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Comprehensive analysis of slope stability and determination of stable slopes in the Chador-Malu iron ore mine using numerical and limit equilibrium methods

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Abstract: One of the critical aspects in mine design is slope stability analysis and the determination of stable slopes. In the Chador-Malu iron ore mine, one of the most important iron ore mines in central Iran, it was considered vital to perform a comprehensive slope stability analysis. At first, we divided the existing rock hosting pit into six zones and a geotechnical map was prepared. Then, the value of MRMR (Mining Rock Mass Rating) was determined for each zone. Owing to the fact that the Chador-Malu iron ore mine is located in a highly tectonic area and the rock mass completely crushed, the Hoek–Brown failure criterion was found suitable to estimate geo-mechanical parameters. After that, the value of cohesion (c) and friction angle (φ) were calculated for different geotechnical zones and relative graphs and equations were derived as a function of slope height. The stability analyses using numerical and limit equilibrium methods showed that some instability problems might occur by increasing the slope height. Therefore, stable slopes for each geotechnical zone and prepared sections were calculated and presented as a function of slope height.
Key words: slope stability; limit equilibrium method; numerical method; rock mass classification

1 Introduction

The Chador-Malu iron ore mine is located in the middle of Iran at latitude 32˚17' and longitude 55˚30' (Fig. 1). This mine, which is operated by CMMIC (Chador-Malu Mining and Industrial Company), is a major open pit exploiting 200 Mt reserves currently defined at a rate of 7.2 Mt per year. The Chador-Malu deposit consists of four anomalies; three of them are located to the north and the last one to the south. The northern anomalies have been operated since September 1995. In preliminary studies, the pit (with a width of 950 m and a depth of 225 m) was designed for a 30 year period. The height of the bench was designed at 15 m, but by merging two benches, their combined height changed to 30 m. The angle of the benches was designed for 70˚ which created an overall pit slope of about 54˚. After 8 years, the mine encountered some instability problems. Even though these were restricted to local, instabilities, they demonstrate that a major failure might occur if necessary analyses and remedial works were not performed.

2 Geology of mine

The Chador-Malu iron deposit has a length of 2 km and a width ranging from 150 to 750 m and stretches from the northeast to the southwest. Its maximum depth from the surface is about 310 m. This deposit, which consists of four anomalies (three anomalies in the north containing about 80% of deposit and are mined and the last one in the south), was explored by V. Kumel, a German geologist, in 1941. According to the metasomatic process and highly tectonic condition in that area, the geology of the mine is fairly complex and hematite veins existing in that area (especially in the main ore body) demonstrate that magma was injected in a delayed phase. The geological reserve of the Chador-Malu iron ore mine are about 400 Mt and consists of magnetite and hematite with an average grade of 54.96%. Like other deposits in that area, phosphor is a co-mineral with hematite and magnetite[1].

3 Rock mass classification

One of the basic methods in the geomechanical analyses is an empirical rock mass classification Based on the fact that the MRMR classification system (Mining Rock Mass Rating), proposed by Laubscher (1990) has some noticeable advantages, this system was selected for rating the rock mass[2]. In this system, three major parameters, i.e., rock strength,

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joint condition and ground water needed to be defined. After that, four adjustments (weathering, orientation, induced stresses and blasting) were used to modify rock mass ratings. In the case of the Chador-Malu iron ore mine, all rocks were divided into six geotechnical zones, based on variation in the rock type and weathering conditions (Table 1) and MRMR values were defined for each unit (Table 2). In this classification, the MRMR value was not defined for Talus, the sloping pile of rock fragments at the bottom of a cliff.

