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Risk Appraisal Approach of Open-pit Slope Design in Indian Mines

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ABSTRACT

The factor of safety (FoS) of a slope is the fundamental engineering design index for an open pit mine. But the problems related to safety of persons employed in mines are highly dynamic in nature and change abruptly. A methodology that aims to solve this problem is the risk-based safety appraisal and is a kind of complement of FoS. The main objective of this paper is to develop a risk classification based on total risk and FoS. The proposed methodology of risk analysis considers the use of non-formal sources of information (engineering judgment, expert knowledge) together with large volumes of statistical database of stable and failure pit slopes for the assessment of risk criteria. The results indicate the development of risk rating criteria and risk classification were to prioritize the mines for addressing immediate hazards. In this research work, the guidelines are developed for categorization of the open pit mines based on the total risk and FoS. The findings of this research can be applicable to all the mines with similar geo-mining conditions to predict and check the risk potential for pit slope failures.

1. INTRODUCTION

As far as planning and operation of open pit mines is concerned, the design of slope is rendered the most challenging step [1]. The primary concern for management while designing an open pit mine is to render an optimized layout to obtain profitable financial return with safety. Lately, it has been observed that the accidents related to slope failure in open pit mines have gained upward trend [2]. The year-wise number of fatalities due to slope failure in India is given in the Figure 1 [3].

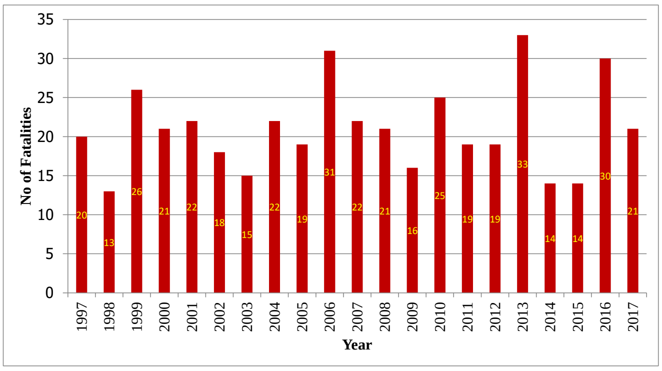

Figure 1. Year-wise number of fatalities due to slope failure in India

From Figure 1, it is evident that fatalities are not reducing considerably, even if the mines are adopting high mechanization reducing exposure of work persons at the working benches. It can be ascertained that the risk is a redundant phenomenon yet, an inevitable part of any mining operation. The ongoing tussle between obtaining profitable production and maintaining safe environment is impetus to such failures. In light of the adoption of high degree of mechanization, yet a surge has been observed in accidental incidents revealing the real level of risk. The author has made this inference from the analysis of recent accidents. The FoS of a pit slope is the fundamental engineering design index for an open pit mine. But, the safety problems in mines are highly dynamic in nature and change abruptly. A methodology that aims to solve this problem is the risk-based safety appraisal.

2. RISK APPRAISAL APPROACH OF OPEN-PIT SLOPE DESIGN

Mining is a high-risk business and, due to the fact that owners have an appreciation and an appetite for risky ventures, is often successful. In contrast, technical specialist is generally risk averse and have an appetite for technical excellence. In many instances, the slope angles are the dominant parameter that define the mineral reserve, and therefore become a critical decision for the owner. Suitable communication between the owner and technocrat is required to enable the best decision to be made on design slope angles.

2.1 Fundamental understanding of risk analysis

In this paper the concept of risk is addressed in terms of both chance of occurrence (likelihood) and consequence, where;

Risk = Chance of Occurrence × Consequence.

Risk implies about the future likelihood of the course of events. Therefore, the definition of risk in the context of mining would mean a certain knowledge or experience, which would be a guide to understand the likelihood of occurrence and the related consequences pertaining to a certain condition. Geotechnical Engineers, the primary designers of the open pit mine slopes analyse several factors and propose the probability of failures, factor of safety, etc. based upon the geotechnical characterization of the mine slopes and the previous knowledge obtained. The limitation with such approach is that the models proposed by them only infer that which is already known or understood. If any new geological condition is encountered it becomes a difficult job.

Therefore the basic rudimentary question that had to be addressed during mine development is; "Has there been any previous experience with the geo-mining conditions of a particular mine slope?" In case of limited or no experience with identical geological condition, then there exists uncertainty or risk.

