Numerical Simulation of Direct Test for Rock

Shrivastava, A.K.  
Assistant Professor  
e-mail: aksrivastava@dce.ac.in  
Department of Civil Engineering, Delhi Technological University, Delhi

Rao, K.S.¹  
Professor  
e-mail: raoks@civil.iitd.ac.in  
¹Department of Civil Engineering, Indian Institute of Technology Delhi

ABSTRACT

The shear behaviour of rock joint is a combination of complex phenomena such as normal dilation, asperity shearing or sliding, contact area undergoing shearing or sliding and stiffness of the surrounding rock mass. Hence, a constitutive model for joint behaviour has to consider a large number of assumptions and uncertainties. Considerable efforts have been made in the past by various researchers to explain the shear behaviour of rock joint. Based on their laboratory, analytical and numerical studies various shear strength models have been proposed by them. In the present study numerical modeling is done for simulating the experimental conditions. Numerical study is performed based on the Distinct Element Method (DEM) and using the Universal Distinct Element Code (UDEC) developed by ITASCA Consulting Group Inc. Direct shear test were carried out on numerically simulated rock joint using UDEC. The shear behavior of rock joint examined with asperity like 15°-15° and 30°-30° at different normal stress. The result of the laboratory shear test performed on the sample with asperity 15°-15° and 30°-30° at different normal stress is compared with the shear behaviour and failure process of numerically simulated rock joint.

1. INTRODUCTION

The correct evaluation of shear behaviour of rock mass is important in the design of excavations in rocks, stability analysis of rock slopes, anchored rock slopes and design of rock socketed piles. There are various factors which influence the shear behavior of rock joint, Shrivastava (2009). It is very difficult to simulate all the factors influencing the shear behavior in the constitutive modeling. Hence, a constitutive model for joint behaviour has to consider a large number of assumptions and uncertainties, which may sometimes unable to predict correctly the stress and deformation characteristics of the sample. It is also very difficult to conduct the experiment on the large sample under simulated field condition to find out the shear and deformation parameters require for design of underground structure, rock-socketed piles, rock foundation and rock slopes. Hence, in this paper an attempt has been made to do the numerical simulation of the rock joint to study the shear and deformation characteristics and compare the results of the numerical study with experimental results done on the sample. Numerical study is performed based on the distinct element method (DEM), using the universal distinct element code (UDEC) developed by ITASCA consulting group inc.

2. LITERATURE REVIEW

A number of numerical programs are available to perform the numerical simulations of the geotechnical problems, but identification of the proper numerical program for the specific geotechnical problems, selection of the correct input parameters and their interpretation is very important.

Many of the analytical and numerical programs like finite element, boundary element and finite difference, used for the representation of the rock mass were inadequate as they have treated the rock mass as a continuum, and to model discontinuity interface elements or rock mass is cut by a limited number of discontinuities represented by the slide lines. But, the above approach of modeling rock joints, fails to analyze properly either due to breakdown of logic when many intersecting interfaces are used or non availability of scheme for automatic identification of new contacts, Itasca (2004). But the rock mass are discontinuous and considering the rock mass as continuum gives erroneous result especially while analyzing the large deformation behavior of the rock joints, underground structure and stability of slopes, also when these structure is subjected to dynamic load.

In such situations discontinuum approach may provide a better solution. The most commonly used method for this
category is the discrete element method (DEM). The first step of this method is to discretise the rock mass into elements. The elements interact with one another through the forces developed at the contact points. Thus the rock mass behaves as an assemblage of intact rock pieces separated by explicitly define discontinuities. This allows the modelling of the simultaneous failure of the intact rock and the discontinuities. Complex constitutive laws for the rock mass behaves as an assemblage of intact rock pieces separated by explicitly define discontinuities. This allows the modelling of the simultaneous failure of the intact rock and the discontinuities. Complex constitutive laws for the behaviour of the contacts can be applied. The approach also allows the rotation of intact rock piece i.e. rock block, which is absent in case of continuum approach, and the displacement along the discontinuities. A major limitation of currently available commercial software’s on this approach is that they are unable to model crack initiation and prorogation through intact blocks i.e. once the intact material with in the model starts to fail, movement along the fracture is not allowed, Szymakowskai, (2003). However, the approach is very useful for explaining the deformation and failure of the blocky rock masses and provides valuable insight into the failure mechanisms occurring with in the rock masses, Curran and Ofoegbu, (1993). The commercial software package available is UDEC which may be used to model the deformation and rotation of rock blocks and the sliding along joints.

3. NUMERICAL ANALYSIS BY UDEC PROGRAM

The Universal Distinct Element Code (UDEC) is a combined distinct element and explicit finite difference two-dimensional numerical modeling program. UDEC is a command-driven (rather than menu-driven) computer program. UDEC simulates the response of discontinuous media (such as a jointed rock mass) subjected to either static or dynamic loading. The discontinuous medium is represented as an assemblage of discrete blocks. The discontinuities are treated as boundary conditions between blocks; large displacements along discontinuities and rotations of blocks are allowed. Individual blocks behave as either rigid or deformable material. Deformable blocks are subdivided into a mesh of finite-difference elements, and each element responds according to a prescribed linear or nonlinear stress-strain law. The relative motion of the discontinuities is also governed by linear or nonlinear force-displacement relations for movement in both the normal and shear directions. Several models for joint behaviour are available in the UDEC.

Development of Experimental Model in UDEC

The UDEC models an experiment on the computer in similar way it is performed in the laboratory. For UDEC modeling of the direct shear test, model geometry is created, material and joint models are assigned, initial boundary condition is applied, initial normal stress is applied, stepping is applied to reach the sample at equilibrium, the shear load is applied to the sample by providing shear velocity to the sample, the shear load is monitored at five places in the sample, similarly shear deformation and normal displacement is also monitored at different places, average shear stress, shear and normal displacement is calculated.

