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Prediction of One-Dimensional Compression Test using Finite Elements Model

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***Abstract*— Finite element models are widely used by geotechnical engineers to investigate some important parameters to solve many geotechnical problems particularly in the preliminary design. Plaxis 2D finite element software is used here to predict the Oedometer tests (One-dimensional compression tests) results were conducted on cohessionless specimens for both dense and loose sand in the geotechnical laboratories of Wasit University. The finite elements (Plaxis 2D software) results were also compared with the obtained results from the experimental tests. The boundary conditions were taken into the account during setting of the finite elements boundary models that were strongly influenced by soil physical properties (i.e. dry density, angle of dilation and soil stiffness). The applied stresses on the One-dimensional cell were presented as a uniform distributed load on the model. Void ratios corresponding to the effective stresses and the stress-strain relationship were observed to give predicted. It was observed also the measured settlement at the end of tests was very close to the calculated values from the finite elements model. Finally, the values obtained from the finite elements can be used at begging of the footing or foundation design stage of any Structure.**

Keywords—Oedometer Testnumerical Modeling; Relative Density; Sand; Effective Stress.

INTRODUCTION

The finite element models are widely used by geotechnical engineers in the world to investigate different parameters to overcome a lot of geotechnical problems before embarking the design steps details. Many researchers conducted the numerical modeling and validate the results with either field tests results (i.e. Lozovyi and Zahoruiko, 2012; Li, 2004) or, against centrifuge tests (i.e. Haward et al.,2000; Al-defae et al., 2013; Al-Baghdadi et al., 2015) or comparing with laboratory tests (i.e. Schanz, et al., 1999; Brinkgreve, et al., 2010).

In this paper, full numerical modeling principles of plane strain using a finite element method (FEM) will be conducted on the similar physical properties, and some other stiffness parameters applied to simulate laboratory test, with the aim of producing an analysis of the axial compression test (One-dimensional oedometer test) which captures both the void ratio, effective stress relationship and the vertical stress-vertical strain relationship respectively. These models will be validated against actual oedometer tests results that have been conducted specimens for both loose and dense state. The ability to realistically model an oedometer test without requiring a number of laboratory tests, will allow the finite element model procedures developed to be used in routine geotechnical problems and particularity during the preliminary design steps.

I. SOIL PROPERTIES AND EQUIPMENTS

Commercial silica sand is used in this paper for the laboratory test (One-dimensional compression test). The physical properties for this kind of silica sand are very close to HST95 Silica sand it has been used in the pile tests by Lauder, 2012 and in many other researches in the University of Dundee (i.e. Al-defae et al., 2013; Al-Defae and Knappett, 2014; Al-Defae and Knappett, 2015; Bertalote et al., 2012) and others. The used sand has a round particles shape, and it was classified as well graded sand. The diameter of the mean average particle size (D50) is about 0.15mm which is very close to that one used in University of Dundee, 0.17mm. The sand was well dried in as oven before using in the pluviation processing during specimen preparation. Tow relative densities were used (two Oedometer tests) and similar procedure for the centrifuge model had been followed to achieve the desired density, but sieve No. 4 from 0.5m height and 1m height are used as a pluviation process instead of the pluviator (see Al-Defae, 2013) that has been calibrated before, to achieve both loose (approximately 25%) and dense state (approximately 75%) respectively (see figure 1-a). Oedometer tests have been carried out in the University of Wasit (UoW) geotechnical laboratory (see figure 1-b) to determine the stress-strain relationship and the variation of a void ratio with effective stress. Furthermore, the stiffness properties are investigated. After the pluviation excess material was scooped off using a steel knife. Even though great care was taken during the sample preparation it is not possible to achieve uniform a sample, and the relative density measured may well differ from the actual. This is even more magnified due to the small scale of the prepared sample. The relative density is defined as:

$$ID = \frac{(e_{\max} - e)}{e_{\max} - e_{\min})} \quad (1)$$

The Relative density was calculated using the minimuam and maximum void ratio found geotechnical group in University of Wasit, e_{max}=0.78 and e_{min}=0.47. These with measured specific gravity (2.61) allowed calculating unit weight of dry sand as well.

