Design Analysis in Rock Mechanics

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List of Abbreviations

ASTM	American Society for Testing and Materials
BEM	Boundary Element Method
BFEM	Base Force Element Method
BPM	Bonded Particle Model
BQ	Basic Quality
DDM	Displacement Discontinuity Method
DEM	Discrete Element Method
DFN	Discrete Fracture Network
DI	Depth Index
FE	Finite Element
FEM	Finite Element Method
FOS	Factor of Safety
GCD	Gouge Content Designation
GIS	Geographic Information System
GRL	Ground Reduced Levels
GSI	Geological Strength Index
HF	Hydraulic Fracture
HPFM	Heat Pulse Flowmeter
ISRM	International Society for Rock Mechanics
JRC	Joint Roughness Coefficients
LPI	Lithology Permeability Index
MTS	Mechanics Test Systems
NFR	Naturally Fractured Reservoirs
PDI	Potential Degradation Index
PFC	Particle Flow Code
RAC	Recycled Aggregate Concrete
RMR	Rock Mass Rating
RQD	Rock Quality Designation
SDT	Slake Durability Test
SJM	Smooth Joint Model
SRM	Synthetic Rock Mass
SRMR	Slope Rock Mass Rating

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Preface

Rock mechanics is a theoretical and applied science of the mechanical behavior of rock and rock masses; compared to geology, it is that branch of mechanics concerned with the response of rock and rock masses to the force fields of their physical environment. The text *Design Analysis in Rock Mechanics* treats the basics of rock mechanics in a clear and straightforward manner and discusses important design problems in terms of the mechanics of materials. The purpose of first chapter is to determine the bench slope angle and overall slope of the west wall in Chadormalu mine in points susceptible to rupture. In second chapter, to simulate the fissure development of jointed rock mass under fissure water pressure, we propose a novel numerical model on the basis of secondary development in Lagrangian analysis of continua (FLAC3D), which is an explicit finite difference method (FDM). Study on the constitutive model for jointed rock mass has been presented in third chapter. The aim of fourth chapter is to find out a simple way to calculate the asymmetric rock pressure for design of tunnel lining in super-shallow surrounding rock. Based on the concept of generalized plasticity, fifth chapter proposes a constitutive model to describe the time-dependent behavior and wetting deterioration of sandstone. In sixth chapter, a semivariogram model has been developed along with the kriging model for the reduced level of the rock in the subsurface of Bangalore. The aim of seventh chapter is to propose a method for characterizing the weathering behavior of carbonate lithologies that outcrop in heterogeneous Flysch-like slopes. Eighth chapter proposes two empirical models to estimate hydraulic conductivity of fractured rock mass. In ninth chapter, the base force element method (BFEM) on complementary energy principle is used to analyze the engineering problems of rock mechanics. Three-dimensional numerical model of hydraulic fracturing in fractured rock masses has been focused in tenth chapter. Roughness research of center profile curve on rock fracture surface based on statistical method has been presented in last chapter.

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Chapter 1

DESIGN OF OVERALL SLOPE ANGLE AND ANALYSIS OF ROCK SLOPE STABILITY OF CHADORMALU MINE USING EMPIRICAL AND NUMERICAL METHODS

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ABSTRACT

In engineering projects associated with rock mechanic science like open pit mines, assessment and slope stability of mine walls is one of the important performance in generate of these structures. Estimating and knowledge of stable slope angle is one of main parts that should be occurring to special attention in open pit mines studies phase. Considering the importance of economic costs in mining issues, the need for appropriate design slope angle that can cause an adverse minimize project costs and throws the other hand, the stability conditions in the safe walls of the mine life will provide essential and seems obvious. Therefore, in this study to determine the optimal slope angle of overall and bench of west wall of the Chadormalu ore iron mine, has been trying, first, done field studies on the discontinuity of western wall, engineering classification and geomechanical properties of rock masses of wall, then assess the amount of optimal slope angle using empirical method. Finally, in order to ensure stability and accuracy of the wall slope angle based on the obtained (empirical method) tries to analysis is amount of Factor of Safety (FOS), displacements and mean stress condition atwalls calculated from drilling use Phase2D powerful software.

INTRODUCTION

The purpose of this study is to determine the bench slope angle and overall slope of the west wall in Chadormalu mine in points susceptible to rupture. To do so, the survey tries to; first, detect sensitive points by current empirical methods. Then it determines the bench and overall angle of slope.

In order to be sure about the results validity obtained by the empirical methods, the study attempts to analyze stability and determine the slope safety factor and the wall displacements using finite element method and powerful Phase2D software.

