PREDICTION OF UNDRAINED TRIAXIAL TEST RESULTS FROM DRAINED TESTS: DISCRETE ELEMENT SIMULATIONS USING PFC³D

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ABSTRACT: In geotechnical engineering practice particularly in consulting projects, conducting undrained shear tests with pore water measurements is complicated and in particular very few laboratories have equipments and trained manpower to conduct the undrained shear tests with pore water pressure measurements tests and interpret the results effectively. Norris et al. (1997) proposed a technique to predict the undrained response of sands from drained triaxial tests carried out from isotropic rebound paths. In this paper, discrete element simulation using PFC³D has been used for predicting undrained response from drained test results. Triaxial shear tests are conducted on a cylindrical assembly which consists of 1000 spherical particles. Assembly considered for the simulations is having different particle diameters with uniform soil gradation. These results show an excellent correlation between the predicted undrained behaviour from drained triaxial tests and the observed response in undrained test simulation (constant volume simulations). The simulation results are presented to demonstrate the concept which allows the prediction of undrained response from drained triaxial tests.

1. INTRODUCTION

The response of isotropically consolidated saturated sands under undrained conditions is associated with the generation of excess of pore water pressure in the sample. The contractive or dilative responses of the material generate positive and negative excess pore water pressures respectively. The increase or decrease in the induced excess pore water pressure ceases, once critical state (steady state) is reached. Recent studies by (DeGregorio, 1990) indicate that the steady-state response is very much dependent on the method of soil sample preparation. This is because as the method of preparation changes, the fabric of the sand also varies resulting in a difference in the volume change tendencies. Hence in this paper, PFC³D which applies DEM (Cundall & Strack, 1979) technique is used which helps to prepare identical samples and conduct numerical simulations in an identical initial state and understand the mechanical behaviour of granular media.

2. TEST ASSEMBLY

Numerical simulations are carried out on a cylindrical assembly consisting of 1000 spheres with a uniform gradation. The length to diameter ratio of the sample is kept as 2 similar to a triaxial specimen. The assembly of spheres is generated according to the desired particle size and are placed at random locations without any initial overlapping within the specified cylindrical boundary. Initially the assembly is generated in a very loose state to avoid any overlap and an appropriate coefficient of contact friction is assigned to all particle contacts. The ratio of normal to tangential stiffness is kept unity based on Winkler’s (1983) experimental observation. An initial isotropic packing of the assembly as shown in Figure 1 is obtained by DEM cycling. An appropriate value of inter particle friction is set to facilitate the initial compaction. Figure 1 shows the initial cylindrical assembly. The properties of the spheres used to create cylindrical assembly are shown in Table 1.

Fig. 1: Initial Particle Assembly
Table 1: Input Parameters for the Assembly Used for Simulations

<table>
<thead>
<tr>
<th>Properties</th>
<th>Symbol</th>
<th>Values used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal contact stiffness of spheres</td>
<td>( K_n )</td>
<td>( 1.0 \times 10^7 \ \text{N/m} )</td>
</tr>
<tr>
<td>Tangential contact stiffness of spheres</td>
<td>( K_t )</td>
<td>( 1.0 \times 10^7 \ \text{N/m} )</td>
</tr>
<tr>
<td>Particle density</td>
<td>( \rho )</td>
<td>2000.0 kg/m(^3)</td>
</tr>
<tr>
<td>Coefficient of interparticle friction</td>
<td>( \mu )</td>
<td>0.5</td>
</tr>
</tbody>
</table>

3. NUMERICAL SIMULATIONS

The initially generated assembly is isotropically compressed to a confining pressure of 200kPa. The isotropic compression is performed by activating the numerical servo control and the sample is brought to equilibrium under the desired isotropic stress i.e. \( \sigma_{11} = \sigma_{22} = \sigma_{33} \). This isotropically compressed sample is then rebound to various lower confining pressures which is represented as \( \sigma_r \). Figure 2 illustrates the void ratio-log confining pressure curve for a sample which is normally consolidated from a void ratio at some initial confining pressure to a final void ratio when isotropically consolidated to \( \sigma_{33} \). It also shows the rebound curve which indicates the isotropic expansion as the samples are rebounded from a higher pressure to lower confining pressures.

