Comparison between numerical and experimental behaviour of granular soil

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Abstract

Despite the recent interesting development in elasto-plasticity soil modelling, the plane-cap and elliptical-cap Drucker-Prager models are still widely used in numerical analyses, particularly for full-scale problems. The aim of this paper is to evaluate the reliability of these models in predicting soil behaviour by means of a comparison with experimental results regarding some specimens subjected to traditional laboratory tests. The paper reports a preparatory study for the numerical-experimental comparison of the soil behaviour under the Noto Cathedral in Sicily, that was seriously damaged after the earthquake of 1990.

1 Introduction

Although numerous, new, interesting results have been recently achieved on the modelling of soil behaviour (Di Prisco et al. [1]), the Drucker-Prager model has been until now one of the most widely used soil models in commercial, finite-element codes, such as the ADINA code (ADINA [2]) used in this paper and the FLAC³D code (FLAC³D [3]), for solving static and dynamic problems.

The present paper reports the comparison of numerical and experimental results concerning the behaviour of different sand specimens subjected to typical laboratory tests, to evaluate the applicability of the plane-cap and elliptical-cap versions of the Drucker-Prager model in the numerical analyses of full-scale problems, such as soil-structure interaction phenomena.

2 The Drucker-Prager model applied in the soil numerical analyses

The Drucker-Prager yield criterion is given by:
being $I_1$ the first stress invariant, $J_2$ the second deviatoric stress invariant, and $\alpha$ and $k$ two material property parameters, related to the well-known Mohr-Coulomb parameters $c$ and $\phi$.

In particular, in 3-D analyses for a Drucker-Prager surface that circumscribes the Mohr-Coulomb surface, it was found that (Chen [4]):

$$\alpha = 2 \sin \phi / \sqrt{3 \times (3 - \sin \phi)}$$ (2)

$$k = 6 c \cos \phi / \sqrt{3 \times (3 - \sin \phi)}.$$ (3)

In the present analysis two cap yield functions are considered.

The plane-cap yield function takes the form:

$$f_c = -I_1 + I_1^a = 0$$ (4)

being $I_1^a$ a function of the plastic volumetric strain $\varepsilon_p^v$, as reported in the following expression:

$$I_1^a = -\frac{1}{D} \cdot \ln \left( 1 - \frac{\varepsilon_p^v}{W} \right) + I_1^{a,0}$$ (5)

being $I_1^{a,0}$ the cap initial position and $W$ and $D$ two material constants.

The elliptical-cap yield function takes the form:

$$f_c = (I_1 + L)^2 + R^2 \cdot (J_2 - B^2) = 0$$ (6)

being $L$ the value of $I_1^a$ in correspondence to the vertical semi-axis of the elliptical cap, $R$ the ratio between the major and the minor semi-axis of the elliptical cap and $B$ the vertical semi-axis of the elliptical cap.

Both the plane-cap and the elliptical cap models need the definition of a tension cut-off limit plane:

$$f_t = I_1 - T = 0$$ (7)

being $T$ the tension cut-off limit.

Finally, an associate flow rule using the Drucker-Prager and cap functions is considered. This hypothesis represents a clear limit of the above formulation in soil mechanics, overcome in several researches (Cuomo et al. [5]). However, in some cases, like in the present, it does not influence the results significantly.
3 A comparison between soil laboratory test results and numerical results

In order to evaluate the reliability of the results given by the plane-cap and elliptical-cap Drucker-Prager models implemented in the ADINA code, the experimental results of some laboratory tests on the McCormick Ranch sand reported in DiMaggio & Sandler, 1971 (Di Maggio & Sandler [6]) are considered. The commercial ADINA code allows the study of several civil engineering problems. Particularly, due to its rich bibliography in terms of elements, material models, contact surfaces and boundary and loading conditions, it can give a comprehensive view of soil-structure interaction phenomena, very important in the serviceability state analysis.

As far as the laboratory tests are concerned, the cylindrical specimens [6] are characterised by the “model parameters” reported in Table 1. Fig. 1 shows the comparison between the experimental and numerical results, in terms of \(\sigma_a\) versus \(\varepsilon_a\), being \(\sigma_a\) the axial stress and \(\varepsilon_a\) the axial strain for a uniaxial strain test. Then two proportional loading tests are considered, one for \(\sigma/\sigma_a = 0.4\) and the other for \(\sigma/\sigma_a = 0.8\), being \(\sigma\) the radial stress (Fig. 2).

![Table 1. Drucker-Prager model parameters utilised in the numerical analysis carried out by the ADINA code](image)

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>(E)</th>
<th>(\nu)</th>
<th>(\alpha)</th>
<th>(k)</th>
<th>(W)</th>
<th>(D)</th>
<th>(R)</th>
<th>(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>100</td>
<td>0.25</td>
<td>0.10</td>
<td>0.07</td>
<td>-0.066</td>
<td>0.67</td>
<td>2.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Finally, Fig. 3 reports for a triaxial stress test (\(\sigma_r = 0.4\) KSI) the trend of \(\sigma_a - \sigma_r\) versus \(\varepsilon_r\), being \(\varepsilon_r\) the radial strain. As far as the uniaxial strain tests are concerned, both the plane-cap and the elliptical-cap Drucker-Prager models offer results very close to the experimental ones; nevertheless the plane-cap model underpredicts the axial deformation more than the elliptical-cap model. The same trend can be observed for the proportional loading test with \(\sigma/\sigma_r = 0.8\). In all the other loading conditions only the elliptical-cap model gives, once more, good results; while, as far as the plane-cap model is concerned, remarkable differences exist with the experimental values.

4 Conclusion

[1] The analysis of the numerical and experimental behaviour of some sand specimens, subjected to uniaxial strain, proportional loading and triaxial stress tests, leads to the following conclusions. 1) The plane-cap Drucker-Prager model appears inadequate for soil material. This model has the
merits of the improvement of the hardening function under hydrostatic loading, of a limited dilatancy and of limited tensile strength. However, it is not accurate in predicting the soil behaviour under shear loads. For this reason it can predict very well uniaxial strain tests, i.e. oedometer tests, but no proportional loading or classical triaxial tests. 2) The elliptical-cap Drucker-Prager model prevents too much dilatancy on the failure surface under high hydrostatic pressure and offers reliable results for all the considered loading conditions. 3) Considering that the last model reproduces the soil stable behaviour corresponding to no-high stress levels quite well, then it can be used for predicting soil behaviour in serviceability state.

Figure 1. Uniaxial strain test
Figure 2. Proportional loading tests
Figure 3. Triaxial stress test

References