DESIGN OF STABLE SLOPE FOR OPENCAST MINES

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ABSTRACT: Slope stability analysis forms an integral part of the opencast mining operations during the life cycle of the project. In Indian mining conditions, slope design guidelines were not yet formulated for different types of mining practices and there is a growing need to develop such guidelines for maintaining safety and productivity. Till date, most of the design methods are purely based on field experience, rules of thumb followed by sound engineering judgment. During the last four decades, the concepts of slope stability analysis have emerged within the domain of rock engineering to address the problems of design and stability of excavated slopes. The basic objective of the project is primarily addressed towards: a) Understanding the different types and modes of slope failures b) Designs of stable slopes for opencast mines using numerical models. Analyses were conducted using the finite difference code FLAC/Slope. The work was aimed at investigating failure mechanisms in more detail, at the same time developing the modeling technique for pit slopes. The results showed that it was possible to simulate several failure mechanisms, in particular circular shear and toppling failure, using numerical modeling. The modeling results enabled description of the different phases of slope failures (initiation and propagation). Failures initiated in some form at the toe of the slope, but the process leading up to total collapse was complex, involving successive redistribution of stress and accumulation of strain. Significant displacements resulted before the failure had been developed fully. Based on parametric studies it can be concluded that friction angle plays a major role on slope stability in comparison to Cohesion.

Keywords: Slope stability, open pit mining, numerical modeling, rock mass strength, failure mechanisms.

I.INTRODUCTION

1.1 Overview

Slope stability analysis forms an integral part of the opencast mining operations during the life cycle of the project. In Indian mining conditions, slope design guidelines are yet to be formulated for different types of mining practices and there is a growing need to develop such guidelines for maintaining safety and productivity. Till date, most of the design methods are purely based on field experience, rules of thumb followed by sound engineering judgment. During the last four decades, the concepts of slope stability analysis have emerged within the domain of rock engineering to address the problems of design and stability of excavated slopes. In India, the number of operating opencast mines is steadily increasing as compared to underground mines. It is due to low gestation period, higher productivity, and quick rate of investment. On the contrary, opencast mining attracts environmental concerns such as solidwaste management, land degradation and socio-economical problems. In addition to that a large number of opencast mines, whether large or small, are now days reaching to deeper mining depths. As a result analysis of stability of operating slopes and ultimate pit slope design are becoming a major concern. Slope failures cause loss of production, extra stripping cost for recovery and handling of failed material, dewatering the pits and sometimes lead to mine abandonment/premature closure. Maintaining pit slope angles that are as steep as possible is of vital importance to the reduction of stripping (mining of waste rock), which will in turn have direct consequences on the economy of the mining operation. Design of the final pit limit is thus governed not only by the ore grade distribution and the production costs, but also by the overall rock mass strength and stability. The potential for failure must be assessed for given mining layouts and incorporated into the design of the ultimate pit.

1.2 Objectives

The prime objectives of the project are addressed towards: a) Understanding the different types and modes of slope failures; and b) Designing of stable slopes for opencast mines using numerical models.

1.3 Research Strategies

Extensive literature review has been carried out for understanding the different types and modes of slope failures. Numerical model FLAC/Slope was critically reviewed for its application to evaluation of the stability of slopes in opencast mines. Field investigation was conducted in Jindal Opencast Mine with 116 m ultimate pit depth at Raigarh in Chhattisgarh State. Laboratory tests were conducted for the rock samples taken during field investigation. Parametric studies were conducted through numerical models (FLAC/Slope) to study the effect of cohesion (140-220 kPa) and friction angle (20°-30° at the interval of 2°). Pit slope angle was varied from 35° to 55° at an interval of 5°

II.LITERATURE REVIEW

2. O pen Pit Slopes —An Introduction In open pit mining, mineral deposits are mined from the ground surface and downward. Consequently, pit slopes are formed as the ore is being extracted. It is seldom, not to say never, possible to maintain stable vertical slopes or pit walls of substantial height even in very hard and strong rock. The pit slopes must thus be inclined at some angle to prevent failure of the rock mass. This angle is governed by the geomechanical conditions at the specific mine and represent an upper bound to the overall slope angle. The actual slope angles used in the mine depend upon (i) the presence of haulage roads, or ramps, necessary for the transportation of the blasted ore from the pit (ii) possible blast damage (iii) ore grades, and (iv)economical constraints.