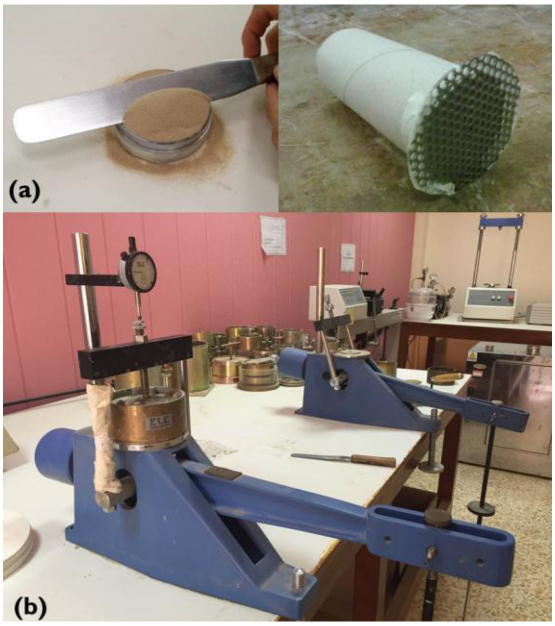

Figure 1: Small scale pluviator and one-dimensional compression test

The load increments that have been used during loading, and re-loading stages were started from 25 kPa to 200 kPa and subsequently, the first re-loading stage (200 kpa to 100 kpa); new loading stage from 100 kPa to 400 kPa and second re-loading stage (400kPa to 200 kPa) are followed whereas the last loading stage started from 200 kpa to 600 and then the latest reloading stage (600 kPa to 420). These load increments are to allow covering all or full medium stress levels that well known in most geotechnical problems particularly in foundation design.

INITE ELEMENT MODEL

Plaxis 2D finite elements software, version 8.6 is used to simulate the consolidation phenomenon in oedometer test. A simple rectangular was used in axisymmetric model having dimensions similar to the lab experiments – 19mm high and 38mm wide (gives a diameter of 76mm). Very fine mesh was used for more accuracy during matrices solving and total boundary fixities are used as well. Vertical distributed load was applied over the full length of the top surface for representation the loads stages during loading and re-loading process. Default value of this load gives a One kPa, and this was changed during deactivation stages in calculation phases. Figure (2) shows the model set up in Plaxis clarifying the mesh and the distributed load and obviously the boundary conditions. To simulate the load steps that were used in the laboratory, the vertical load was specified in the calculation program as different phases. A point on the top surface was selected to track the load-displacement behaviour. All the points showed exactly the same Stress-Strain behavior.

To represent the loading and re-loading stage in Plaxis, the Calculation phases allow to change the desired (applied) load during activation of the load before updating the phase. This means for the next phase, it could be easily to change (increasing or decreasing) the applied load.

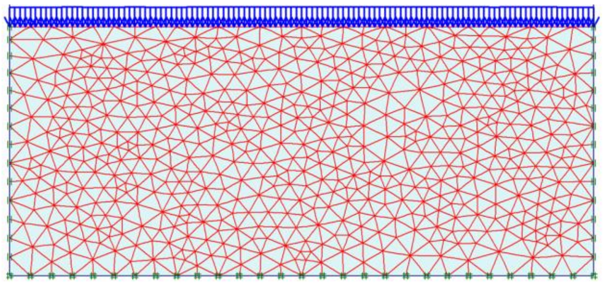

Figure 2: One-dimensional compression model set up in Plaxis 2D

For more accuracy, intermediate loads were applied (calculation phases) for getting a smooth relationship or curves. Figure (3) shows the total used phases during calculation processing.

MODEL MATERIAL PROPERTIES

Due to stiffness decreasing of the soil specimen during load stages, the hardening soil model is used for material representation.

