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Research Paper

Ramp Safety Risk Analysis in Open-Pit Mines to Identify Accident-Prone Zones

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Abstract: The first step for carrying out mining operations in surface mines is to build a network of communication routes to access different parts of the mine, and also transport ore and waste. For the successful design of ramps in open pit mines, it is necessary to evaluate and analyze the related safety risk based on the geological conditions, geomechanical characteristics, type of machinery, and the mine design. In this research, the ramp safety risk was investigated to determine the accident-prone zones. In this regard, the information obtained from the exploration boreholes of the Chadormalu iron ore mine was used for modeling. At first, the economic block model of the mine and the ramp were modeled in different scenarios. After selecting the optimal ramp, the total length of the ramp was zoned at 100-meter distances to assess the safety risk in 42 zones, and to identify accident-prone zones by calculating the total risk index. Thus, by drawing a bow-tie diagram, the five initial events including wall instability, car crash, stone throwing, slippery, and accident were identified as the main events leading to incidents; then the probability and consequences severity of each initial event were determined. According to the results, the car crash and wall instability events have the most negative impact on the ramp safety. Also, the highest and the lowest values of the total risk index were 110 (in zones 37 and 42) and 5 (in zones 4, 5, and 9), respectively.

Keywords: Risk analysis, Safety, Ramp design, Open-pit mining method.

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INTRODUCTION

The process of risk management is one of the main parts of project management and includes the main stages of planning, risk analysis, and risk control [1,2]. The main goal of risk management is to identify the high-risk events, evaluate the identified risks, and determine the preventive measures in order to reduce the overall risk of the project to an acceptable level [3].

After accepting the feasibility of the open pit mining method for the exploitation of a particular deposit, one of the most important issues is to design a suitable ramp for material transportation during the life of the mine. The designing, locating, and implementing processes of the ramp will directly affect the final pit limit and production planning. Due to the necessity of servicing the ramp during mining operations, ensuring its safety and analyzing possible risks seem necessary. If the ramp is not correctly designed and positioned, the safety of the ramp may decrease in the last years of the mine life as the depth of the pit increases. On the other hand, the ramp should be designed in terms of distance and stability to take into account technical and economic considerations for reducing human errors, geomechanical risks, and operating costs.

In this research, the ramp safety risk is investigated during the design process. In this way, five main factors have been investigated as the initial events leading to incidents in the design of ramps in open pit mines. For this purpose, information obtained from exploration boreholes of the Chadormalu iron ore mine has been used for modeling various scenarios using Datamine software for optimal ramp design. In this research, by calculating the value of the total risk index, the severity and probability of the risk occurring in the entire ramp route at 100-meter intervals have been investigated to identify the accident-prone zones.

RESERVE ESTIMATION AND RAMP DESIGN IN CHADORMALU MINE

In order to implement the principles of ramp design and risk assessment, the block model is defined based on the information used for reserve estimation. The data are obtained from 124 exploration boreholes in a regular drilling network of 100×100 square meters [4]. By applying the geometrical, physical, and exploration data to the model, the initial design of the block model is formed. The volume of the model is equal to 93501065 cubic meters and its tonnage is equal to 252452880 tons, with an average density of 2.7 tons per cubic meter. In this research, the height of the blocks is equal to the bench height, and equal to 15 meters. The final slope of the mine is 45 degrees, and the length and width of the blocks are assumed to be 12 meters. In order to perform the technical and economic assessments of the project, the economic block model has been prepared by NPV Scheduler software (Figure 1). The final pit limit is designed according to the two goals of maximizing the cash flow and the mining capacity. The value of the annual discount rate is 15%, the annual extraction capacity is 12 million tons, and the number of working days is assumed to be 365 days per year. The tonnage of the estimated reserve is about 250 million tons with an average grade of 53%, and the tonnage of the wastes that must be removed to reach the ore is estimated at about 285 million tons.