2.1 Slope Stability Slope stability problem is greatest problem faced by the open pit mining industry. The scale of slope stability problem is divided in to two types: Gross stability problem: It refer to large volumes of materials which come down the slopes due to large rotational type of shear failure and it involves deeply weathered rock and soil. Local stability problem: This problem which refers to much smaller volume of material and these type of failure effect one or two benches at a time due to shear plane jointing, slope erosion due to surface drainage. To study the different types and scales of failure it is essential to know the different types of the failure, the factors affecting them in details and the slope stability techniques that can be used for analysis. The different types of the slope failure, factors affecting them, stability analysis techniques.

III.NUMERICAL MODELLING

3.1 Introduction

Many rock slope stability problems involve complexities relating to geometry, material anisotropy, non-linear behaviour, in situ stresses and the presence of several coupled processes (e.g. pore pressures, seismic loading, etc.). Advances in computing power and the availability of relatively inexpensive commercial numerical modelling codes means that the simulation of potential rock slope failure mechanisms could, and in many cases should, form a standard component of a rock slope investigation. Numerical methods of analysis used for rock slope stability may be conveniently divided into three approaches: continuum, discontinuum and hybrid modelling. Table 2 provides a summary of existing numerical techniques.

3.1.1 Continuum Modelling

Continuum modelling is best suited for the analysis of slopes that are comprised of massive, intact rock, weak rocks, and soil-like or heavily fractured rock masses. Most continuum codes incorporate a facility for including discrete fractures such as faults and bedding planes but are inappropriate for the analysis of blocky mediums. The continuum approaches used in rock slope stability include the finite-difference and finite-element methods. In recent years the vast majority of published continuum rock slope analyses have used the 2-D finite-difference code, FLAC. This code allows a wide choice of constitutive models to characterize the rock mass and incorporates time dependent behaviour, coupled hydro-mechanical and dynamic modelling.

3.1.2 Discontinuum Modelling Discontinuum methods treat the rock slope as a discontinuous rock mass by considering it as an assemblage of rigid or deformable blocks. The analysis includes sliding along and opening/closure of rock discontinuities controlled principally by the joint normal and joint shear stiffness. Discontinuum modelling constitutes the most commonly applied numerical approach to rock slope analysis, the most popular method being the distinct-element method. Distinctelement codes such as UDEC use a force-displacement law specifying interaction between the deformable joint bounded blocks and Newton’s second law of motion, providing displacements induced within the rock slope.

3.1.3 Hybrid Techniques

Hybrid approaches are increasingly being adopted in rock slope analysis. This may include combined analyses using limit equilibrium stability analysis and finite-element groundwater flow and stress analysis such as adopted in the GEO-SLOPE suite of software. Hybrid numerical models have been used for a considerable time in underground rock engineering including coupled boundary-/finite-element and coupled boundary-/distinct-element solutions. Recent advances include coupled particle flow and finite-difference analyses using FLAC3D and PFC3D

3.2 General Approach of FLAC The modeling of geo-engineering processes involves special considerations and a design philosophy different from that followed for design with fabricated materials. Analyses and designs for structures and excavations in or on rocks and soils must be achieved with relatively little site-specific data, and an awareness that deformability and strength properties may vary considerably. It is impossible to obtain complete field data at a rock or soil site. Since the input data necessary for design predictions are limited, a numerical model in geomechanics should be used primarily to understand the dominant mechanisms affecting the behavior of the system. Once the behavior of the system is understood, it is then appropriate to develop simple calculations for a design process. It is possible to use FLAC directly in design if sufficient data, as well as an understanding of material behavior, are available. The results produced in a FLAC analysis will be accurate when the program is supplied with appropriate data. Modelers should recognize that there is a continuous spectrum of situations, as illustrated in Figure , below

Typical Situation	Complicated geology; inaccessible; no testing budget	←--------→	Simple geology; Lots of money spent on site investigation
Data	None	←--------→	Complete
Approach	Investigation of mechanisms	← Bracket field behaviour by parameter studies →	Predictive (direct use in design)

Fig. Spectrum of modeling situations

Perform the Model Calculations

It is best to first make one or two model runs split into separate sections before launching a series of complete runs. The runs should be checked at each stage to ensure that the response is as expected. Once there is assurance that the model is performing correctly, several data files can be linked together to run a complete calculation sequence. At any time during a sequence of runs, it should be possible to interrupt the calculation, view the results, and then continue or modify the model as appropriate.