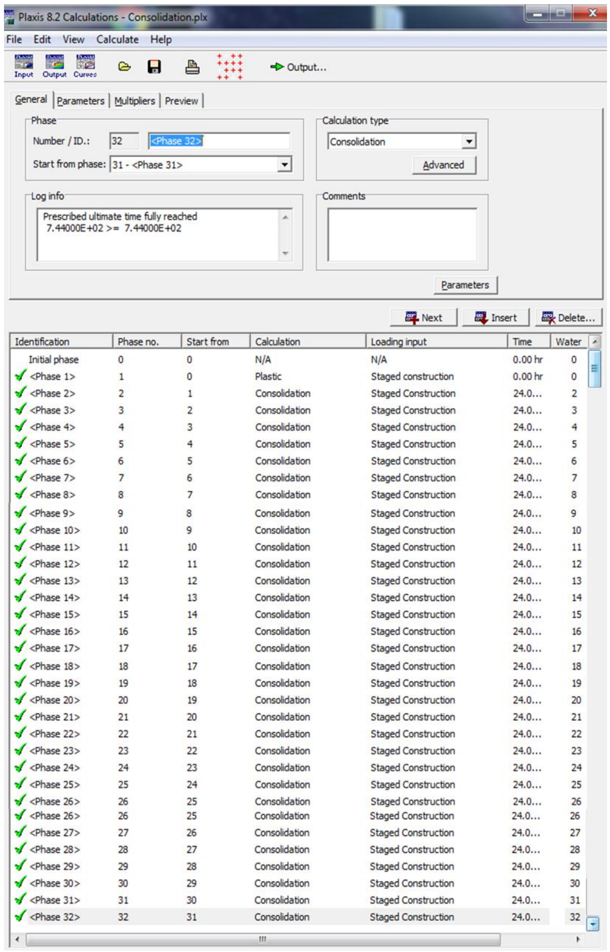

Figure (3): Total calculation phases

Table 1: Physical properties of silica sand

The physical property	HST95	Silica sand of this paper
Specific Gravity (G_s)	2.63	2.62
Shape	Rounded	Rounded
D_{10}	0.09	0.08
D_{30}	0.12	0.11
D_{60}	0.17	0.15
C_u	1.9	1.9
C_z	0.95	1
Optimum dry density (kN/m^3)	15.35	15.35
Maximum dry density (kN/m^3)	17.58	17.58
Minimum dry density (kN/m^3)	14.59	14.59
Maximum void ratio (e_{max})	0.769	0.769
Minimum void ratio (e_{min})	0.467	0.467

By this model, both the shear hardening due to the deviatoric loading and the compression hardening due to primary compression in oedometer loading and subsequently, irreversible strain is taken into account during the simulation process (Schanz, 1998). Theory of plasticity is included instead of elasticity with this model and soil dilatancy is well included that is found for specimen used in this paper. The material properties that used in this model are identical with those of Al-Defae et al., 2013 for silica sand which its same physical properties and grading. Table (1) shows the physical properties for the used silica sand in the lab tests whereas table (2) shows all properties for the hardening soil model used in the numerical modelling.

Table (2): Summary of parameters used for FE model

Parameter	Parameter description	HST95	Silica sand (this paper)
φ'	Effective angle of friction	32°	31.7
c'	Effective cohesion	0.3 kPa	0.1
E_{oed}^{ref}	Oedometer loading stiffness	34 MPa	33 Mpa
E_{50}^{ref}	Triaxial loading stiffness	42.5 MPa	41.6
E_{ur}^{ref}	Triaxial unloading stiffness	102 MPa	98
νur		0.2	0.2
m	Power term (for soil hardening)	0.55	0.54
G_0^{ref}	Small strain shear mudulus	116.3 MPa	111 Mpa
εs,0.7	Strain level when G0 reduces to 70% of initial value	0.016%	0.014%
γdry	Dery unit weight	16.2 kN/m3	16.07
Rf	Failure ratio	0.9	0.9

RESULTS AND DISCUSSION

The results of of both laboratory test (One-dimensional compression test) and the finite element models are plotted in e-logσ'1 space as well as stress-strain relationship. First of all, Figure 4 shows the vertical displacement at the end of numerical test in both rainbow shading (i.e. Figure 4 a)