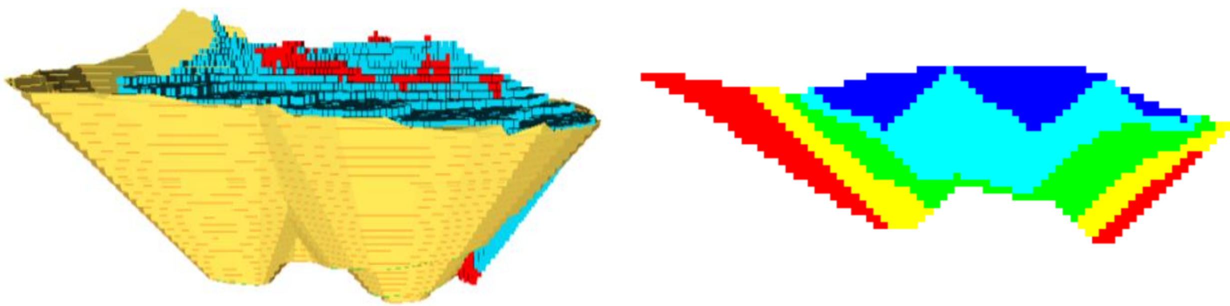

Figure 1. Economic block model and the sequence of pit extraction

Therefore, the overall stripping ratio is about 1.15, and the life of the mine is about 21 years. As shown in Figure 1, the sequence of extraction in eight pushbacks has been chosen in such a way that the high-grade part of the reserve will be extracted in the first years to decrease the payback period.

Taking into account that the maximum and minimum heights of the economic block model are 1700 and 1000 meters, respectively, the depth of the pit from the highest topographic level is considered to be 700 meters. Because the height of each bench is assumed to be 15 meters, a total of 47 15-meter benches is designed for this mine. A switchback is also used during the ramp design to prevent an excessive increase in the length of the ramp in the last years of the mine life. It has also been tried to locate the entire ramp route in the footwall of the deposit so that its stability is less affected by mining operations.

RAMP SAFETY RISK ASSESSMENT AND ANALYSIS RESULTS

The purpose of risk management is to identify risky situations or events, evaluate them, and determine preventive measures with the aim of reducing the probability of occurrence or the severity of their effect [5]. Therefore, to evaluate the safety risk of the designed ramp, 42 zones with 100-meters intervals have been selected in such a way that risk zoning can be done along the entire length of the ramp (Figure 2). In this way, the accident-prone zones in the entire ramp distance have been investigated using five initial events including wall instability (R1), car crash (R2), stone throwing (R3), slippage (R4) and accident (R5).

Figure 2. Ramp safety risk zoning in 42 100-meter zones

The risk indices resulted from each of the initial events in 42 zones are evaluated, and the total risk zoning map along the ramp route is shown in Figure 3. In order to facilitate the analysis of the results, the total risk index is classified in five ranges as low risk in gray color (in the range of 5-20), medium risk in orange color (in the range of 20-45), relatively high risk in green color (in the range of 45-65), high risk in blue color (in the range of 65-90) and very high risk in red color (in the range of 90-110). In this way, the blue and red zones should be prioritized to reduce the probability of initial events as much as possible by timely implementing preventive measures. Therefore, the safety of the ramp may be ensured during mining operations, especially in high-risk and accident-prone zones.

Figure 3. Zoning of the total risk index in the proposed ramp

CONCLUSION

Based on the results, the highest value of the wall instability risk index is obtained in the zones 35 and 36. The highest value of the car crashing risk index is obtained in the zones 6, 12, 14, 15, 17, 19, 20, 23, 31, 32, 33, 34, 35, 37, 38, and 42. In zones 33, 34, and 36, the highest risk index of stone throwing is observed. The highest value of the slippage risk index is obtained in zones 37 and 42. Also, the highest value of the accident risk index is obtained in the zones 12, 17, 37, and 42. To determine the total risk indices in all 42 examined zones, the total risk index resulting from the occurrence of all initial events in each zone was calculated through the sum of the risk index of all initial events. Thus, the lowest amount of the total risk index is related to zones 4, 5, and 9, which is estimated as 5. Also, the highest value of the total risk index is 110, and is observed in the zones 37 and 42. The concluding remark is that by performing the risk analysis, it is possible to easily control and manage the potential risks of the project and take preventive and timely measures, especially in high-risk and accident-prone zones.

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