UDEC Modeling of an Underground Opening in Rock Masses of Varying Quality

Tye J. Lasich, Undergraduate Student
Mary M. MacLaughlin, Associate Professor
Department of Geological Engineering, Montana Tech of The University of Montana, Butte, MT

Thomas M. Brady, NIOSH Spokane Research Laboratory, Spokane, WA

Abstract

This project involved modeling rock masses with varying Rock Mass Rating (RMR) values to determine the degree of instability that develops around an underground opening as a function of RMR. The modeling was performed using Itasca's UDEC distinct element software, which allows explicit modeling of blocks of rock and how they interact with each other. The analyses included three different orientations of the joint sets, four different joint spacings and three different values of joint strength, which combine for a total of 36 different combinations of model parameters. Two different modes of behavior were observed: local failure of area immediately surrounding the roof and sides of the opening, and deep-seated failure extending a large distance beyond the opening. Quantification of the size of the unstable area that developed provides numerical validation of empirical guidelines used in design of ground support and instrumented monitoring systems.

Introduction

The development of the discrete element methods of numerical modeling have greatly increased our ability to model the behavior of discontinuous materials like blocky rock. One way to use these tools is to perform parametric studies to facilitate growth of our understanding of the behavior of rock masses. Another use is to provide validation for empirical design guidelines. This study made use of one particular discrete element method, the distinct element method in the form of Itasca's UDEC software (Itasca 2000), for both of these purposes.

An underground opening in a shallow rock mass was modeled to determine the difference in behavior expected when the Rock Mass Rating (RMR) classification of the rock mass varies. Rock mass classifications such as the RMR (Bieniawski, 1974) were developed to facilitate fast and inexpensive characterization of rock masses. The RMR system provides a rating that generally ranges from close to 0 for the worst possible situations, to 100 for perfect rock. Design of ground support in underground mines is often based on RMR ratings of the rock.

The two thrusts of this study were to 1) document qualitative correlation between RMR ratings and behavior of the rock mass, and 2) investigate the dimensions of the unstable zone that develops around the excavation. Researchers at the University of British Columbia are performing similar studies to investigate these issues, as well.

Model Description

Dimensions and Loads

The model was specified using a homogenous material with dimensions 126 m long by 84 m tall. All of the boundaries were fixed, and since the model was intended to simulate an excavation at shallow depth, only gravity load was applied rather than a combination of gravity and in situ stress. In order to minimize computer run time, the blocks within the model were specified to be rigid rather than deformable. The excavated drift was rectangular in shape, with length 6 m and height 4 m.

Parameters Investigated

There were three parameters of interest in this investigation: friction angle, joint spacing, and joint orientation. Table 1 shows parameter values that were varied in the suite of models.

Table 1. Model parameters varied for parametric study.

Friction Angle, Degrees	Orientation, Degrees from Horizontal	Joint Spacing, Meters
40	-30,30	1
25	-60,30	0.6
10	-60,60	0.4
		0.2

RMR Range

The target RMR range for the project was between 30 and 50, indicating "fair" to "good" rock. The RMR ratings were calculated by determining the point totals for Rock Quality Designation (RQD), joint condition, joint spacing, intact rock strength, and groundwater, as well as the joint orientation modifier (Waltham, 2003).

RQD values were calculated using the joint spacing parameters using the relationship RQD = 115 – 3.3Jv (Hoek et al, 1997), where Jv is the number of joints per representative cubic meter of the rock mass. The joint spacings were used to calculate the number of joints per meter for each set, and then added together.

Assigned friction angle values was used to simulate different fracture conditions. A friction angle of 40 was assumed to correspond to "rough, tight" joints with a score of 30, while a friction angle of 25 would be "weathered" with a score of 20, and a friction angle of 10 would be "gouge > 5 mm" with a score of 0.

Joint spacing values shown in the above table were assigned to bracket a range of categories. The 1.0 m spacing is within the 15 point range. The 0.6 m spacing is on the border between the 15 and 10 point ranges. The 0.4 m spacing is in the middle of the 10 point range, and the 0.2 m spacing is on the border between the 10 and 8 point ranges. A smaller joint spacing of 0.06 m was attempted, but we did not have sufficiently powerful computers to run the models.