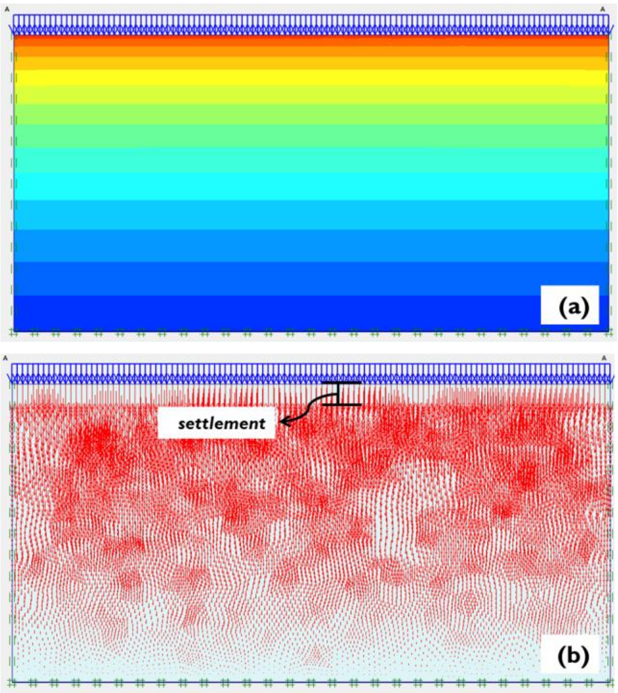

Figure 4: Vertical displacement of the model in term of; (a) shadings and; (b) arrows

and in term of arrows (i.e. figure, b). It can be seen that the maximum vertical displacement (settlement) at the top of the model whereas minimum or zero displacement at the base of the model and this id identical with what should have to be in the consolidation test.

It can be stated also that the oedometer test results agree with typical results found for soils such as in Knappett and Craig (2012) for e-logσ'1 space and Benz (2008) for σ'_1- ε_1 space. In the e-log'σ_1 a clear distinction can be seen between virgin compression and unload/reload stiffness. Figure (5) shows the results for both dense cohesionless specimen (i.e. figure 5, a) and loose cohesioless specimen (i.e. figure 5, b). Great prediction is observed for both states from the begging of the loading stage to the end of the test. Ratio of the void ratio variation with stress increasing for laboratory test also is uniform with those for the finite element model and only approximately 0.1 differences in the value of the void ratio.

As expected looser samples show higher drop in voids ratio than the dense samples. Figure (6) shows all the results for both loose and dense sand in one view.

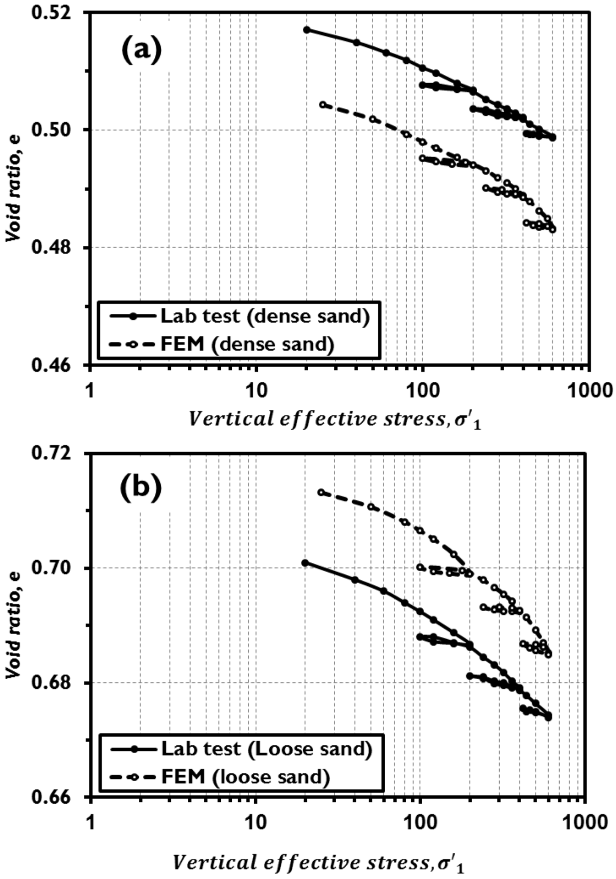

Figure 5: Oedometer and finite element results for e-log $\sigma_v^{'}$

The FEM model results were found to be very slightly under predicting the stiffness in the loose state at low stress level (around 240 kPa) whereas it was tiny over predicting for higher stress level (above 240kPa).

