OEDOMETER TEST CONTRIBUTION FOR THE STUDY OF COLLAPSIBLE SOILS

Kawtar Ouatiki
Mohammed V University in Rabat, Ecole Mohammadia d’Ingénieurs, L3GIE, Rabat, Morocco

Pr Lahcen Bahi
Mohammed V University in Rabat, Ecole Mohammadia d’Ingénieurs, L3GIE, Rabat, Morocco

Pr Latifa Ouadif
Mohammed V University in Rabat, Ecole Mohammadia d’Ingénieurs, L3GIE, Rabat, Morocco

Anas Bahi
Mohammed V University in Rabat, Ecole Mohammadia d’Ingénieurs, L3GIE, Rabat, Morocco

ABSTRACT
The criteria for identifying collapsible soils are numerous, subjective, differ from each other, and most importantly, they favor one parameter over the others, which puts the engineer in front of a panoply of costly tests. The finite element method uses powerful algorithms to calculate complex equations related to a geotechnical problem. Since the oedometer test is commonly exploited in quantifying deformations of soils, and since Plaxis code offers a simple interface to the user to elaborate parametrical studies, the present work aims to analyze the behavior of tufa soil in the presence of water through experimental and numerical tests. To achieve the objective, we plot the compressibility curves corresponding to both tests in order to compare the results obtained by using the oedometer test conducted on laboratory and simulated by plaxis code using the Mohr coulomb constitutive law in the first time and then the soft soil creep model law.

Key words: Plaxis code, Oedometer test, deformation, tufa, compressibility curve.

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1. INTRODUCTION
The collapsible soils correspond to metastable soils that exhibit a radical rearrangement of particles and therefore a significant change in volume due to wetting or additional loads. They are widespread throughout the world and especially in arid and semi-arid areas. Only Loess covers 17% of the USA, 17% of Europe and 15% of Russia and Siberia and a large part of China [1]. They are "geologically young" and can be triggered suddenly by various natural or anthropogenic factors.

The most notable collapsible soils are:
- Granite sands of South Africa;
- Aeolian sands of the Sahara borders;
- Loess from North and South America;
- Loess and saline soils of China;
- The loess of Eastern Europe and Central Asia;
- Loess from Pakistan, India, Thailand, New Zealand;
- Clay from Canada;
- Cemented soils of northern Niger.

There are four factors needed to produce the collapse in soil fabric [2,3]:
- An open loose and unsaturated structure;
- High total stress: can result from the gradual accumulation of the deposits on the top of soil or through dynamic processes like earthquakes or construction works;
- A bonding or cementing agent that stabilizes soil (clay bridges – clay bonds – carbonates and negative pore water pressure are the most common holding bonds)
- Addition of water which causes the bonding agent to be reduced: refers to an increase of initial water content from a partially saturated state to a one approaching full saturation. In Rissa (Norway, April 1978) [4]
- The Loess of China has caused avalanche in Shaxi. Between 1965 and 1979, 1142 people were killed, 17,500 houses were destroyed and 22,500 ha of farmlands were inundated. [5]

The list of this type of soil is not exhaustive; numerous soils in “safe” areas can fall in the category of collapsible soils which leads to study criteria’s gathering more than one of these parameters: the initial water content, the granularity, the degree of saturation, the dry density, the void ratio, etc. [6,7,8,9,10,11,12]

In this article we will focus on collapsible soils by liquefaction where interstitial pressure does not dissipate quickly before shearing and then the collapse happen. We will conduct in parallel two methods of identification of this type of soil. The first one based on oedometric test conducted on tufa sample from Casablanca and the second method is the simulation of this test by Plaxis code using Mohr Coulomb law. Our objective is to compare the experimental and the numerical results in order to prepare of a parametric study.

2. MATERIALS AND METHODS
Collapsible soils are generally associated with an open structure formed by sharp grain, low initial density, low natural water content, low plasticity, relatively high stiffness and strength in the dry state, and often by fine granulometry. As their name indicates, these soils can
exhibit a large volume change upon wetting, with or without extra loading, thus, they may present significant challenges to geotechnical profession.

The oedometer test is widely used by engineers to quantify the compressibility of soils, and then to calculate their settlement. The potential of collapse has been introduced, based on this test to quantify the amplitude of collapse as well. [13,14] This procedure can be simulated numerically by Plaxis code. The aim of modeling is to save time and expenses by conducting a series of calculations based on powerful algorithms following specific steps:

- Cutting of the continuous medium into subsets;
- Construction of the nodal approximation by subsets;
- Calculation of elementary matrices relating to the problem of origin;
- Assembly of elementary matrices;
- Construction of boundary conditions;
- Solving equations.
- The main equation describing the modeling is expressed as:

\[ M(v) = f \] (1)

Or \( v \) denotes the unknowns of the problem, \( M \) represents the partial derivative operator, and \( f \) represents a given function. Mathematically, solving the problem (1) amounts to writing it, under conditions imposed in the shape of:

\[ M(v, u) = h(v) \] with \( M \) a function belonging to the functional space and \( h(v) \) the linear form associated with the function of the problem.