This index in reality can be attributed to the index of experience and expertise of the design engineer. It does not completely portray the risk associated with the slope but is just a preliminary assessment tool. Engineering judgement has to be taken at each stage of the design process, be it, ground characterization by borehole drivage or mapping for design analysis [4, 5]. The index is then used to map the probability of likelihood for occurrence of failure. It can thus be inferred that there exists an inherent uncertainty and risk even in the relatively uncomplicated engineering computations.

What can be conceived about consequence? In straightforward problems that can be practically calculated such as development of tension crack on the bench, the consequences can be effortlessly perceived and risk can be computed. However, the problems associated with large open pit mines are complicated. Some of them can be categorized under improper design of slope or bad decision of management. When these factors concur, the problem becomes apparent. It takes years for these kinds of problems to surface. In order to cater to such problems, one needs much experience to rightly anticipate, and comprehend the consequences. Hence, it can be said that the problems pertaining to open pit mine slopes are complicated and bear inherent significant uncertainty and risk.

The title of this paper Risk Appraisal Approach of Open-Pit Slope Design, implies the geotechnical input to a safe and efficient open pit mine is contained only in a single element, the pit slope design. However, it is fundamental to the understanding presented in this paper that geotechnical engineering for open pits has two components:

- Firstly, the pit slope design, which means the design of the environment from where excavation has to be done; and
- Secondly, the pit slope management, which includes numerous management techniques of the mining environment so that the overall risk is minimized, and the objectives for safe working environment is achieved.

With the passage of time, the domain of slope design has emerged to be a prominent area of research for mining professionals. The author has covered and answered certain important questions concerning risk related to safety and economy in the context of pit slope design and management.

The design exercise that has been undertaken and proposed in this thesis renders the owner to efficiently decipher the level of risk in terms of steepest slope angle which is allowable to him and permits the mining professionals to develop the mine in that direction, thereby satisfying the risk criteria. These risk criteria are developed according to the consequences of potential failure that a mine can experience. In other words the risk/ consequence process espouses the mining venture of slope into a design criterion. As a result of it, suitable areas for geotechnical exploration can be identified in order to minimize risk.

From the Figure 1, it can be inferred that there is a need for a fresh initiative that can possibly reduce the upward trend of the fatal accidents and catastrophic disasters, which are occurring, in a repetitive fashion every year. If a hierarchy is drawn for prevention and control of accidents in open pit mines, the first priority will always be to avert disaster followed by fatal and serious accidents. The International Labour Organization (ILO) has undertaken a commendable initiative to attain zero harm and no injury in the working environment. It can be deduced from the above discussion that an integrated approach needs to be developed in terms of risk assessment and risk management techniques. As a result of this initiative, the accidents can be eliminated or reduced and minimal risk of accidents can be achieved at the vicinity of the work place.

2.2 Analysis of pit slope failures

The Indian Coal Mining Industry has experienced the pit slope failures at Dorli OC-I of M/s SCCL, SRP OC-I of M/s SCCL, Medapalli OCP of M/s SCCL, KTK OC sector-I of M/s SCCL Juna Kunada Colliery of M/s WCL Kawadi OCP of M/s WCL and Rajmahal OCP of M/s ECL. The Indian Coal Mining Industry is moving towards deeper opencast mines upto a depth of around 500m like Manuguru OC-II Extension and RG OC-II extension [6]. In India, Lot of accidents have been occurred due to slope failure (Figure 1). Some of the slope failures in India are shown in the Figure 2.

Figure 2. Photographs showing some of the pit slope failures in India

The analysis of about 100 slope failure cases by the author has converged on one common but a major factor causing the accidents that of the lack of scientific design and monitoring of the pit and the dump slopes in mines.

2.3 Pit slope stability analysis

In simple terms, slope stability is perceived to be the ratio of forces in resistance to the forces driving over an inclined surface that may lead to either collapse or slide [7]. Slope stability analysis comprises of significant steps, some of which are to observe and identify the mechanism of failure, identify critical location posing danger to slopes, identify critical factors stimulus to failure followed by optimal design of slope considering safety and profitable economics. Consequently, the engineering judgement has to be made on the basis of the assessment of the results of analysis, taking into consideration allowable risk or factor of safety [8]. The Figure 3 visualizes the flow chart for pit slope stability analysis.

