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APPLICATION OF THE DEGRES SOFTWARE AT THE SARCHESHMEH PORPHYRY COPPER OPEN PIT

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ABSTRACT: A thorough stability analysis of the sides in an open pit requires to consider the influence of the geometrical parameters of the pit slopes, the geological structures, the groundwater conditions, the mechanical parameters of the material, and the effects of seismic loading.
This can be done using the DEGRES software which is a computational tool to help with decisions about geometrical design and geotechnical studies in open pit mining and quarrying. Firstly, it automatically provides a geometrical model of the pit. Then, in association with geological and geotechnical models of the ore body, various basic failure mechanisms are analyzed for the total or partial height of each pit side. Regarding the calculated safety factor and volumes of unstable rock masses, this program helps the users to design the walls of the optimum ultimate pit.

1. INTRODUCTION

The Sarcheshmeh porphyry copper-molybdenum deposit which ranks between the largest in the world, is located in the south part of Iran, about 60 km southwest of the town of Rafsanjan.
A large scale open pit mine was started-up, by the National Iranian Copper Industries Co. (N.I.C.I.Co.) in 1974.

Based on the economical study, the cut-off grade of the mine is reduced from 0.40% to 0.25% copper. This implies an increase in area and depth from about 2,300 m long, 1,200 m wide, 350 m depth, to 3,000 m long, 1,800 m wide, 850 m depth for the expansion project, respectively. The ore body contains 1,200 Mt. of ore. Average sulfide is 0.7% copper and approximately 0.03% molybdenum. The mine produces 100,000 tons of copper and 2,200 tons of molybdenite concentrate per year.
Many factors govern the size and the shape of an open pit. This must be properly understood and used in the planning of any mining operation. At Sarcheshmeh mine, rock mass structural properties are known as the most important point for pit slope design. The majority of failure types is controlled by the geological structures. This paper attests that the structural systems play an important role in slope stability analyses.

2. GEOLOGICAL SETTING

The geology of Sarcheshmeh porphyry copper-molybdenum deposit is complex, with widely varying rock properties. Instability of slope in

Sarcheshmeh occurs because of failures along structural features, such as joints, geological contacts, faults and dikes.

Mineralization in Sarcheshmeh porphyry copper-molybdenum deposit is associated with a Late Tertiary granodiorite porphyry stock, the whole complex is criss-crossed by a series of intra-mineral and postmineral dikes. The original subcircular Sarcheshmeh porphyry stock exhibits an east-west elongation due to dilation by the dike swarm, which strike is predominantly NNW. The highest grade hypogene zone occurs as an annular ring in altered andésite around the periphery of the Sarcheshmeh stock (Fig. 1), (Waterman et al., 1975).

The purpose of this paper, is to prescribe practical procedures for determining the ultimate pit wall geometry. The data come from economical geology and structural investigations, groundwater and mechanical properties of the rock masses. The failure conditions depend on the relationship between the slope and the structures.

3. THEORETICAL CONSIDERATIONS RELATED TO THE DEGRES SOFTWARE

The DEGRES software has been designed at the Center for Engineering Geology in the Paris School of Mines in collaboration with Institut National de l'Environnement Industriel et des Risques (INERIS, previously CERCHAR) and Houillères de Bassin du Centre et du Midi (HBCM from Charbonnages de France) in the framework of the Carmaux coal mine project (Tanays et al., 1992, Fleurisson et al., 1996).

Firstly, this software automatically builds up the geometrical model from the input of a basis contour line and the geometrical parameters of. the benches and the pit sides. From this model, contoured plans of the pit can be drawn in agreement with the usual drawings of land surveyors in planning department. The geometrical model is then divided into a series of sectors. In each sector, the strike and dip angles of the various geometrical features (average plan of sector, slope face of bench) are calculated.