Several of the parameters included in the RMR calculation were not incorporated into the UDEC models, and were assumed to have one specific value. Intact rock unconfined compressive strength (UCS) was assumed to be within the middle range of "50-100 MPa" corresponding to a value of 7 points. Ground water was assumed to be wet, corresponding to a value of 7 and fracture orientation was given a value of -15 for "unfavorable." This combination essentially cancels out the effects of these three parameters on the total RMR values.

Example UDEC File

Table 3 shows the commands used in a typical UDEC analysis file. The first 8 lines define the corner rounding, the model block external dimensions, and the cracks used to create the excavation boundaries. The save files are used throughout the code to facilitate rerunning the analyses without having to start over from the beginning, which saves a lot of time in some models. Next are lines that define the rock material and joint properties followed by the fixed boundaries section. Gravity is set to -10 [m/s^2] and a title is added to the computation. After all of the data is input an initialization solve is performed to make sure that all of the blocks are in equilibrium before the main part of the analysis is started. After the initial solve is done the excavation is removed and a second solve is initiated to allow the blocks to move, if necessary, to attempt to reach equilibrium. The final state of the model is then saved.

Table 3. Commands used in a typical UDEC analysis file.

```
ro 0.01
block 0,0 0,84 126,84 126,0
jset -30,0 160,0 0,0 0.02,0
jset 30,0 160,0 0,0 0.02,0
crack 60,40 66,40
crack 66,40 66,44
crack 66,44 60,44
crack 60,44 60,40
save 3030sp20.sav

prop mat=1 dens 2000
prop jmat=1 jkn 5e8 jks 1e8 jfric 40

fix range 0,126 0,3
fix range 123,126 0,84
fix range 0,3 0,84
fix range 81,84 0,126
grav 0,-10
title
      Roof shape with -30/30 joints, fric. ang.=40, spacing=0.02
his unbal
damp local
solve
save 3030sp20f40equil.sav

del range 62 66 40 44
save 3030sp20f40excavated.sav
solve
save 3030sp20f40final.sav
```

At this point more code was required to observe what actually happened during the analysis. The objective was to determine the configuration of the excavation after equilibrium is reached, or after a substantial number of timesteps have been run. To get a picture of the model the code contained in Table 4 needed to be typed in.

Table 4. UDEC commands used to observe and record behavior.

```
plot block nc disp red
set plot jpg
set output 3030sp20f40.jpg
copy
```

Plotting the block configuration is done by using the "plot block" command. The "nc" helps the plot function work faster because it doesn't show the rounding of the corners of the blocks in the file (rounded corners take longer to draw on the screen). The "disp red" shows red arrows that display the displacement vectors of blocks indicating the direction and magnitude of movement. Setting the plot to "jpg" creates a jpeg image file. "Set output" allows the user to name the file and, if necessary, specify the file location. "Copy" sends the previous screen plot to the jpeg output file.

**Results, Discussion and Conclusions**

In all, there were 36 models that were run to collect data of the excavations failure type. Figure 1 shows one of the UDEC models that was run, with close-up views of the excavation with the three joint orientation combinations. Table 5 contains a summary of the RMR values for each model, with the corresponding contributions from each component, and a qualitative indication of the mode of failure of the model. Two types of behavior were observed: local failure of area immediately surrounding the roof and sides of the opening, and deep-seated failure extending a large distance beyond the opening. Figure 2 shows models that display the two different failure modes. Although there is some scatter in the lower RMR values, the general trend is that higher RMR values correspond with "local wedge failure" behavior; of the 21 models with RMR 47 or higher, only 1 displayed the deep-seated failure mode. The 15 models with RMR < 47 were very evenly split between the two failure modes.

During the modeling it was found that the models that collapse completely take much more time to run than the models that only drop the roof and sides of the excavation. The smaller the joint spacing, the longer the models took just because there are more blocks moving so it takes many more calculations to run the model. There were patterns observed in some of the models that were a result of the orientation. In the -30,30 models, there were diamonds around the excavation that showed up often in those models. In the -60,30 models it was common to find a chimney that stretched from the excavation to the top of the model. The -60,60 models seemed to settle very well and no common pattern was visible.