2.1 Specimen used in Numerical and Experimental Tests
The specimen used in the present work is tufa soil extracted from Casablanca (fig.1)

![Tufa soil from casablanca-Morocco (soil D)](image)

Figure 1 Tufa soil from casablanca-Morocco (soil D)

We have conducted a series of coring samples in the region of casablanca (Morocco) and have studied the lithological columns of soil (D) which contains basically tufa. This soil is predominant in this region and shows susceptibility of collapse in some of its parameters. [15]

2.2 Oedometer Test Conducted at the Laboratory
The oedometer test allows the geotechnical risks associated with soils to be identified by describing the amplitude and speed of soil compaction. The test system has two parts:

- A cell containing the soil sample; (fig.2)
The loading system: The loading can be by weight or by pneumatic or hydraulic loads

The oedometric cell is held laterally by non-deformable walls and vertically between two stones that let the water circulate through its pores. The stresses are applied vertically and the deformations of the specimen are read by comparators or recorded by displacement sensors.

![Figure 2 Oedometer schema](image)

The loading consists of a succession of effective stresses \( \sigma'_n \) applied on the top of the oedometric cell at the end of loading of each level:

\[
\sigma'_n = \sigma_n - u_{cp} \tag{2}
\]

Where \( \sigma'_n \) represents Effective stress, \( \sigma_n \): Total normal stress and \( u_{cp} \): Interstitial pressure

This law depends on the initial effective stress existing in the sample. The first applied load must then be small and generally taken equal to 5 KPa. This first load contributes to correct the surface defects and will give the first point of the compressibility curve. Each charge applied is double of the previous one.

The ‘preconsolidation’ pressure \( \sigma'_p \) generally unknown at the beginning of the test is determined graphically from the settlement curve in function of the applied stress. This constrain approximates the maximum curvature of the curve. It represents the maximum stress experienced by the sample throughout its history. The duration of each stage is taken equal to 24 hours. We applied then a series of stresses: 5Kpa, 20Kpa, 40Kpa, 80Kpa, 160 Kpa, 320Kpa, 650 Kpa, 1200Kpa, 650Kpa, 320Kpa and 5Kpa. The surface section is equal to 39,80cm², the height of the sample is 2cm, the initial void ratio is 0.634 and the initial water content is 4.92%. The curve of compressibility is expressed in fig. 3

![Figure 3 Compressibility curve by oedometer test conducted in the laboratory](image)
0.014, the swelling index is 0.3 and the preconsolidation pressure is 55 Kpa. The final void ratio is 0.232 and the final height of the specimen is 1.58 cm.

2.3. Simulation of Oedometer Test by Plaxis

The code plaxis has been specially developed for geotechnical deformation and stability analysis. Its performance depends on the generation of complex finite element models from a simple graphical data input. The calculation is automated and based on numerical procedures and precise algorithms. This works consists in using a simple rheological model: isotropic-linear plastic. The geometry of the numerical model is similar to the sample used in the laboratory oedometric test. To generate the mesh in the plane, we used the axis of the symmetry since the specimen has a revolution axis. So the dimensions of the sample will become as shown in figure 4. We choose triangular elements with 15 nodes per element, each nodes has two degrees of freedom.

![Figure 4 Model used for the simulation](image)

The bottom of the sample is totally blocked in all directions, rotation and translation relative to the main axes x and y. Both sides of the specimen are locked as well in rotation and translation. In order to simulate the oedometer test, we applied a vertical stress $\sigma_y$ to the upper part of the sample; this stress is a surface charge, applied to the upper face of the specimen. During the calculation, the software Plaxis will distribute this surface charge on all the nodes of the mesh.

The soil is undrained and we choose the Mohr Coulomb model in the first time to simulate the soil behavior. This model involves five parameters: the cohesion $c$, the Young modulus $E$, the friction angle $\phi$, the dilatancy angle $\psi$ and the poisson ratio $\nu$.

The characteristics of the soil are represented in the table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>cohesion $c$</td>
<td>11Kpa/m²</td>
</tr>
<tr>
<td>Young modulus $E$</td>
<td>3858Kpa/m²</td>
</tr>
<tr>
<td>friction angle $\phi$</td>
<td>23</td>
</tr>
<tr>
<td>dilatancy angle $\psi$</td>
<td>0</td>
</tr>
<tr>
<td>poisson ratio $\nu$</td>
<td>0.30</td>
</tr>
</tbody>
</table>
To these parameters we included as well the permeability \( K \), the saturated and unsaturated weight \( \gamma_{\text{unsat}} \) and \( \gamma_{\text{sat}} \) and the hight of the grains \( h_p \) calculated by the formula:

\[
h_p = \frac{P_s}{\gamma_s \gamma_w} \quad (3)
\]

Where \( P_s \) represents Dry weight of the soil; \( \gamma_s \) : Soil density, \( \gamma_w \) : Water specific weight.