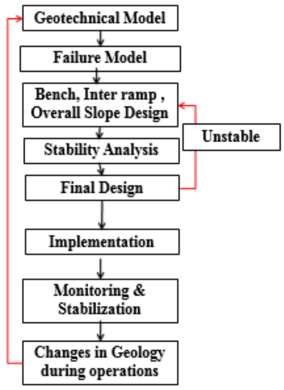

Figure 3. Flow chart for pit slope stability analysis

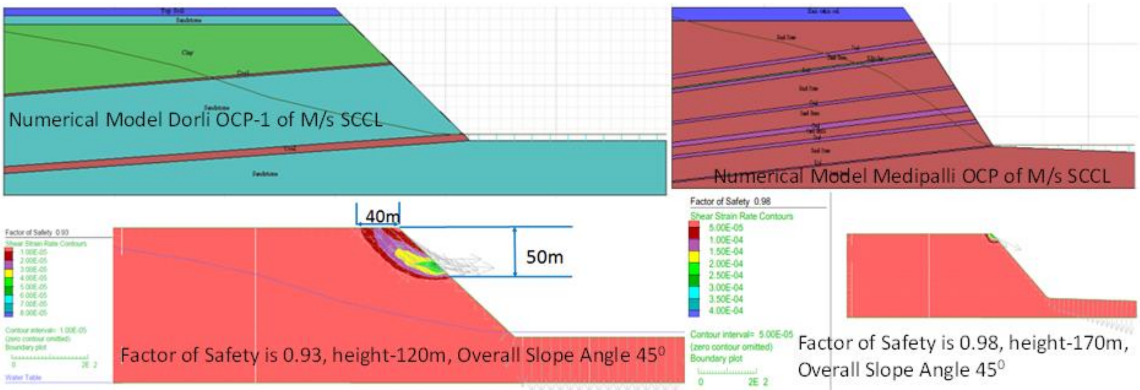

Figure 4. Numerical analysis results of Dorli OCP-1 and Medapalli OCP of M/s SCCL

The evaluation of the stability of rock slopes is a critical component of open pit design and operation [9]. So, the Indian coal mining industry has identified optimum design of slope as one of the thrust areas.

Based on field observations and numerical analysis results of some of the above-said failures shown in Figure 4, it is concluded that the groundwater, higher slope angle and soft material like soil and clay leading to improper design and inadequate slope monitoring are the major influencing parameters for causing instability of pit slope.

Because of the unpredictability of slope behavior, slope monitoring can be of value in managing and preventing slope hazards, and they provide information that is useful for the design of remedial work. Slope monitoring is a key aspect of mining operations due to volatility of slope behaviour. It has to be done consistently. The information collected from monitoring of slope renders to manage and mitigate slope hazards. The system of slope monitoring can be classified into four categories. Figure 5 illustrates them as an observation through visual monitoring, surface measurements, subsurface measurements and remote monitoring technologies. In order to obtain an effective slope monitoring system, the idea of real time monitoring has been proposed which will be able to collect large volume of geotechnical information for the mine [10]. Through the analysis of Indian accident statistics, it is suggested to maintain well-developed drainage system in and around the open pit mine to avoid entry of rain/surface water into it to maintain pit slope stable and carry out continuous intensive slope monitoring to detect any instability well in advance [10].