Observations of the extent of the failed zone around the opening indicate that the joint orientations have a large influence on the results. The failed zone extends about ¼ of the span for the 30,30 joints, about 1/3 span for the 60,30 configuration, and 1 full span for the 60,60 joints. It should be noted, however, that the models assume that both sets of joints are perfectly persistent, which is not very common in nature.
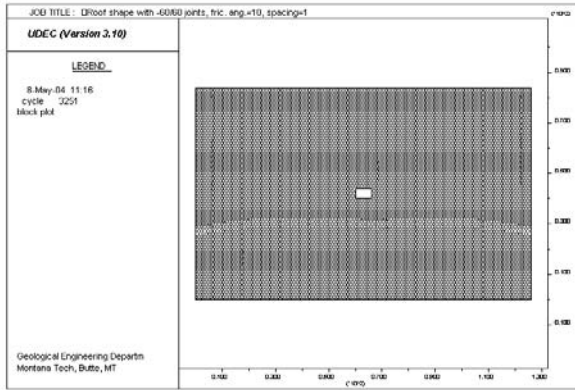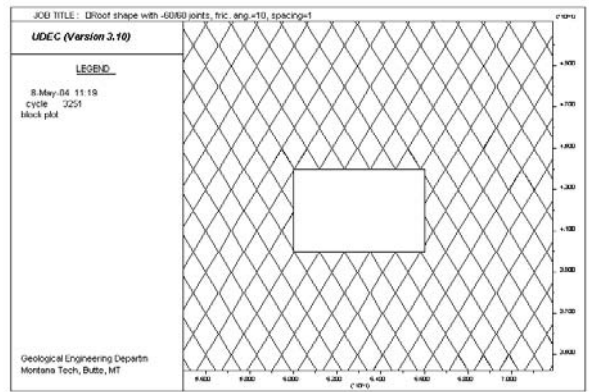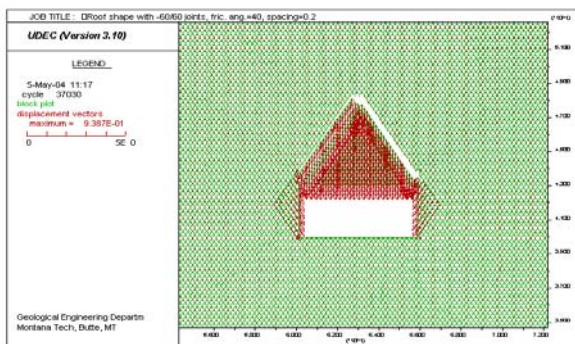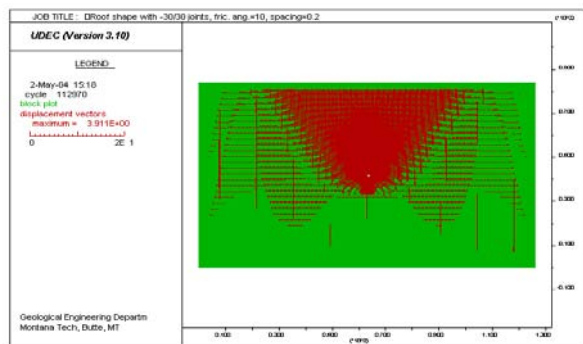
(a)
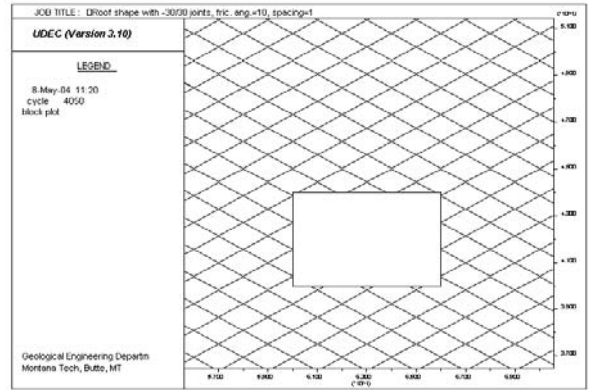
(b)
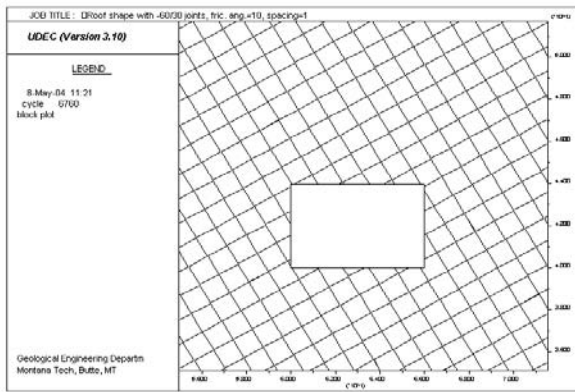
(c)

(d)

Figure 1. a) full model, b) 30,30 close-up, c) 60,30 close-up, d) 60,60 close-up; all 1 m spacing.