Norris et al. (1997) has pointed out that the undrained (constant volume) behaviour in a consolidated-undrained test is the result of opposing volume change tendencies from isotropic and deviatoric stress changes accompanying the change in the effective confining pressure. Hence the stress-strain response of an undrained triaxial test can be predicted from the associated drained triaxial test stress-strain-volume change curves. In the case of undrained shearing of an isotropically consolidated sample, as the volume is constant during the application of deviatoric stress, excess pore water loading is similar to conventional drained axisymmetric triaxial tests where the ratio of \( q/p \) is maintained as 3. The stress-strain and volumetric responses during the drained shear tests on the isotropically rebounded samples is shown in Figures 3 and 4 respectively. The plots are recorded for the assemblies rebounded to 175, 150, 140 and 125 kPa. The stress strain curves for the drained simulation show that with an increase in confining pressure there is an increase in peak deviatoric stress. Also it can be observed that a sample rebounded to lower confining pressure exhibits a greater isotropic expansion (Fig. 2), but smaller compressive volumetric strains during shear (Fig. 4).
pressure develops. As a result the effective confining pressure decreases and hence the sample will have a tendency to expand by an amount \( \varepsilon_{v,iso} \). But the total volumetric strain due to the changes in both effective confining pressure and deviatoric stress should be equal to zero as the loading condition is undrained. This implies that the strains due to deviatoric stress \( (\varepsilon_{v,shear}) \) and effective confining pressure\( (\varepsilon_{v,iso}) \) must be equal and opposite. The undrained volumetric responses due to deviatoric as well as effective confining pressure occur simultaneously. Here, to predict the undrained response of the sample, the stress-strain-volume behaviour curves obtained during drained triaxial simulations along with the isotropic rebound curve should be used. Figure 5 shows the undrained stress-strain response during shear on a sample which has been isotropically consolidated to a confining pressure of 200kPa.

![Fig. 5: Stress Strain Response of Undrained Loading Condition](image)

### 3.1 Steps for the Prediction of Undrained Response

The amount of expansion occurring when a sample is rebounded to lower confining pressures (say \( \sigma_r \)) from a higher confining pressure (200kPa) is obtained from Figure 2. This expansion corresponds to \( \varepsilon_{v,iso} \) of undrained loading which happens due to the decrease in the effective confining pressure when excess pore pressure develops. This value is plotted in the volume change curve (Fig. 4) corresponding to \( \sigma_r \). A horizontal line parallel to the axial strain and passing through the value \( \varepsilon_{v,iso} \) cuts the respective volume change curve at a particular value of axial strain say \( \varepsilon_1 \) and \( \varepsilon_2 \). Note the axial strains and from Figure 3 corresponding deviatoric stresses (q) are obtained. From these drained axial strains, corresponding undrained axial strains are obtained as \( (\varepsilon_u = \varepsilon_1 - \varepsilon_{v,iso} / 3) \). Having obtained this, the predicted coordinates corresponding to the undrained response is \( (q, \varepsilon_u) \) and is shown in Figure 5. In addition to the stress-strain response, the corresponding effective stress paths can also be predicted and is shown in Figure 6.

![Fig. 6: Predicted Undrained Effective Stress Path from Drained Simulations](image)

### 4. CONCLUSIONS

In this paper, an approach for predicting the undrained response of a cylindrical sample from drained triaxial tests on isotropically rebounded samples at different confining pressures is validated using 3-dimensional DEM considering spherical particle assembly. This is done by using PFC3D software which is based upon discrete element technique. The results presented here show that the predicted undrained responses from drained numerical simulations is having good correlation with the response obtained from undrained test simulation (constant volume simulation). This method to obtain an undrained response is particularly useful when conventional triaxial undrained tests with pore water pressure measurements are difficult to be done, whereas drained tests with volume change measurements are possible at all laboratories.

### REFERENCES