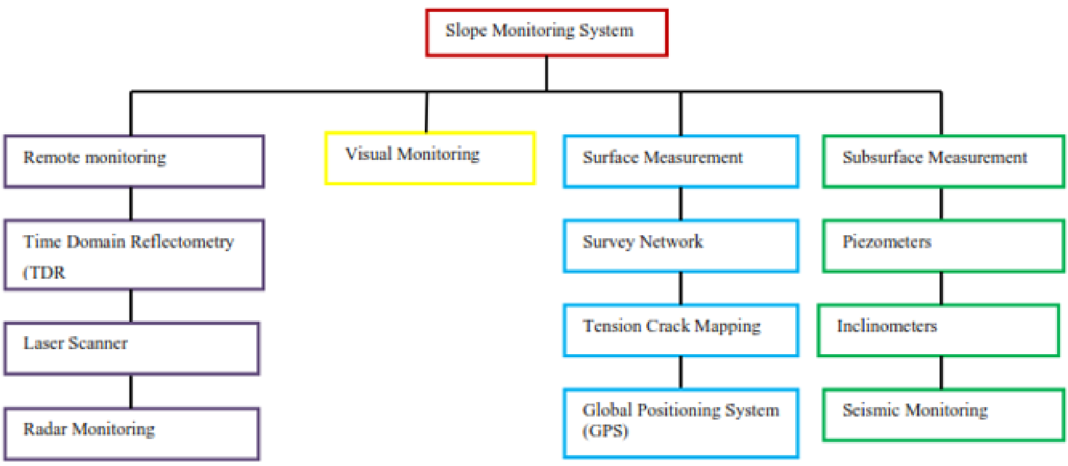

Figure 5. Slope monitoring system

3. RESULTS AND DISCUSSION

Investigation through numerical simulation is needed to be conducted so as to develop an optimum design and safe model for opencast pit mines before opening of the mine. Suitable instrumentation and real-time monitoring system shall be provided for advance warning of potential failures during operational phase. The risk appraisal should be carried out and control measures should be taken to bring the mine to acceptable risk or safe condition. The basic methodology developed for pit slope design, monitoring and risk evaluation is to

a. Collection of sufficient geo-technical data essential for scientific design of a pit slope.

b. Design the different cases/options of pit slopes to an acceptable FoS using geotechnical analysis under different practical conditions.

c. Proposal of an optimum slope angle to the mine management for design consideration and economic computation.

d. Implement the finalised case/ option by mine planners while opening the mine

e. Apply stabilization/monitoring procedures to determine the suitable performance of the slope rendering to the expectations during operations of the mine.

f. Then, determine the risk criteria based on broad three categories i.e. Major/Principal Risks, Operational and Historical Risks and give rating.

g. Sum up of all risk ratings and Rank the mine.

h. Take measures to control the factors contributing to High Risk and

i. Review risk ratings & control measures quarterly, accordingly Rank the mine till it falls under the category of acceptable risk or safe.

j. Repeat the steps from ‘a’ to ‘i’, if there are any abnormal changes in geometry, geology and hydrogeology of the slope during operations.

This new methodology developed as a risk appraisal approach is beneficial for pit slope design as it renders the owner to determine effectively the risk criteria after carefully analysing the consequences of prospective failures that can occur. This has to be done by proper communication with the design engineer or researcher. This averts the risk associated with the traditional design approach for slopes in opencast mines. Table 1 indicates Risk criteria and Rating devised by the author based on the extensive study of around 100 pit slope failures as explained above.

Table 1. Risk rating matrix for pit slope stability

Major risk associated (Level 1)			
S.No.	**Risk Criteria**	**Scale**	**Numerical Value (Risk Rating)**
1	Overall Pit Slope Angle	00-10	00 – Not applicable 01 – Less than 30 degrees 05 – Between 30 and 45 degrees 10 – More than 45 degrees
2	Individual Bench Angle	00-10	00 – Not applicable 01 – Less than 45 degrees 05 – Between 45 and 70 degrees 10 – More than 70 degrees
3	Geological structures like faults, joints, etc.	00-10	00 – No discontinuities 05 – Minor discontinuities 10 – Major discontinuities
4	Depth of the Mine	00-10	01 – less than 50m 03 – between 50m and 150m 05 – between 150m and 250m 10 - More than 250m
5	Ground Water	00-10	01 – Dry Slope 05 - Semi-Saturated Slope 10 – Wet/Saturated Slope
6	Scientific Analysis for Design of Slope by Scientific bodies	00-10	00-Yes 10-No
Operational risk associated (Level 2)			
S.No.	**Risk Criteria**	**Scale**	**Numerical Value (Risk Rating)**
7	Slope Monitoring	00-05	00 –Not applicable (mines below 30m depth) 01- Real-time Continuous Monitoring 03- by total station 05- by physical observation
8	Drainage System	00-05	00 – Adequate 03- Significant 05 – Inadequate
9	Proximity of opencast workings in relation to public place/structure	00-05	00 – More than 500 m/Not applicable 01 – More than 300 m but less than 500m 03 – Less than 300 m but more than 100m 05 – Less than 100m
10	Blasting practices	00-05	00 – No blasting 01 – Short hole blasting 05 – Deep hole blasting
11	Level of mechanization in opencast mine	00-05	01 – Highly mechanized 03 – Semi-mechanized 05 – Manual working

