A CASE STUDY ON OPEN PIT MINE ROCK SLOPE STABILITY

Jeong-Gi Um

Department Environmental Exploration Engineering
Pukyung National University, Busan, Korea

ABSTRACT

Development of a three-dimensional mine visualization model for a section of the mine is addressed first. Discontinuity orientation and location information was taken from this visualization model for use in slope stability analyses. Estimated shear strength properties of discontinuities and mechanical properties of intact rock from the rock mass samples obtained from the mine are discussed next. The third part of the paper is focused on the results obtained for maximum safe slope angles for the section considered of the mine based on block theory analysis conducted under only the gravitational forces using the mapped discontinuities at the mine. Finally, the effects of water that exist in the rock mass, a tension crack, slope face inclination, overall wedge height and double benching on factor of safety of wedge stability are illustrated through limit equilibrium slope stability analyses conducted on a single tetrahedral wedge belonging to potential key block category that exist in the investigated area of the mine.

INRODUCTION

The Phelps Dodge Sierrita-Esperanza open pit copper mine is located 40 km southwest of Tucson, Arizona, on the southeast flank of the Sierrita Mountain Range. Figure 1 shows the investigated area that is on the north side of the Esperanza pit. The area investigated includes eleven benches each about 15 m high and approximately 305 m in length, encompassing two different rock types namely, Esperanza Quartz Monzonite Porphyry (EQMP) and the Triassic Oxframe Andesite (TrOA). This area is very much affected by the Cooper fault (Fig.1), better described as a fault zone. This fault strikes NE-SW and dips towards NW. The main trace of this fault is the apparent contact of the EQMP and TrOA. The other important component of the structure in this area is the difference in fracture intensities between the TrOA and EQMP. In places, the TrOA was so heavily fractured, it was difficult to perform scanline mapping. This problem was not seen with the EQMP. Nearly all exposures of EQMP were workable with some localized heavy fracture intensity, most probably due to blasting. This paper covers the studies performed to investigate the slope stability of the selected area of the mine.

DISCONTINUITY MAPPING AND DEVELOPMENT OF A 3D MINE VISUALIZATION MODEL

Discontinuity mapping with scanline surveys were performed on 1020, 1065 and 1125m benches of Esperenza pit near Cooper fault. A total of 27 scanlines were completed (Um et al., 2000). Out of these, 4 scanlines were in the TrOA rock mass. The rest were in the EQMP rock mass. A total of 1145 discontinuities (883 from EQMP and 262 from TrOA) were mapped from these scanlines. In addition, information on 87 major discontinuities (length greater than about 15 m) at bench levels starting at 1095, 1110 and 1125 m and on 42 major discontinuities at bench levels starting at 1020 and 1035 m were available for this study from previous investigations conducted for the mine.

In order to visualize discontinuities that have been mapped within the mine, a research initiation was made to develop a three-dimensional visualization model. The goals of this model are to act as a repository for all geologic mapping in the mine and as a tool to visually inspect the pit walls for areas of potential instability. For the scope of this project, only discontinuities mapped on the final pit wall in the North side of the Esperanza Pit were used.

The foundation of the visualization model is an aerial survey, which was performed with the resulting map entered into an AutoCAD drawing. Input data for the Visualization Model came from numerous sources including mine geologic maps and scanlines conducted for this project. The model has four basic input entities namely, faults, joints and joint sets, scanlines and scanline data, and lithology. Other important features of the model are the toe-lines of the benches, crest-lines of the benches and the 3 m (10 feet) elevation contour lines. A snapshot of the visualization model can be seen in Figure 2. Shown discontinuity lines indicate the strike direction with the orientation given by a three-digit dip direction followed by a two-digit dip along with a dip symbol indicating the direction of the dip. When projecting discontinuities onto the upper and lower benches dashed lines were utilized to indicate uncertainty.

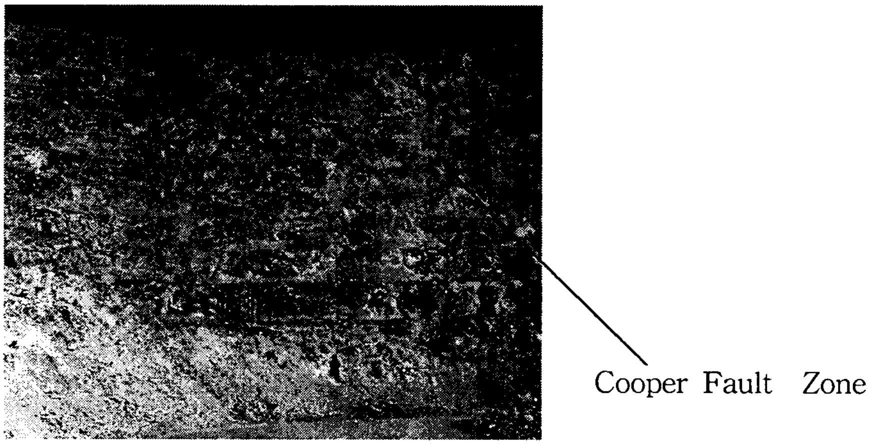

Figure 1. A photograph of the study area.

