Numerical Modelling of Oedometer Test

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Abstract

The oedometric test is a test widely used in civil engineering. The main objective of this article has been to investigate the primary consolidation behaviour of the intact soil samples by comparing the results obtained from finite element analysis computations in PLAXIS^{2D} with the experimental result of the soil samples obtained from the site of the Al-Ahdab oil field in the east of Iraq. Three different material models were utilized during the finite element analysis, comparing the performance of the more advanced constitutive Soft Soil material model against the modified Cam Clay and Mohr-Coulomb material models. Numerical results of Oedometer test show that the Soft Soil model behaviour is the most appropriate model to describe the observed behaviour.

Key words: consolidation, PLAXIS, behaviour, numerical, soil samples

1 Introduction

Fine saturated soils such as clays and silts are characterized by low permeability so that under the effect of an overload transmitted by the foundations to the soil, the pore water slowly infiltrates and the volume of the skeleton granular decreases. The reduction in volume results in a compaction of the soil which changes as the flow of water occurs. This is called a settlement of the soil by consolidation. [1]. Terzaghi (1923) [2] has proposed the one-dimensional consolidation for saturated soils firstly. Several researchers and practitioners such as [3-12] dealt with the limits of Terzaghi's theory in the case of soils compressible clay. L Arabet [13], A. Hana et al. [14] and M Klai et al. [15], discussed the one-dimensional consolidation of fine saturated soils, in the form presented by Terzaghi in 1925, and described the oedometric test, which provides the parameters of this theory. They showed how the theory of one-dimensional consolidation served as a basis for modern models of soil

behaviour.

The progress of the computer code and the provision of various software to researchers save a lot of time and presents an economical solution. Indiscriminate use can sometimes cause bad consequences. To shed light on the effectiveness of the constitutive laws able to better describe the target behaviour of fine saturated soils, a numerical analysis of the oedometer test was carried out using the PLAXIS^{2D} code V8.6 [16]. Four types of Clays (S0, S1, S2 and S3) tested and published by M O. Karkush et al. (2020) [17] were modelled. The compressibility curve will be compared with the experimental ones using different constitutive models: Mohr-Coulomb model "MC", Soft Soil Model "SSM" and Modified Cam Clay "MCC". The effectiveness of the studied constitutive models is discussed based on the comparison made between experimental and numerical results.

2 Simulation of observed behaviour of the soil samples

2.1 Presentation of the soil samples

As indicated in the work of M O. Karkush et al. (2020) [17], the intact soil samples were brought from the site of Al-Ahadab oil field that located in Al-Ahrar city located in the north-west of Wasit province at the east of Iraq.

The saturated soil sample was obtained by drilling to a depth of 3 m below the existing ground level (EGL). The groundwater table was 2.65 m from EGL [17]. Figure 1 shows the shapes of some soil samples. The mechanical properties of the soils tested by samples of clay soils tested by M O. Karkush et al. (2020) [17] are summarized in Table 1.

Figure 1: Soil samples [17]

Where:

S0: Undisturbed intact soil sample.

S1: Sample of soil contaminated with 100 g of $\text{Pb}(\text{NO}_3)_2$

S2: Soil sample contaminated with 200 g of $\text{Pb}(\text{NO}_3)_2$

S3: Sample of soil contaminated with 300 g of Pb (NO₃)₂

Table 1: Parameters of the soils simulated in this study and tested by M. O Karkush et al. (2020) [17]

Parameter	S0	S1	S2	S3	Unit
γ_{sat}	18.35	17.39	17.14	17.99	KN/m ³
γ_{nsat}	15.09	14.68	14.59	15.38	KN/m ³
$K_x = K_y$	3.22e-10	2.6e-10	1.98e-10	1.86e-10	m/s
ν	0.43	0.47	0.47	0.47	/
C	108	59	26	18	KN/m ³
φ	13.4	6.0	5.7	6.0	(°)
λ^*	0.024	0.057	0.066	0.044	/
k^*	7.7e-3	9.5e-3	8.8e-3	0.011	/
K_0^{nc}	0.768	0.895	0.90	0.895	/

2.2 Numerical simulation of Oedometer test

The numerical simulation of oedometer test is used by the two dimensional PLAXIS^{2D} software version 8.6 [16]. Figure 2 showed the mesh adopted in this present study. As shown in Fig. 2, the numerical adopted model has 50mm width and 19mm height. To make the mesh in the plane, we used the axis of symmetry since the specimen has an axis of revolution, and triangular elements with 15 nodes by element, each node can move in two directions. To find more precise results it was assumed, only vertical displacement allowed to ensure the same principle of the oedometer test.

Figure 2: Numerical model of sample geometry

In order to properly simulate the one-dimensional consolidation of the modeled soil, a

uniformly distributed effective stress is applied to the surface of the sample.