Present Results for Interpretation

The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen, or as output to a hardcopy plotting device. The graphical output should be presented in a format that can be directly compared to field measurements and observations. Plots should clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. The numeric values of any variable in the model should also be readily available for more detailed interpretation by the modeler.

IV.CASE STUDY

JINDAL POWER OCP, MAND RAIGARH COALFIELD

4.1 Introduction

Jindal Power Opencast Coal Mine is captive mine of Jindal's 1000 MW (4 x 250 MW) thermal power plant. The block is located between Longitudes - 83°29'40" to 83°32'32" (E) and Latitude - 22°09'15" to 22°05'44" (N) falling in the topo sheet no. 64 N/12 (Survey of India). Administratively, the block is under Gharghoda Tahsil of Raigarh District, Chhattisgarh. The block is well connected by Road. It is about 60 km from Raigarh town, which is the district head quarter and nearest railway station on Mumbai - Howrah Main Line.

4.2 Geology

In general area of the coal block - Jindal Power Open Cast Coal Mine is almost flat with small undulations from surface the lithological section comprises about 3-4 m unconsolidated loose soil/alluvium. Below the top soil there is weathered shale/sandstone up to 6–8 m depth. The weathered shale/sandstone is competitively loose in nature and can be excavated without blasting. Below weathered mental (which varies from 3 – 10 m), the rock is hard, compact and massive in nature it can be excavated only after blasting. In the sub-block IV/2 & IV/3 only lower groups of Gondwana seams have been deposited. The general strike of the seams in NW-SE is almost uniform throughout the block. Two normal faults of small magnitude have been deciphered based on the level difference of the floor of the seams, though the presence of some minor faults of less than 5 m throw cannot be overruled. The Mand Raigarh basin is a part of IB River - Mand - Korba master basin lying within the Mahanadi graben. Sub block IV/2 & IV/3 of Gare-Pelma area is structurally undisturbed except one small fault (throw 0-15 m) trending NE-SW with westerly throws. The strike of the bed is NW-SE in general with dip varies from 2° to 6° southwesterly. In the sub block IV/2 & IV/3, total 10 coal seams have been established. They are seam X to I in descending order. The lithology of the seams and details of the seams are given in Table 4.1 and Table 4.2 respectively.

Data Collection

The objective of the investigation was to design stable slopes so that it facilitates safe operations. The typical analysis ingredients are cohesion and angle of internal friction. These data represent the engineering properties of the area under investigation.

4.4 Laboratory Test

4.4.1 Sample Preparation

Three rock samples are taken from undisturbed specimens by boring. After boring the samples are cut into required dimension (Length/Diameter is greater than 2). The dimensions are given in the Table

Table : Dimensions of the tested samples

Sl. No.	Average Length(cm)	Average Diameter (cm)	Length/Diameter Ratio
Sample 1	11.5	5.38	2.1
Sample 2	11.49	5.43	2.1
Sample 3	11.38	5.55	2.1

Triaxial Testing Apparatus for Determination of Sample Properties

The equipment is designed for testing rock samples with a cell which is designed to withstand a lateral pressure of 150 bar (150kgf/cm2) and can be used in AIM-050, Load Frame 500 kN (50,000 kgf) capacity. Lateral pressure can be applied with the help of AIM – 246, Constant Pressure System, 150 bar (150 kgf/cm2). The equipment consists of a base which houses four valves these valves can be used for measurement of pore pressure, top drainage, bottom drainage, and for entry /exit of cell water. Base has a hole in the center for fixing the locating g pin and bottom pedestal of various sizes. It also has ten threaded holes and two locating pins for aligning and clamping chamber with bolts to base. Chamber has ten free holes and two lifting handles. Top cap is fixed with the chamber. Top cap has an air plug and a pressure inlet plug. A grooved and lapped plunger which can be lifted with the help of two pins provided on the top of the plunger.

