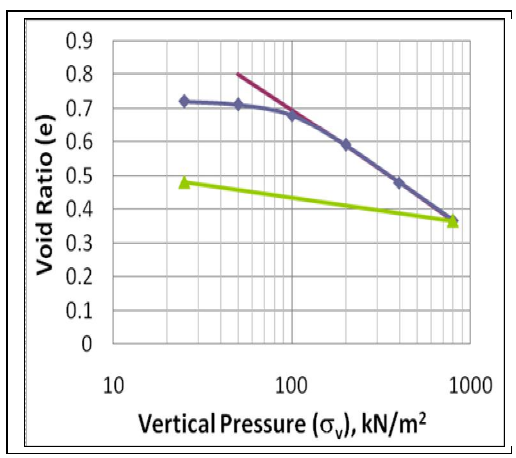

Fig. 2: Consolidation curve for Sample-1

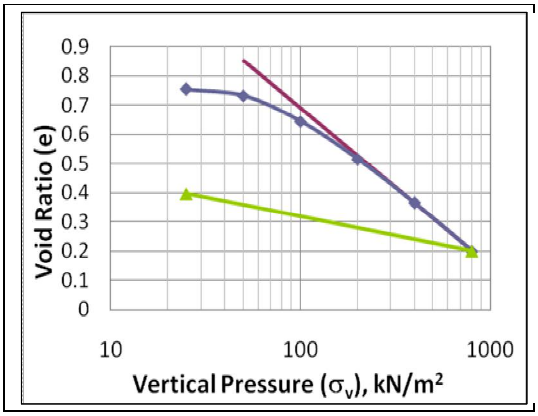

Fig. 3: Consolidation curve for Sample-2

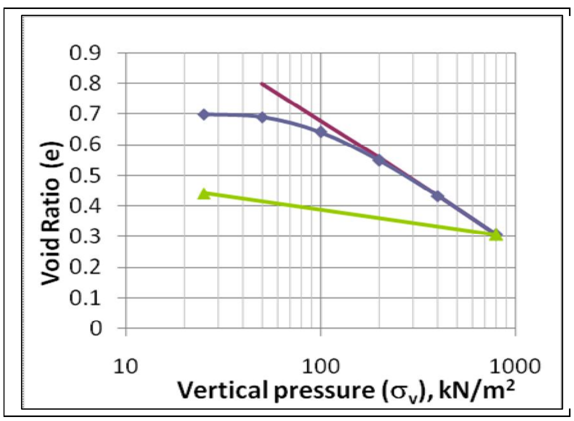

Fig. 4: Consolidation curve for Sample-3

Table 2: Consolidation parameters

Soil type	C_c	C_s	σ_{vm} (kN/m^2)
Sample-1	0.372421	0.075	100
Sample-2	0.541474	0.13	90
Sample-3	0.416005	0.09	85

4.2 MCC model parameters

The MCC model parameters are calculated from the shear strength parameters and the consolidation parameters using the procedure explained in section 3 above. The values of the parameters are listed in Table 3 below.

Table-3 MCC model parameters

Soil	Mu	κ	λ	M
Sample-1	0.3	0.03	0.16	0.546
Sample-2	0.3	0.06	0.24	0.369
Sample-3	0.3	0.04	0.18	0.463

V. CONCLUSION

It is well established that MCC model is mostly used in the past for numerical analysis of boundary value problems in the field of geotechnical engineering. For using the model in an analysis, its parameters are required to be known for a given soil. In the present study the type of tests required and procedure of estimation of MCC model parameters from these tests are discussed. These parameters for some soils collected from inside the NERIST campus are determined. The parameters determined can be used for analyzing any practical boundary value problems involving these soils.

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