POSITION AND GEOLOGY OF THE WEST WALL OF THE MINE

Chadormalu iron ore mine is located in central Iran and in northern slope of Chah-Mohammad grey mountains in southern margin of Saghand salt marsh about 180 km from north-east of Yazd and 300 km from south of Tabas desert. According to the geology studies performed in this region, it was cleared that Chadormalu fault between the plain and high lands is the major factor of ore creation and mineralization in the region formed in two forms of northern and southern anomaly. Also, petrography studies on the mine rocks shows that major rocks in Chadormalu mine area are Metasomatite, Albitite, Diorite, Magnetite and Hematite[4,5]. It should be mentioned that, performance of different faults in this area makes the mine rocks tobe severely tectonizedand provide suitable conditions fordifferent ruptures of the wall. The western wall of this mine is made up of igneous rocks and various metamorphic rocks such as Diorite, Albitite and Metasomatite[4]. Generally speaking, **Figure 2** shows the geological profile perpendicular in the western wall of the mine together with its lithological combination.

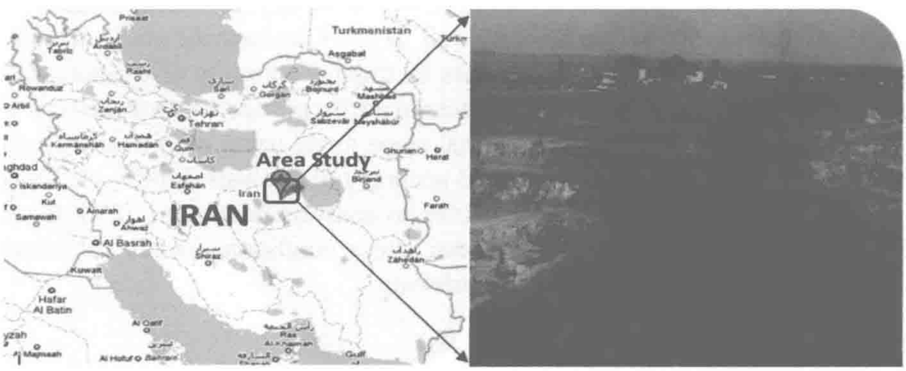

Figure 1: Location of area study on the Iran map.

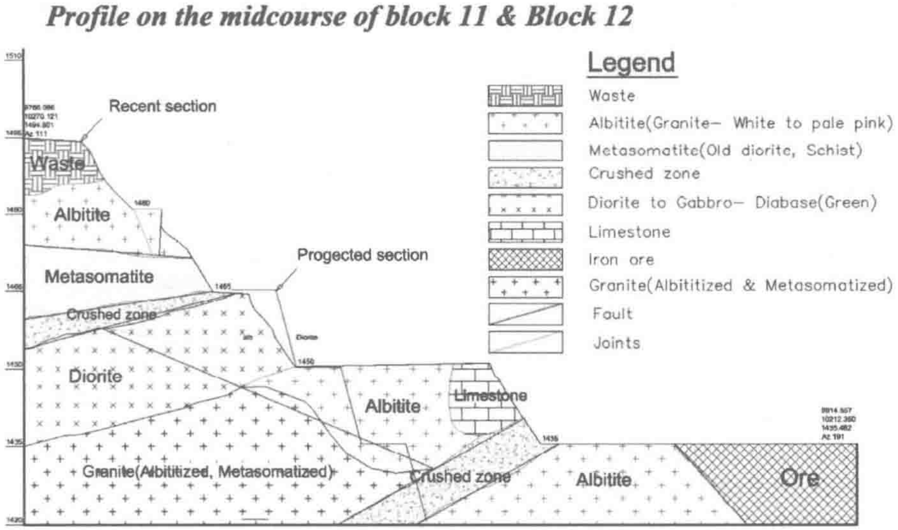

Figure 2: The geological profile perpendicular on the west wall of Chador-malu iron ore mine.

In this study, in order to save time and costs, three blocks (No. B-10, B-11, and B-13) in instability intensity wear detected as the conclusion of the geological surveys on the mine western wall, than engineering surveys and joint studies ware done on each of these blocks [5].

CLASSIFICATION OF ROCK MASS AND DETERMINATION OF ENGINEERING PARAMETERS

As the main purpose of engineering projects is to use classification systems to determine geomechanical characteristics of rocks by simple methods, this study tries to do joint studies on present discontinuities; and then it classifies the rocks enclosed in each of the blocks using Rock Mass Rating (RMR), Geological Strength Index (GSI) and Slope Rock Mass Rating (SRMR) classification systems [3]. **Table 1** indicates the results of the classification of the rocks of the western wall in Chadormalu iron ore mine.

Results obtained from this table indicate that the quality of the rocks in the west wall area in Chadormalu mine is poor due to breakings and development of lots of joints and fractures.

As in engineering works especially in analysis of rock slopes, the purpose is to classify rocks to estimate and measure their engineering and geomechanical features correctly, this study uses results of rocks classification and Roclab software [6] for each of the rock pieces enclosed in block B-11 to detect those parameters that have been introduced by empirical methods established by researches throughout the world. **Table 2** shows the most important calculated engineering parameters which are used in Phase2D software [7].