Fig. A typical triaxial test apparatus

Table : Readings of proving and deviator and dial gauge

Sl. No.	Dial Gauge Reading	Corrected Area	σ_3 = 100 kPa			σ_3 = 200 kPa			σ_3 = 300 kPa		
			Proving Reading	Deviator Reading	Deviator stress (kPa)	Proving Reading	Deviator Reading	Deviator stress (kPa)	Proving Reading	Deviator Reading	Deviator stress (kPa)
1	0	12.19	0	0	0	0	0	0	0	0	0
2	50	12.25	16	54.4	44.40	16	54.4	44.4036	21	71.4	58.279
3	100	12.31	34	115.6	93.88	21	71.4	57.9869	33	112.2	91.122
4	150	12.38	39	132.6	107.14	33	112.2	90.662	49	166.6	134.62
5	200	12.44	45	153	123.0	62	210.8	169.47	59	200.6	161.269
6	250	12.50	56	190.4	152.28	87	295.8	236.591	86	292.4	233.87
7	300	12.57	68	231.2	183.97	109	370.6	294.899	112	380.8	303.015
8	350	12.63	99	336.6	266.46	121	411.4	325.678	149	506.6	401.04
9	400	12.70	114	387.6	305.24	143	486.2	382.897	176	598.4	471.258
10	450	12.76	132	448.8	351.60	157	533.8	418.194	205	697	546.05
11	500	12.83	139	472.6	368.31	179	608.6	474.299	244	829.6	646.529
12	550	12.90	146	496.4	384.82	196	666.4	516.61	265	901	698.478
13	600	12.97	152	516.8	398.51	219	744.6	574.179	283	962.2	741.975
14	650	13.04	163	554.2	425.08	241	819.4	628.498	301	1023.4	784.970
15	700	13.11	192	652.8	498.03	258	877.2	669.234	319	1084.6	827.463
16	750	13.18	211	717.4	544.37	268	911.2	691.436	346	1176.4	892.674
17	800	13.25	234	795.6	600.45	276	938.4	708.226	379	1288.6	972.528
18	850	13.32	252	856.8	643.12	298	1013.2	760.523	389	1322.6	992.763
19	900	13.40	261	887.4	662.45	314	1067.6	796.978	406	1380.4	1030.48
20	950	13.47	265	901	668.91	332	1128.8	838.034	411	1397.4	1037.44
21	1000	13.54	267	907.8	670.23	341	1159.4	855.997	417	1417.8	1046.77
22	1050	13.62	267	907.8	666.51	345	1173	861.226	421	1431.4	1050.94
23	1100	13.70	-	-	-	345	1173	856.415	423	1438.2	1050.03
24	1150	13.77	-	-	-	-	-	-	424	1441.6	1046.60
25	1200	13.85	-	-	-	-	-	-	424	1441.6	1040.69

Plotting of Mohr's Circle

With σ3 = 100 kPa, 200 kPa and 300 kPa respectively and the total stress σ1 = 670 kPa, 861 kPa and 1050 kPa the respective Mohr's circles are drawn. Mohr's circle showed cohesion and angle of internal friction as 180 kPa, and 26 degrees, respectively.