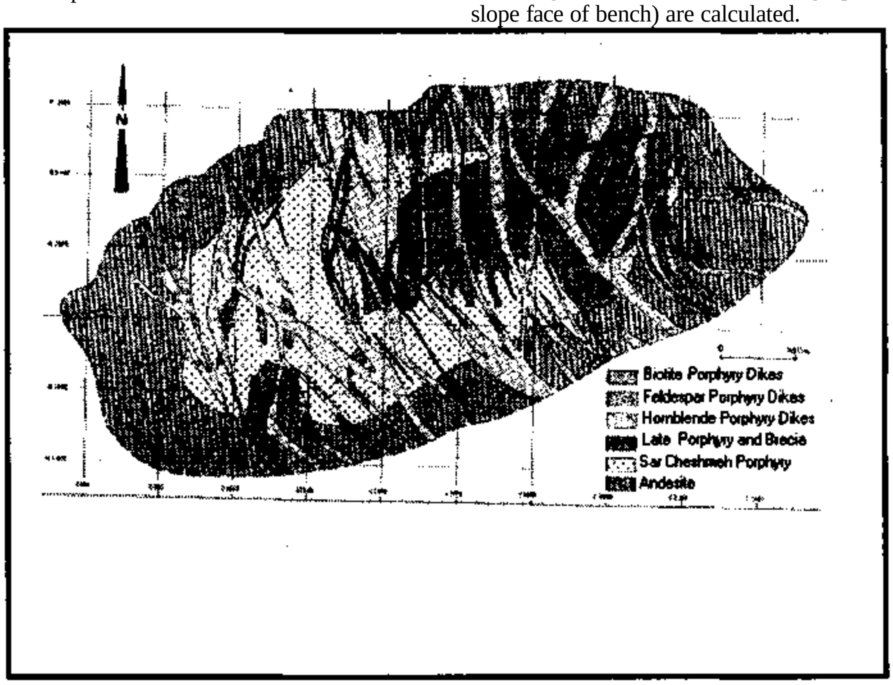

Fig. 1. Distribution of the rock types at 2400 m elevation within outer 0.40% copper line Sarcheshmeh deposit (after Etminan, 1977).

In a second stage, geological and geotechnical models have to be defined. They mainly concern the discontinuity sets models, each set (fractures, joints) is represented by its strike, dip angle, persistence, spacing, cohesion and friction angle. The number of sets and their respective geometrical and mechanical characteristics result from statistical treatments of field data. Additional models dealing with the faults or stratigraphie limits may be defined.

Finally, the detection of slope instability may be carried out depending on the two following phases.

The purpose of the first phase is to identify the kinematic probability of occurrence of various failure mechanisms: plane failure, wedge failure, step failure, toppling failure and bi-planar failure. This is done according to the rules established by Hoek and Bray (1981).

This operation is repeated for various associations of discontinuities such as faults, bedding planes, joints and small fractures.
The numerical results give, for each sector and for each failure mechanism, the discontinuity set number involved in kinematic instabilities. These results can also be plotted on a plan of the sectored pit showing the failure mechanisms detected in each sector.

In the second phase, computations of safety factors are undertaken for each failure mechanism identified at the previous stage and for a bench, a set of benches or the whole pit wall. The geometry of failure surfaces is simulated in the analyzed volume according to the geometrical parameters of the involved discontinuities. The factor of safety of the potential unstable volume is then calculated using limiting equilibrium methods.

The results give, for each sector and for each failure mechanism, the minimal factors of safety with their associated volumes of failed masses and the maximal volumes of failed masses with their associated factors of safety.

Various hydraulic conditions in the structural features can be considered in the calculations: dry discontinuities, saturated discontinuities with or without drainage at the discontinuity bottom.

Therefore, the DEGRES software is a real helpful tool to help with decisions in the field of rock slope engineering, and to design ultimate open pit geometry taking into account geotechnical criterion.

4. APPLICATION OF THE DEGRES PROGRAM AT SARCHESHMEH MINE

At Sarcheshmeh mine, the results obtained using this software can help to make decisions about the geometrical planning and slope stability analyses.