DETERMINATION OF BENCH SLOPE AND OVERALL SLOPE

According to definition of slope geometry, it is said that height, width, and angle of bench slope are the most significant geometrical parameters of slopes and steep surfaces where any alternation each of these features can put a direct effect on the slope stability. On the basis of these words, therefore, one can admit that optimum determination of these geometrical features of a slope in preventing rupture is one of most important parts of rock and soil slopes analysis, so that importance of this issue in open pit mine activities and road cuttings are observable and underst-andable [2].

This study tries to apply not only ranking system, but also other empirical methods in determina-tion of bench slope and overall steep of the slope in order to promote the obtained results safety factor. Therefore, value of the rocks of each block, one can determine slope steep angle by the empirical methods obtained from Rock Mass Rating (RMR), Mine Rock Mass Rating (MRMR) and Slope Rock Mass Rating (SRMR) values. Results on overall angle and safe bench slope angle for each block are shown in Tables 3 and 4 respectively. Also, **Table 5** indicates features and final geometry of the west wall in Chadormalu mine.

Table 1: Results of the classification of the west wall Chadormalu mine according to various classification systems

System	NO. Block	Metasomatite	Albitite	Diorite	Fault	Crushed zone	Average
	B - 10	28	-	-	25	23	25
RMR	B - 11	26	26	-	-	21	24
	B - 12	39	39	38	-	-	39
	B - 10	23	-	-	20	18	20
GSI	B - 11	21	21	-	-	16	19
	B - 12	34	34	33	-	-	34
	B - 10	52	-	-	45	44	47
SRMR	B - 11	52	49	-	-	44	48
	B - 12	65	62	60	-	-	63

Table 2: The most important engineering parameters of each rock groups

Material	Albitite	Metasomatite	Granite	Diorite	Crushed zone
Unit weight (MN/m^3)	0.024	0.028	0.024	0.028	0.026
Compressive Strength of Rock mass (MPa)	2.29	2.52	3.24	3.31	1.83
Young's modulus (MPa)	1632	1691	3901.5	3270	1268
Poisson's ratio	0.26	0.23	0.23	0.24	0.26
Tensile strength (MPa)	0	0	0	0	0
Peak friction angle (degrees)	27.1	26	56.1	33.5	22.2
Peak cohesion (MPa)	0.67	0.68	0.21	1.01	0.54
Dilation Angle (degrees)	0	0	0	0	0
Residual Friction Angle (degrees)	27.1	26	56.1	33.5	22.2
Residual Cohesion (MPa)	0.67	0.68	0.21	1.01	0.54

STABILITY ANALYSES OF THE MINE WEST SLOPE

Introduction

Today, there are several methods for slope stability analysis, each has its own advantages and disadvantages. Numerical analyses methods are the most common ones that are used for rock and soil slope analyses. One of the software's that can analyze rock slope stability in a numerical way is powerful software called Phase2D. This software was used in the present study for analyses of stability in the west wall of Chadormalu mine.

Hypotheses of Analyses

In this research, it is supposed the all analyses have been done in conditions prior to excavation of berm 1435 and for both static and dynamic states whit 0.31 g earthquake acceleration.

Analyses and Results of the Slope Stability

Modeling and bordering the concerned slope in finite element Phase2D software and running the program, result of stability in the west slope of the mine were examined. The results show that safety factor of the slope designed under static and dynamic conditions will be 3.39 m and 2.26 m, respectively (**Table 6**). Also, displacement due to berms excavation is 1.5 cm for static state and 1.6 cm for dynamic one. Figures 3 and 4 represents the outcome model of Phase2D software (Factor of safety, total displacement and mean stress status) in condition prior to excavation of bench 1435 and **Figure 5** shows the shear-strain changes for both static and dynamic states, respectively.

Table 3: Safe overall slope angle obtained by Bieniawski (1989)[1] method

NO. Block	Metasomatite	Albitite	Diorite	Fault	Crushed zone	Average
B - 10	45.6	-	-	41.7	38.7	42.0
B - 11	42.6	42.6	-	-	35.0	40.1
B - 12	57.4	57.4	56.5	-	-	57.1

Table 4: Safe bench slope angle obtained by Slope Rock Mass Rating (SRMR)

NO. Block	Metasomatite	Albitite	Diorite	Fault	Crushed zone	Average
B - 10	69	-	-	66	65	66
B - 11	69	67	-	-	65	67
B - 12	74	73	72	-	-	73

CONCLUSIONS

Results obtained from this study confirm that; in dynamic condition, to obtain a safety factor upper than 2.2, the bench slope angle and its overall slope angle should be 70 degree and 44 degree. Also, according to the features of the rock masses in this area, numerical analysis results indicate that; under such a condition, displacement due to bench excavation will be led than 1.5 cm.

Table 5: Features and final geometry obtained for bench for the west wall in Chadorm-alu mine

Slope Parameters	Value
High (m)	15
Width of bream (m)	8.5
Bench Angle (degree)	70
Inter-ramp Angle (degree)	47
Overall Angle (degree)	44