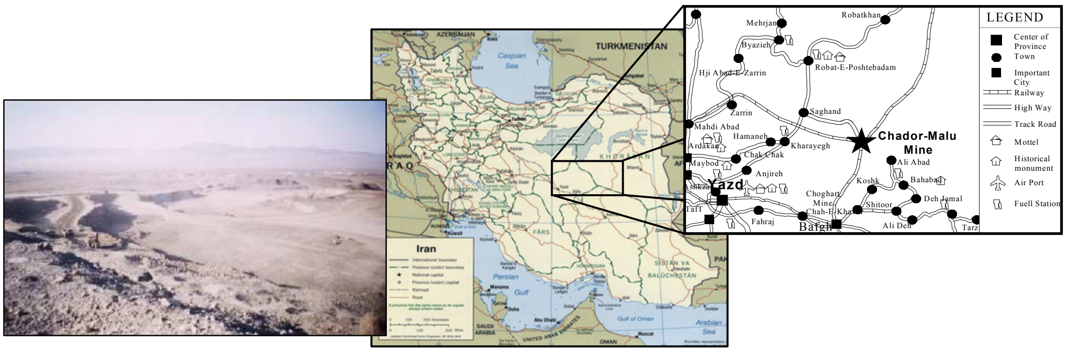

Fig. 1 Location of the Chador-Malu iron ore mine

Table 1 General rock mass description in the Chador-Malu mine

Geotechnic type	Rock mass description
Type I	Blocky, well jointed to massive Ironstone (Magnetite and Hematite), very to extremely strong. Good rock mass, occasionally sheared and faulted, with shears rotating intact blocks and faulting in large areas of rock. Internally, discontinuities are rough, wavy and unaltered, but faults are generally highly sheared, with polished surfaces and weak gouge plus breccia.
Type II	Blocky, well jointed Diorite/Felsite/Metasomatite/Dyke, very strong. Good rock mass occasionally sheared and faulted. Internally, discontinuities are rough, slightly undulating and unaltered, but faults are generally highly sheared, with polished surface and weak gouge plus breccia.
Type III	Mixed rock: generally intact blocky Diorite/Metasomatite, strong and surrounding zones of highly sheared and disturbed rock weak to very weak. Discontinuities generally unaltered to sheared, infilled with fine soft sheared material or weak gouge and breccia.
Type IV	Highly altered and disturbed rock, generally Metasomatite/altered Diorite/Albitite/Fault rock, very weak to weak. Mostly totally disturbed and sheared, with occasional blocks of intact material, if any, floating in a matrix. No joint structure, but numerous faults and shear zones, with highly polished surfaces and clay gouge, crushed breccia.
Type V	Light brownish white-off white, clast to matrix supported breccia/conglomerate, very weak (R1) to weak (R2), well cemented in places. The matrix is cemented with calcareous clay and sand. Calcites are fine to coarse angular to subrounded gravel, predominantly granite, rare iron stone. Occasional gypsum and calcite precipitation. No structure, homogenous, massive weak rock/soil.

Table 2 MRMR values for different geotechnic zones

		Geotechnic zone				
		Type 1	Type 2	Type 3	Type 4	Type 5
Intact rock strength	Value (MPa)	185	120	65	10	15
	Rating	18	12	8	2	3
Fracture frequency	Joint sets	3	3	3	3	1
	FF (m)	1.0	1.4	2.4	3.3	0.25
	Rating	26	24	20	18	40
Joint condition	Water	Dry	Dry	Dry	Dry	Dry
	JA	0.85	0.85	0.85	0.85	0.95
	JB	0.80	0.80	0.70	0.70	0.80
	JC	1.00	1.00	1.00	1.00	1.00
	JD	0.80	0.70	0.45	0.30	0.90
	Rating	22	19	11	7	27
RMR	Rating	66	55	39	27	70
	Class	2B	3A	4A	4B	2B
	Description	Good	Fair	Poor	Poor	Good
Adjustments	Weathering	1	1	0.8	0.8	0.8
	Orientation	0.8	0.8	0.8	0.8	1
	Stresses	1	1	1	1	1
	Blasting	0.9	0.9	0.9	0.9	0.9
MRMR	Rating	48	40	22	16	50
	Class	3B	4A	4B	5A	3B
	Description	Fair	Fair-good	Poor-very poor	Very poor	Fair-poor

4 Determination of required parameters for stability analysis

The parameters, required for stability analysis, are comprised of rock mass strength, water ground level and earthquake loading. The rock mass strength for different zones was determined according to discontinuities surveying and point load tests carried out in the field. In order to determine rock strength for different zones, several point load tests were performed (Table 3). Inappropriate results obtained from unrepresentative samples were eliminated from the outcomes. Since some test samples gave extremely high intact rock strength values, greater than 400 MPa according to an engineering opinion, a maximum of 300 MPa was chosen as the cut-off level and sample results where their strengths were more than 300 MPa, were eliminated.

Source: Kani Kavan (2003)

Ground water is one of the most important issues in geomechanical analyses which plays a significant role in stability. Unfortunately, there are no documents about the ground water in Chador-Malu; so, based on previous reports, we assumed the water