For analysis purposes, the pit is divided into several design sectors. These sectors require separate stability analyses according to the different rock conditions and operating factors. Within each sector, kinematically possible modes of instability were identified taking into account structural features. The presented analysis was carried out to determine individual or combinations of discontinuity sets which could possibly lead to slope instability as the pit was deepened. Both overall slope failure and bench failure were considered.

Considering the structural information, the Sarcheshmeh pit was initially divided into 4 pit sectors in terms of the anticipated hydrogeological conditions and slope stability performance.
These four sectors are described below in order of decreasing importance concerning slope stability:

West pit wall: The crests are parallel to the general strike of the dikes with a dip angle of 70° to 85° towards the east. Considering the general hydraulic gradient from South to North, the dikes act as barrier to groundwater flow. Geological data indicated that the stability of this sector is controlled by the orientation of the discontinuities and by the shear strength along the critically oriented discontinuities.

South pit wall: The crests are approximately perpendicular to the strike of dikes which appear to be no structural barriers to groundwater flow.

East pit wall: Hydrogeologically, this sector is similar to the west-wall but the dips of the dikes are against the bench slope.

North pit wall: It is similar to the south wall.

It can be underlined that the conditions of the west wall are sufficiently different from the other sides. Therefore this wall is divided into several sectors.

The main discontinuity sets classified in Table 1 are resulting from statistical treatment of field measurements of structural features.
For evaluating the shear resistance of the discontinuities, it has been considered that the major

joint and fault planes contain thick gouge material. Therefore, their shear strength is governed by the shear strength of the gouge material.
For the first estimation the average values of 14 kPa for the cohesion and 20° for the friction angle correspond to the clay filled faults as well as major fractures are used.

4-1. Pit Geometry of the Current and Modified Expansion Projects

Two configurations of the open pit without haul road are compared and analyzed. The first configuration corresponds to the current expansion project, (Fig. 2) and the second is named the modified expansion project (Fig. 3).

The results of the slope stability evaluation of the first configuration are presented in Table 2 considering saturated and drained discontinuities.

At the scale of a set of benches, the association of discontinuity sets number 11 and 13 may lead to wedge with a volume of about 7500 m^3. With the association of discontinuity sets number 11 and 13, wedge failures with volume of about 2300 and 3000 m^3 may occur for the sectors 7 and 8, respectively.

In order to obtain stable sectors all around the pit, the orientation of the unstable sectors should be changed on the basis of the neighbouring stable sectors. The new pit geometry corresponds to the modified expansion configuration.

This modified geometrical configuration is then analyzed with the same mechanical and hydraulic parameters. The likelihood of potential failures is summarized in Table 3.

From the slope stability point of view, these results are more satisfactory than the results of the current expansion project.

This new pit configuration will be applied in Sarcheshmeh mine after the impact of an economical and geotechnical investigation.

Table 1. Properties of the discontinuity sets used in the DEGRES software.

Type of discontinuity	Set No.	Dip Angle	Dip Direction	Persistence (m)	Spacing (m)	Cohesion (kPa)	Friction angle (degree)
Joint	1	86	10	25	0.2	50	40
Joint	2	67	85	25	0.2	50	40
Joint	3	43	298	25	0.2	50	40
Joint	4	84	128	25	0.2	50	40
Joint	5	53	211	25	0.2	50	40
Major joint	6	55	104	100	100	14	20
Major joint	7	84	148	100	100	14	20
Major joint	8	46	292	100	100	14	20
Major joint	9	87	12	100	100	14	20
Major joint	10	58	51	100	100	14	20
Fault	11	88	224	300	200	14	20
Fault	12	45	105	300	300	14	20
Fault	13	45	82	300	200	14	20
Fault	14	55	125	300	300	14	20
Fault	15	70	10	300	300	14	20