Historical risk associated (Level 3)			
S.No	**Risk Criteria**	**Scale**	**Numerical Value (Risk Rating)**
12	Average Accident severity index during last three years due to pit slope failure [{(50K+S)*1,00,000}/manshifts] K - No. of persons killed S - No. of persons seriously injured	00-05	00 – less than or equal to 0.1 01 – Index more than 0.1 but less than or equal to 1 03 – Index more than 1 but less than or equal to 10 05 – Index more than 10
13	Proactive Attitude of management towards Safety to avoid pit slope failures	00-05	01 – Leader 03 – Follower 05 – Reluctant
14	Compliance history of violations pointed out by Internal Safety Organization, Safety Committee, DGMS and other regulatory authorities	00-05	00 – Good 03 – Average 05 – Below average
15	Average manpower employed per day	00-05	01 –Less than or equal to 100 03 – More than 100 but less than or equal to 400 05 – More than 400
16	Deployment of qualified & technical personnel to manage safety of pit slope	00-05	00 – Adequate 03 – Significant 05 – Inadequate

Table 2. Status of the conditions of the pit slopes of different mines

Sl No.	Name of Mine	Total/ Collective Risk	Factor of Safety	Condition of Slope
1	Medapalli OCP of M/s SCCL	81	1.01	Unstable (Pit slope failure Occurred)
2	Dorli OCP-1 of M/s SCCL	73	0.93	
3	GK OCP of M/s SCCL	78	0.91	
4	Dorli OCP-II of M/s SCCL	73	0.95	
5	Koyagudem OCP of M/s SCCL	72	0.98	
6	Rajmahal OCP of M/s ECL	95	Geotechnical parameters are not available for numerical analysis	
7	Juna Kunada OCP of M/s WCL	90		
8	Kawadi OCP of M/s WCL	94		
9	Umrer OCP, M/s WCL	79		
10	RG OCP-II extension of M/s SCCL	47	1.25	Stable (No failure Occurred)
11	Khairagura OCP	44	1.21	
12	Koyagudem OCP-I Pit-II of M/s SCCL	43	1.30	
13	Tadicherla OCP-I of M/s SCCL	41	1.31	

Table 3. Guidelines for risk classification

Sl. No	Risk Classification	Total/ Collective Risk	Factor of Safety
1	High Risk	More than or equal to 70	Less than 1.20
2	Medium or Acceptable Risk	In-between 30 and 70	1.20 to 1.50
3	Low Risk or Safe	Less than or equal to 30	More than 1.50

The total risk of the failure and stable slope cases studied in this paper is calculated by summing all the values of different risk criteria provided in the risk rating matrix in the Table 1. The maximum value of all the 16 risk parameters is 110. Table 2 shows the total risk obtained through risk rating matrix mentioned above, factor of safety obtained by numerical analysis and the condition of slope for some of the mines studied.

With this research and study, the guidelines are framed for categorization of the open pit mines based on the risk rating (Table 3).

4. CONCLUSIONS

The success of the opencast mining largely depends upon the stability of the slopes of the open pit. After careful investigation it has been deduced that the recent accidents in the opencast mines pertaining to slope failures have taken an upward trend in the recent times. Mining depths in open pits are steadily increasing from time to time thereby rendering increased risk of slope failures. Factor of safety as an index has been extensively used for evaluation of pit slope stability. From the field and geotechnical analyses, it is found that the unscientific & experience-based design, hydrostatic pressure built up by groundwater, higher slope angle, weak strata and inadequate slope monitoring are the root causes for the pit slope failures.

This demanded the need for stability analysis and scientific design of pit slopes in India along with real time monitoring of slope to decipher the signs of instability prior to the actual failure. The problems related to safety of persons employed in mines are highly dynamic in nature and change abruptly. A methodology that aims to solve this problem is the risk-based safety appraisal. The risk analysis technique is a supplement to the scientific calculation of factor of safety. The proposed methodology of risk analysis in this paper is based on the use of non-formal sources of information (engineering judgment, expert knowledge) together with large volumes of statistical data available at DGMS for the assessment of risk criteria. The risk rating criteria and risk classification were developed based on analysis of failure and stable cases of pit slopes in India. The Indian mines can use this risk criteria and check risk potential of the mine for pit slope failure. This study is limited to Indian open pit mines. It is recommended to further study the failure and stable cases of pit slopes in world and to develop a generalized guideline for risk classification applicable all over the world.

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