The phases of the simulation are similar to the ones followed in the laboratory test. (Table 2)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Step</th>
<th>Calculation type</th>
<th>Effective stress (KPa)</th>
<th>Time (Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>plastic</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>consolidation</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>plastic</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>consolidation</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>plastic</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>consolidation</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>plastic</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>consolidation</td>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>plastic</td>
<td>160</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>consolidation</td>
<td>160</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
<td>plastic</td>
<td>320</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>consolidation</td>
<td>320</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>plastic</td>
<td>650</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>consolidation</td>
<td>650</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>plastic</td>
<td>1200</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>consolidation</td>
<td>1200</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>17</td>
<td>plastic</td>
<td>650</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>consolidation</td>
<td>650</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
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<td>plastic</td>
<td>350</td>
<td>0</td>
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<tr>
<td>10</td>
<td>20</td>
<td>consolidation</td>
<td>350</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>plastic</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>22</td>
<td>consolidation</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

After calculations, the vertical displacement is presented as below:

![Simulation inputs](image1.png)

Figure 5 Simulation inputs: on the right, curve of displacements in function of steps, on the left the vertical displacement of the soil sample.
The vertical displacement is represented in function of steps of the simulation. In order to plot the compressibility curve, we calculated the void ratio by the formula:

\[ e = \frac{h_i - h_p}{h_p} \]  

Where \( h_i = H_{\text{sample}} - U_i \); \( U_i \): Displacement at the step I; \( h_i \): Height of the sample at the step i

3. RESULTS AND ANALYSIS

The soil undergoes deformations like any other material with the application of additional loads. These deformations are related more specifically to the difference between the total stresses that represent gravity and any load exerted on the surface such as embankments or inside the ground such as tunnels or excavations, and the interstitial pressure, called effective stress. The effective stress is directly related to the total stress for dry soils, since the pressure of the water is zero, while the intermediate soils, called unsaturated are much more complex.

The surface of the soils is considered generally horizontal, and if moreover the applied loads are uniform, with a width to thickness ratio is greater than 2, which refers to the compressible soils, it is assumed that the deformations are vertical.

When using Mohr Coulomb's law (MC), (figure 7) we find that the compressibility curve is almost confused with the one obtained by laboratory test during the loading process, but it moves away gradually when it is unloaded. So, we can note that MC's error is very significant; one of the main causes of this error is the fact that it does not take into account the effect of unloading because the soil modulus in unloading phases is different and significantly stronger than the one in loading.

We subjected the same soil to another simulation using this time the SSCM (figure 8) constitutive law (soft soil creep model) adding creep parameter \( \mu^* \), compressibility and swelling index respectively \( \lambda^* \), \( \kappa^* \) and coefficient of soil in its consolidated state \( K_{0c}^\text{RC} \) and the critical state line \( M \) given by the relations as: \( \lambda^* = \frac{c_c}{1+e} \); \( \kappa^* = \frac{c_s}{1+e} \); \( M = \frac{6\sin(\varphi+0.1^\circ)}{1-\sin(\varphi+0.1^\circ)} \)
Both curves representing the oedometer test conducted on laboratory and simulated by plaxis code have shown that the soil is highly compressible, which agrees with our previous study conducted on the same type of soil [15,10] Plaxis code can then reproduce good adjustment with experimental results in the loading and unloading process by using SSCM constitutive law, where Mohr Coulomb law can only give similar results to laboratory test in the loading phases. The potential of collapse cannot however be calculated at this level of simulations because the laboratory test and the simulated model must be performed on the soil under its initial water content and under effective stress of 200Kpa [17]. But it is an intermediate stage to calculate parameters related to the soft soil model (SSM) and soil soil creep model (SSCM).

4. CONCLUSIONS

When carrying out oedometer test simulation by plaxis code using the Mohr coulomb constitutive law, we have found that the compressibility curve is only similar to experimental test during the loading phases. But when performing the same test using the soft soil creep model, the results were comparable to oedometer test conducted in the laboratory. The SSCM law takes into account the pre-overburden pressure POP and the over consolidation ratio OCR. Still, further researches are required to discuss the applicability of POP and OCR ratio. [17]

At the end, let’s remember the British mathematician George Box saying: “All models are wrong, but some are useful” let us add that we must use models carefully and correctly.

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