3 Results and Discussions

3.1 Results

Numerical results are run by PLAXIS^{2D} software using Soft Soil Model "SSM", the Modified Cam Clay model "MCC" and Mohr Coulomb model "MC" input parameters. Figure 3 compares compressibility curve obtained experimentally by [17] and numerically results predicted by the SSM, MCC and MC models for sample soils (S0, S1, S2 and S3).

Figure 3: Comparison between predicted behaviours of sample soils modelled by the SSM, MC and MCC model and experimental measurements [17] from oedometer tests

3.2 Discussions

The results obtained in Figures 3 show clearly that the numerical prediction using ‘‘MC’’ law of the primary consolidation phase (straight line with slope C_c) is generally in good agreement with the observed behaviour.

In the loading-unloading phase the numerical prediction underestimates the swelling of the

soil, the void index value for each unloading value returns to the same loading value.

We observe that the same values of the void index for loading and unloading; for example, for the studied soil sample S0 the value of the index of loading voids for the effective applied stress $\sigma'_p = 162.97 \text{ kPa}$ is equal to $e = 0.757$ and also equal to $e = 0.757$ for unloading. So we can say that loading and unloading have the same effects.

The compressibility curves obtained by the "SSM" model are in excellent correlation with the experimental results [17].

The curves plotted in Figures 3 show a remarkable divergence between the experimental compressibility curves [17] and the numerical predictions obtained by the Modified Cam Clay Model "MCC" for all the types of the modelled soils.

According to the samples of soils S0, S1, S2 and S3, the results of the "MCC" model show that a decrease in the void index compared to the experimental curve (Fig 3).

The pre-consolidation stress value, the compressibility index and the swelling index obtained by the numerical simulation are summarized in Tables 2.

Table 2: Values of the compressibility characteristics for sample soils [17]

Parameter	S0	S1	S2	S3
Pre-consolidation pressure σ'_p	69	118	150	70
Compression index C_c	0.10	0.252	0.295	0.189
Swelling index C_s	0.033	0.042	0.039	0.046
The initial void ratio e_0	0.816	0.894	0.926	0.840

In order to compare the pre-consolidation stress, the compressibility index and the experimental swelling index with those obtained numerically by the SSM and MCC models; the relative error percentage is calculated using the following expression:

$$|\Delta E| = \left(\frac{Value_{num} - Value_{exp}}{Value_{exp}} \right) \times 100 \quad (1)$$

Figure 4 presents the relative errors calculated for the different modelled soils (clayey soils S0, S1, S2 and S3) estimated by the models MC, SSM and MCC.

Figure 4: The relative error between numerical predictions obtained by the different 'MC, SSM and MCC' models and those obtained experimentally [17]

The histograms plotted in Figure 4 allow us to see that the Mohr Coulomb model "MC" and the modified Cam Clay model "MCC" have high relative errors by comparing them with those produced with Soft Soil Model "SSM" especially during of the loading-unloading phase.

The numerical calculation of the stress of pre-consolidation σ_p' by the SSM, MCC and MC models of the different modelled soils and its comparison with the experimental ones clearly shows through that the Soft Soil Model "SSM" gives the lowest relative error for the four cases of treated soils (Figure 4). Next is the Mohr Coulomb "MC" for all three soils (except S0) and finally the modified Cam Clay Model "MCC" gives the largest relative error.

So through the numerical computation of the pre-consolidation stress σ_p' we can say that the model of Soft Soil Model "SSM" is the most reliable to describe the observed behaviour.

The numerical estimate of the compressibility index C_c and swelling C_s (Fig. 4) and its comparison with the experimental ones clearly shows that Soft Soil Model "SSM" gives the lowest error, the Modified Cam Clay Model "MCC" comes next and Mohr Coulomb's "MC" presents the greatest relative error.

Through this numerical investigation we can say that the Soft Soil Model "SSM" is in very good agreement with the observed experimental behaviour.

4 Conclusion

The observed behaviour of four types of fine saturated soils was taken as a reference. The compressibility curves were established numerically using different constitutive laws, namely the Mohr Coulomb Model "MC", Soft Soil Model "SSM" and the Modified Cam Clay Model "MCC" by using PLAXIS^{2D} code.

When using computer codes, we are sometimes faced with a choice of the most realistic constitutive model. Our main objective has been to clearly define the most suitable model which can describe the consolidation of fine saturated soils. Through this numerical investigation we can draw the following conclusions:

For compressibility curves, the "SSM" model is recommended; it manages to predict the

compressibility of the soil during the oedometric test in stages. On the other hand, Mohr Coulomb's model "MC" is not recommended because of the unloading module.

Through this work we can say that our numerical model produced by the PLAXIS^{2D} code has proven its reliability and validity in terms of the description of the one-dimensional consolidation under the oedometer.

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