Model geometry of size 297 mm X 297 mm X 125 mm is created in the UDEC model which is same as of laboratory specimen. The desired asperity of 15°-15° and 30°-30° of thickness 5mm is created by crack command. The UDEC model of the sample with asperity 15°-15° is as shown in Figure 1. The two dimensional program treats the model as in plain strain conditions with an out of plane thickness equal to one unit.

Fig. 1: UDEC Model Geometry of 15°-15° Asperity

Physical and engineering property of model material is assigned is as obtained in the laboratory by Rao et al. (2009) on plaster of paris. The basic properties of the model material at 60% of the moisture by weight and 14 days air curing are determined by performing the test on sample. The property of the model material is as given, average density 1234 kg/m³, bulk modulus 1357 MPa, shear modulus 934 MPa, cohesion 3 MPa, angle of friction 33°, dilation angle 5°, tensile strength 1 MPa. The joint property used in the UDEC model are joint normal stiffness 2000MPa, joint shear stiffness 200 MPa, joint friction angle 39°, joint cohesion 0.05 MPa, joint dilation 5° and joint tensile strength 0.01 MPa. For joint coulomb slip model is used.

Initial boundary condition is applied on the sample in such a way that the lower shear box is only allowed to move in X direction and movement in Y direction is restricted by imposing Y velocity at the bottom of the lower shear box as zero. The upper shear box is allowed to move only in the Y direction and movement in the X direction is restricted by imposing X velocity at the sides of the Upper shear box as zero.

Required initial normal stress is applied at the top of the shear box. Model is run for large number of cycle to reach equilibrium and give desired shear displacement to the sample. At equilibrium, the force on one side of a grid
point nearly balance the opposing force. In this study shearing is done to the sample for the shear displacement equal to half the base length of single asperity. Hence, the 15°-15° and 30°-30° asperity has been given 5300000 and 3000000 steps respectively which has caused the shear displacement of 18.7mm and 7.07mm respectively. Shear load is applied to the sample by applying the velocity to the lower sample as in the case of laboratory study. To monitor the shear force five monitoring point is kept at left hand side of the lower sample and four normal displacement monitoring point is selected at the top of the upper sample and shear displacement is monitored at two points on the lower sample. Now the UDEC code is run to find out the result at monitoring point. The UDEC results of deformation characteristics are as shown in the Figures 2 and 3 for 15°-15° and 30°-30° asperity at normal 0.1 MPa respectively. The Figure 4 shows the sheared sample of 15°-15° asperity at normal stress 0.1 MPa after 530000 steps. The similar type of result and graphs are taken as output of the program after every step of 1000000. The shear test is performed on the modeled sample for the initial normal stress at 0.1, 0.51, 1.02 and 2.04 MPa and the shear stress, shear deformation, normal deformation of sheared sample is monitored at monitoring point and graph of this is plotted for every 1000000 steps till half the base length of single asperity is sheared. Due to space constraint one sample result is shown but the final results of each are compared with experimental results.

4. EXPERIMENTAL RESULTS
To study the shear behavior of the rock joint, the extensive tests were planned and conducted on the large scale direct shear testing apparatus developed and fabricated by Rao et al. (2009) on 15°-15° and 30°-30° asperity joint under different initial normal stress (Pi) of 0.1, 0.51, 1.02 and 2.04 MPa. The shear and deformation characteristic of rock joint is as shown in Figure 5 and 6 for 15°-15° and 30°-30° asperity respectively under constant normal load (CNL) boundary condition.
5. COMPARISON OF UDEC RESULT WITH EXPERIMENTAL RESULT

UDEC is two dimensional programs treat the model as in plain strain conditions with an out of plane thickness equal to one unit. The shear stress developed in the sample at five monitoring point is multiplied by the thickness of the lower sample and divided by the shearing length of the sample to get the actual shear stress on the shearing plane. It has been found that the UDEC closely predict the shear strength of the joint and the variation of result between UDEC and experimental result is between 0% to 17.64% and 0% to 17.31% for 15°-15° and 30°-30° asperity joint respectively. UDEC normally over predict the peak shear strength of the joint and at low normal stress variation with experimental result is very less and it increases with increase in normal stress, as shown in the Figures 7 and 8. The UDEC and the experimental results predicted the same pattern of the strength envelope for both the asperity. The strength envelope is curvilinear for both the case.

6. CONCLUSIONS

The tests are performed on the modeled rock sample with asperity 15°-15° and 30°-30° on the large scale direct shear testing apparatus in the laboratory and numerical modeling of the same test is done in the UDEC program. The UDEC is best suited for discontinuous material like rock joint and proper selection of the input parameter and steps in the analysis helps in better prediction of the shear strength of the rock sample by UDEC program. The conclusions made from the experimental and UDEC results are summarized below:

I. UDEC normally over predict the peak shear strength of the joint and at low normal stress variation with experimental result is very less and it increases with increase in normal stress.

II. The curvilinear strength envelope is predicted for both the asperity by experimental study and UDEC program. The curvature of the strength envelope decreases with increase in the asperity angle at low initial normal stress i.e. less than 0.1 time’s uniaxial compressive strength of the model rock and after this initial normal stress it approaches more towards linearity.

III. UDEC program is having facility to see the shearing of the sample at different stages of shearing where as this facility is not available with the experimental analysis, where only sample can be seen at the beginning and end of shearing in the direct shear machine.

REFERENCES


Itasca. (2004). UDEC and FLAC, Minneapolis, USA.