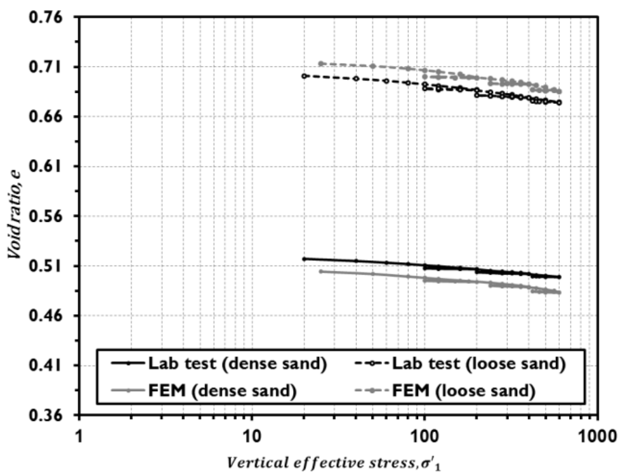

Figure 6: e-log $\sigma_v^{'}$ for both numerical and laboratory test for loose and dense specimen

In the dense oedometer tests specimen, it was under predicting for all stress level. This can be attributed to the dilation phenomenon for the sand and results are strongly influenced by this parameter and it is recommended to use the peak angle of internal friction in the finite element model material instead of the critical state. The magnitude of difference is rather small and the set does characterize this kind of the soil well enough to be used for the simulation of the consolidation test for all cohesioless soil. Hence set of step by step procedures were carried out to calibrate the laboratory test results for silica sand.

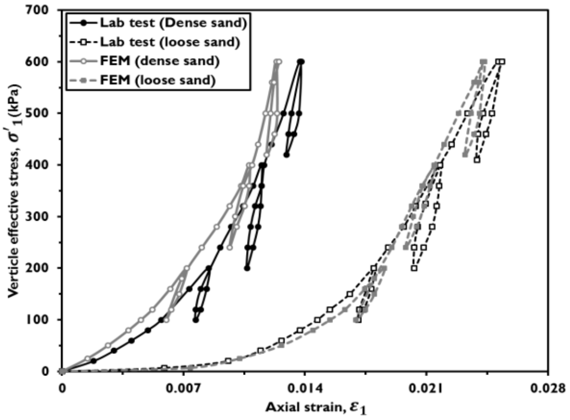

Figure 7: Effective stress, $\sigma_v^{'}$ - strain, ε_1 relationships

CONCLUSSION

The consolidation (One –dimensional compression) tests were used for both loose and dense state of a cohesionless soil. The principles of plain strain of Plaxis 2D finite element models were used to compare the obtained results of settlements, void ratios and stress-strain characteristics with the experimental results. The main finding of this paper are:

1- The void ratios at different effective stress were well predicted for both loose and dense state. For dense state, it should be noticed that the values of finite elements is less than the values of experimental (one-dimensional test) whereas they are over-predicted in case of loose state. This behaviour is because the sand is trend to be more dilation in real or experimental tests while is not in the Plaxis models.
2- Great prediction was observed in the effective stress-axial strain relationship in both the loose and dense state.
3- The One-dimensional consolidation test using finite element models primarily can be used in the initial stages of the design of footing in cohesionless soil.
4- The results of the tests are plotted in e-logσ'1 space as well as stress-strain space. It can be stated that the oedometer test results agree with typical results found for soils for σ'1- ε1 space. In the e-log'σ1 a clear distinction can be seen between virgin compression and unload/reload stiffness. As expected looser samples show higher drop in voids ratio than the dense samples.

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