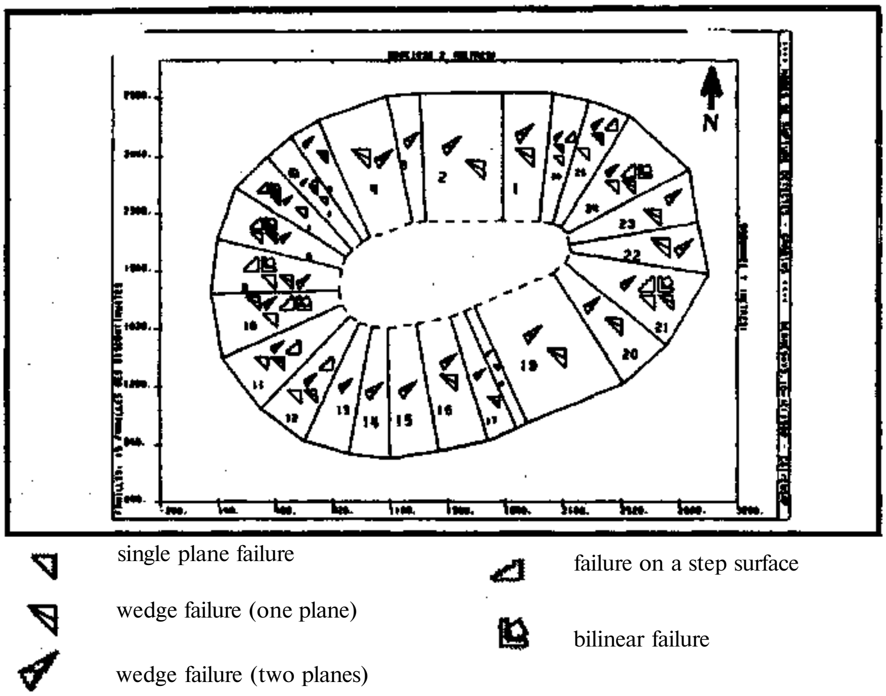

Fig. 2. Sectors of Sarcheshmeh current expansion pit with detected failure mechanisms at the scale of benches.

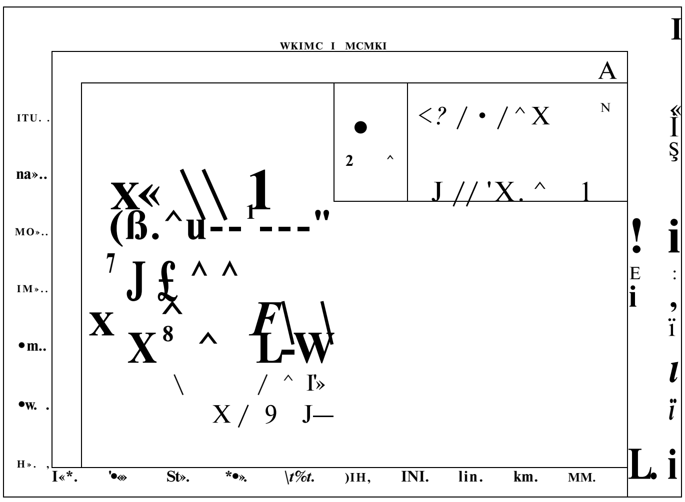

Fig. 3. Sectors of Sarcheshmeh modified expansion pit with detected failure mechanisms at the scale of benches.

Table 2: Slope stability evaluation of the current expansion configuration for bench, set of benches and pit wall.