(a)

(b)

Figure 2. a) local failure, b) deep-seated failure.

Table 5. Failure mode as a function of RMR value.

J set angles	Spacing	Fric. Angle	UCS 50-100MP	Water Wet	Orentation Unfavorable	Frac Spac.	Fracture Cond.	RQD	RMR Value	Behavior
ang-30/30	0.6	40	7	7	-15	15	30	20	64	Local
ang-60/30	0.6	40	7	7	-15	15	30	20	64	Local
ang-60/60	0.6	40	7	7	-15	15	30	20	64	Local
ang-30/30	1	40	7	7	-15	15	30	20	64	Local
ang-60/30	1	40	7	7	-15	15	30	20	64	Local
ang-60/60	1	40	7	7	-15	15	30	20	64	Local
ang-60/30	0.2	40	7	7	-15	8	30	20	57	Local
ang-60/60	0.2	40	7	7	-15	8	30	20	57	Local
ang-30/30	0.2	40	7	7	-15	8	30	20	57	Local
ang-30/30	0.4	40	7	7	-15	10	30	17	56	Local
ang-60/30	0.4	40	7	7	-15	10	30	17	56	Local
ang-60/60	0.4	40	7	7	-15	10	30	17	56	Local
ang-30/30	0.6	25	7	7	-15	15	20	20	54	Local
ang-60/30	0.6	25	7	7	-15	15	20	20	54	Local
ang-60/60	0.6	25	7	7	-15	15	20	20	54	Deep
ang-30/30	1	25	7	7	-15	15	20	20	54	Local
ang-60/30	1	25	7	7	-15	15	20	20	54	Local
ang-60/60	1	25	7	7	-15	15	20	20	54	Local
ang-60/30	0.2	25	7	7	-15	8	20	20	47	Local
ang-60/60	0.2	25	7	7	-15	8	20	20	47	Local
ang-30/30	0.2	25	7	7	-15	8	20	20	47	Local
ang-30/30	0.4	25	7	7	-15	10	20	17	46	Deep
ang-60/30	0.4	25	7	7	-15	10	20	17	46	Local
ang-60/60	0.4	25	7	7	-15	10	20	17	46	Deep
ang-30/30	0.6	10	7	7	-15	15	10	20	44	Local
ang-60/30	0.6	10	7	7	-15	15	10	20	44	Local
ang-60/60	0.6	10	7	7	-15	15	10	20	44	Deep
ang-30/30	1	10	7	7	-15	15	10	20	44	Deep
ang-60/30	1	10	7	7	-15	15	10	20	44	Local
ang-60/60	1	10	7	7	-15	15	10	20	44	Deep
ang-60/30	0.2	10	7	7	-15	8	10	20	37	Local
ang-60/60	0.2	10	7	7	-15	8	10	20	37	Deep
ang-30/30	0.2	10	7	7	-15	8	10	20	37	Local
ang-30/30	0.4	10	7	7	-15	10	10	17	36	Deep
ang-60/30	0.4	10	7	7	-15	10	10	17	36	Local
ang-60/60	0.4	10	7	7	-15	10	10	17	36	Deep

References
Bieniawski, Z.T. (1974). Geomechanics Classification of Rock Masses and the Application is Tunneling. *Proc. Third Intl. Congress on Rock Mechanics*, ISRM, Denver, Vol 11A, pp. 27-32.
Hoek, E., P.K. Kaiser, and W.F. Bawden (1987). *Support of Underground Excavations in Hard Rock*, Rotterdam:Balkema, 215 pp.
Itasca (2000). *UDEC User's Guide (Version 3.1).* Minneapolis:Itasca Consulting Group Inc.
Waltham, A.C. (2002). *Foundations of Engineering Geology, 2nd Ed.*, Spon Publishing, 90 pp.