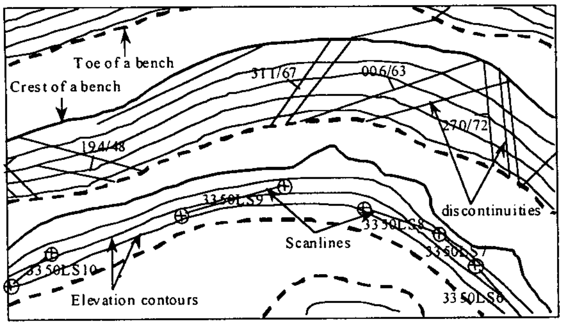

Figure 2. A snapshot of a preliminary mine visualization model.

LABORATORY TESTING AND RESULTS

A large variability in the quality of TrOA samples was noticed, during testing, with most being heavily fractured and veined, while the EQMP was a competent rock with few fractures and little veining. Tensile strength for the EQMP was determined to be 12.5 MPa with a 0.07 coefficient of variation. The mean tensile strength obtained for the TrOA rock type was 18.4 MPa with a 0.06 coefficient of variation. The tensile strengths of the two rock types indicate that the intact material of the two rock types is strong. The average compressive strength for the EQMP was 168.9 MPa, with a 0.13 coefficient of variation. An average Youngs modulus of 21 GPa with a 0.09 coefficient of variation was obtained for EQMP. These values indicate that the intact material of the EQMP rock type is strong. The resulting intact rock characteristics of TrOA have an average compressive strength of 171.5 MPa with a 0.19 coefficient of variation. An average Youngs modulus of 19.5 GPa was obtained for TrOA with a 0.04 coefficient of variation. These values indicate that the intact material of the TrOA rock type is strong. However, because both rock masses are highly fractured, the rock mass strength and deformability of both rock masses would be quite low.

For discontinuity tests, a saw-cut joint and a natural rock joint were tested for each rock type. The purpose of the saw-cut joint is to obtain values close to the basic friction angle, fb, of the rock type, while the natural rock joint would be a representative sample of many joints one might see in the rock mass. For both rock types, natural joints produced higher strengths compared to the saw cut joints due to existence of roughness (Um et al., 2000). Basic friction angles of 30° and 35° were obtained for TrOA and EQMP joints through saw cut samples, respectively. To be on the conservative side, a friction angle of 25° was used for discontinuities of both rock types in the rock slope stability analyses conducted in this investigation.

BLOCK THEORY ANALYSES

From the discontinuities mapped through scanline surveys, the longest 6% were selected from each of the two rock types EQMP and TrOA. This provided 53 and 16 discontinuities, respectively from EQMP and TrOA rock types. These discontinuities are identified by a five-digit number and they are greater than about 10 m for EQMP and 5 m for TrOA. In the five-digit number, the first digit represents the bench level (lower benches=1, middle bench=2 and upper benches=3), the second and third digits represent the scanline number and the last two digits identify the particular discontinuity. In addition, there were 129 other discontinuities that were more than 15 m in length obtained from other sources. The orientation and global location of all these discontinuities are known. Discontinuities were sorted into the following 6 groups (Um et al., 2001): (a) lower benches (1020-1050 m) of EQMP rock mass, (b) middle bench (1065-1080 m) of EQMP rock mass, (c) upper benches (1095-1140 m) of EQMP rock mass, (d) lower bench (1035-1050 m) of TrOA rock mass, (e) middle bench (1065-1080 m) of TrOA rock mass and (f) upper benches (1095-1140 m) of TrOA rock mass.

Block theory analysis (Goodman and Shi, 1985) was performed separately for each of the aforementioned 6 groups of discontinuities. Within each group, each combination of 3 to 7 discontinuities located within a distance up to about 30 m was considered to form possible blocks according to block theory. Different cut slope directions were used to simulate the changing strike direction of the open pit mine in the investigated area. From each combination of discontinuities, key blocks (type I) and potential key blocks (type II blocks) were identified. For each of the two block types, the corresponding sliding mode was determined as either plane sliding or wedge sliding. Through this way, all possible blocks having a number of faces between 4 and 8 producing a type I or type II block having either a plane sliding or wedge sliding mode were determined.