Design sector No.	No. of bench	Mode of failure	Discontinuity sets association	F.S (F.S<1.4)	Volume (> 500 m^3)
7	5 Benches	Wedge (2)*	11&12	1.02	558
		Wedge (2)	11&13	0.62	5593
8	1 Bench	Wedge (1)**	1&12	0.61	998
		Wedge (2)	5&12	1.40	1396
		Wedge (1)	7&12	0.58	832
		Wedge (1)	9&12	0.61	1012
		Wedge (1)	10&12	0.64	970
		Wedge (2)	11&12	0.87	1195
		Wedge (1)	12&13	0.71	819
		Wedge (1)	12&14	0.50	1060
		Wedge (1)	12&15	0.62	904
8	5 Benches	Wedge (2)	11&13	0.58	7500
9	1 Bench	Wedge (2)	1&12	0.82	630
		Wedge (2)	7&12	1.20	803
		Wedge (2)	9&12	0.65	615
		Wedge (2)	10&12	0.64	669
		Wedge (2)	12&13	0.61	987
		Wedge (2)	12&15	0.73	734
9	5 Benches	Wedge (2)	11&13	0.65	6656
10	1 Bench	Wedge (1)	1&13	0.60	2377
		Wedge (1)	5&13	0.69	1315
		Wedge (2)	7&13	0.75	2505
		Wedge (2)	9&13	0.60	2362
		Wedge (1)	10&13	0.58	2427
		Wedge (1)	11&13	0.60	2102
		Wedge (1)	12&13	0.65	2185
		Wedge (2)	13&14	0.66	2359
		Wedge (2)	13&15	0.62	2481
10	5 Benches	Wedge (2)	7&12	0.64	2041
		Wedge (2)	7&14	0.85	1468
11	5 Benches	Wedge (2)	7&12	0.66	1544
		Wedge (2)	7&14	0.85	1420
12	5 Benches	Wedge (2)	7&14	1.34	568
7	pit wall	Wedge (2)	11&13	0.34	23000
8	pit wall	Wedge (2)	11&13	1.04	3000
9	pit wall	Nosignificant failure			
10	pit wall	Nosignificant failure			
11	pit wall	F.S > 1.4			
12	pit wall	F.S > 1.4			
13	pit wall	F.S > 1.4			

*wedge (2): wedge with sliding on two planes **wedge (1): wedge with sliding on one plane

Table 3: The slope stability evaluation of modified expansion configuration for bench, set of benches and pit wall.

Design sector No.	No. of bench	Mode of failure	Discontinuity sets association	F.S (F.S<1.4)	Volume (> 500 m^3)
5	5 Benches	Wedge (2)	11&13	0.47	3823
7	1 Bench	Wedge (2)	1&13	0.90	653
		Wedge (1)	6&13	0.43	633
		Wedge (2)	7&12	1.21	518
		Wedge (1)	7&13	0.59	525
		Wedge (2)	9&13	0.74	668
		Wedge (2)	10&13	1.19	612
		Wedge (2)	12&13	0.61	995
		Wedge (1)	13&14	0.53	685
		Wedge (1)	13&15	0.63	552
7	5 Benches	Wedge (2)	7&12	1.05	1024
		Wedge (2)	7&14	1.02	1263
		Wedge (2)	11&13	1.05	2587
8	5 Benches	Wedge (2)	7&14	1.38	535
5	pit wall	Wedge (2)	11&13	0.88	3317
6	pit wall	Wedge (2)	11&13	0.41	15420
7	pit wall	No significant failure			
8	pit wall	F.S>1.4			

CONCLUSIONS

1 - The analysis of the geological structures is the point of departure for pit planning. In other word, the first criterion for the geometrical design of the pit sectors is the structural features.

2- The wall orientation or the curvature in plan of the pit walls taking into account the variability of the wall material and the operational conditions, should be considered as the second criterion.

3- At Sarcheshmeh mine, the wedge failures in the west wall of the mine are mainly controlled by the structures.

4- By modifying the orientation of the unstable pit walls, the reasons for instability can be decreased. It is however necessary to mention that the DEGRES software evaluates the stability for each sector independently of its neighbors. In other words the DEGRES software, can not identify a failure mechanism involving two sectors.

5- The outcome of the DEGRES software can also help making decision on the implementation of geometrical planning of each bench or a group o\ benches and the evaluation of the groundwatei effects.

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