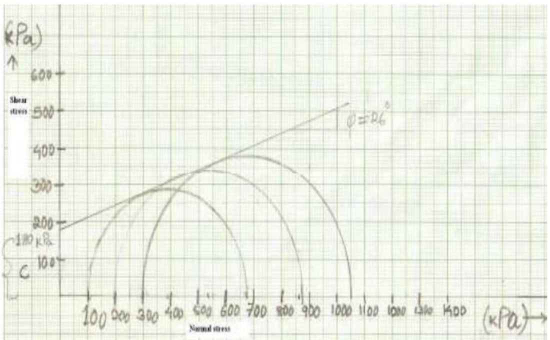

Fig. Mohr's circle for determination of cohesion and angle of internal friction

V.CONCLUSION

Opencast mining is a very cost-effective mining method allowing a high grade of mechanization and large production volumes. Mining depths in open pits have increased steadily during the last decade which has the increased risk of large scale stability problems. It is necessary to assess the different types of slope failure and take cost effective suitable measures to prevent, eliminate and minimize risk. The different types of the slope stability analysis techniques and software are available for slope design. Numerical modelling is a very versatile tool and enables us to simulate failure behavior and deforming materials. FLAC/Slope is user friendly software which is operated entirely from FLAC's graphical interface (the GIIC) and provides for rapid creation of models for soil/rock slopes and solution of their stability condition. Moreover it has advantages over a limit equilibrium solution like any failure mode develops naturally; there is no need to specify a range of trial surfaces in advance and multiple failure surfaces (or complex internal yielding) evolve naturally, if the conditions give rise to them. In this project, an attempt has been made to get acquaintance with the powerful features of FLAC/Slope in analysis and design of stable slopes in opencast mines. Data was also collected from Jindal Opencast Mine with 116m ultimate pit depth at Raigarh in Chhattisgarh State to assess the effects of cohesion and angle of internal friction on design of stable slope using FLAC/Slope. The parametric study which was carried by varying the cohesion, angle of internal friction and ultimate slope angle showed that with increase in ultimate slope angle, the factor of safety decreases. Moreover cohesion and angle of internal friction are quite important factors affecting slope stability. With increase in both the parameters the stability increases. Conduct of slope stability assessment in Indian mines is mostly based on empirical and observational approach; hence effort is made by statutory bodies to have more application of analytical numerical modelling in this field to make slope assessment and design scientific. This will ensure that - 56 - suitable corrective actions can be taken in a timely manner to minimize the slope failures and the associated risks.

VI.Scope for Future work

For the parametric studies, only cohesion and friction angle have been considered. However this study can be extended to individual bench angles where all the benches may not be of same height. The conditions assumed during this analysis are such that there is no effect of water table and geological disturbances. Along with cohesion and friction angle other parameters like effect of geological disturbances, water table and blasting can be carried out. For slope stability analysis other numerical models such as UDEC and Galena can also be used in order to compare the sensitivity and utility of the different software.

REFERENCES

1. Bauer, A. & Calder, P.N. (1971), "The Influence and Evaluation of Blasting on Stability", In Stability in Open Pit Mining, Proc. 1st International Conference on Stability in Open Pit Mining (Vancouver, November 23-25, 1970), New York: Society of Mining Engineers, A.I.M.E, pp. 83-94.

2. Bieniawski, Z.T. (1984), "Input Parameters in Mining", Rock Mechanics Design in

Mining and Tunneling, A.A. Balkema, Netherland, Edition-8, pp.55-92.

3. Call, R. D. & Savely, J. P. (1990), "Open Pit Rock Mechanics", In Surface Mining, 2nd Edition (ed. B. A. Kennedy), Society for Mining, Metallurgy and Exploration, Inc., pp. 860- 882.

4. Call, R. D., Nicholas, D.E. & Savely, J.P. (1976), "Aitik Slope Stability Study", Pincock, Allen & Holt, Inc. Report to Boliden Aktiebolag, Gallivare, Sweden.

5. Coates, D. F. (1977), "Pit Slope Manual", CANMET (Canada Centre for Mineral and Energy Technology), CANMET REPORT , pp 126p

6. Corbyn, J.A. (1978). "Stress Distribution in Laminar Rock during Sliding Failure", Int. J. Rock Mechanics, Vol. 15, pp.113-119.

7. Farmer, I. (1983), "Engineering Behavior of Rocks" Chapman & Hall, U.S.A., pp.145- 167

8. Goodman, R.E. (1975), "Introduction to Rock Mechanics", John Wiley & sons, U.S.A., pp.187-194

9. Hoek, E. (1970), "Estimating the Stability of Excavated Slopes in Opencast Mines", Trans. Instn. Min. Metall. (Sect. A: Min. industry), 79, pp. A109-A132.

10. Hoek, E. (197la), "Influence of Rock Structure in the Stability of Rock Slopes", In Stability in Open Pit Mining, Proc. 1st International Conference on Stability in Open Pit Mining - 58 - (Vancouver, November 23-25, 1970), New York: Society of Mining Engineers, A.I.M.E, pp. 49-63.

11. Hoek, E. & Bray, J.W. (1980), "Rock Slope Engineering", Institute of Mining & Metallurgy, London, pp.45-67.