Table 1. shows the percentages of major discontinuities contributed to possible plane and wedge instabilities under block types I (key blocks) and II (potential key blocks) in the two rock masses for different slope angles according to block theory analysis.

Rock Type		EQMP		TrOA	
Cut Slope Angle		50°	>70°	50°	>70°
Type I	Single Plane Sliding	7%	16%	0%	4.5%
	Wedge Sliding	27.5%	46.6%	10.4%	29.8%
Type II	Single Plane Sliding	0%	0%	0%	0%
	Wedge Sliding	54.2%	61.8%	26.9%	28.4%

LIMIT EQUILIBRIUM SLOPE STABILITY ANALYSES

The results (Figs. 3&4) obtained through limit equilibrium slope stability analyses conducted on a single tetrahedral wedge belonging to type II block category that exist in the investigated area in the mine show the following: (a) how a stable slope under dry condition (factor of safety = 2.28) can fail after a heavy rainfall, (b) how a stable slope under a flatter lower slope face angle can fail as the inclination of lower slope face increases, (c) how a stable slope under single benching (overall wedge height = 15 m) can fail under double benching (overall wedge height = 30 m), (d) how a stable slope can become an unstable slope as the distance of a tension crack from the top edge of the wedge decreases and (e) the effect of the location of the tension crack on double benching and overall slope height. For the chosen type II block, to achieve a factor of safety of 1.5, it is necessary to pick decreasing lower slope face angles as height of the wedge increases from 15 m to 60 m. This information basically provides the concept related to designing slope angles for single benches (15 m), double benches (30 m), inter-ramps (greater than 30 m) and overall pit slopes (greater than 60 m) in mines.

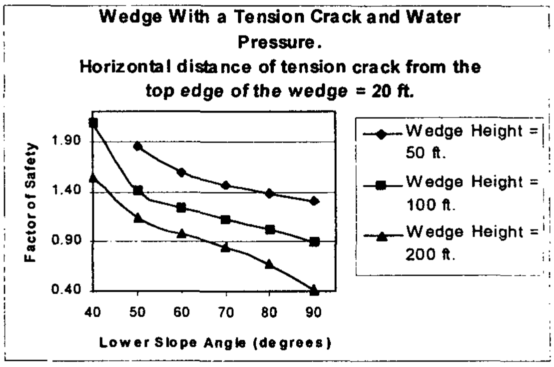

Figure 3. Effect of lower slope angle and wedge height on factor of safety.

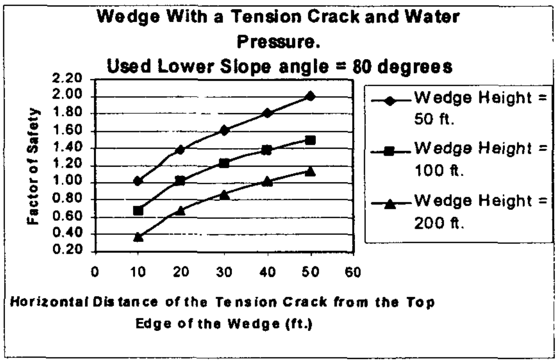

Figure 4. Effect of location of tension crack and wedge height on factor of safety.

CONCLUSIONS

The developed preliminary version of the mine visualization model expected to be a useful tool in selecting discontinuity data for rock slope stability analyses. The model can be improved by showing the discontinuity planes and the possible blocks that can be formed by the discontinuity planes in three dimensions

Intact material of the two rock types was found to be strong based on the mechanical property test results of intact rock. However, because both rock masses are highly fractured, the rock mass strength and deformability of both rock masses seem to be quite low. For both rock types, natural joints produced higher strengths compared to the saw cut joints due to existence of roughness.

The number of failures due to type II blocks increases as the magnitude of the external loading at the site increases. Slope instability taking place due to type II blocks can be reduced by reducing the magnitude of the external loading at the site. Therefore, slope dewatering should be done regularly to keep the water levels down to the bear minimum in the slopes in the investigated region.

The effects of water that exist in the rock mass, a tension crack, slope face inclination, overall wedge height and double benching on factor of safety of wedge stability are illustrated through limit equilibrium slope stability analyses conducted on a single tetrahedral wedge belonging to potential key block category that exist in the investigated area of the mine.

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