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Guidelines for safe design and monitoring of open pit highwalls in India

The geotechnical assessment, safe design and monitoring of highwalls is one of the major challenges in Indian open pit mines. The aim of opencast mines should be to attain steepest possible slope angle without compromising safety in order to maximize profits. Highwall stability is essential for economical and safe exploitation of mineral during open pit mining. Geotechnical investigations are required to quantify the properties of soils and rocks within the mining horizons. The required minimum safety factor for highwalls is 1.2. Highwall should be monitored during open pit operations. This paper addresses the main elements of pit slope failure, accident statistics, design, and monitoring and pit slope management and also the guidelines for safe design and monitoring of open pit highwalls in India,

Keywords: Slope stability, opencast mine, numerical modelling, slope monitoring, factor of safety

1.0 Introduction

There has been a recent trend for serious injury and fatalities due to instability of highwalls in open pit mines. Accidents due to ground instability are one of the leading causes of fatalities at Indian open pit mining operations. The Directorate General of Mines Safety (DGMS) is striving to reduce the fatalities associated with slope failures and other unexpected failures of ground.

The stability analysis, design and monitoring of highwalls is not yet an integral part of the opencast mining operations during the entire life cycle of the open pit 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. The subject gets importance only when slope failure takes place putting in danger the entire mining operations or when a failure is impending. The causes and contributing factors are analyzed in relation to geotechnical knowledge, pit slope design and management. The purpose of this paper is to introduce guidelines for various warning signs of slope instability so that mine operators are better able to recognize hazards.

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2.0 Consequences of slope failures

Unexpected movement of ground causes the potential to endanger lives, demolish equipment, or destroy property. Between 1997 and 2017, 605 out of 1596 fatalities were caused by ground instability. This accounts for approximately 38% of all open pit mine fatalities (Fig.1). These figures include fatalities classified by the DGMS as "fall of overhangs," "landslide," "Fall of sides (other than overhangs)," and other DGMS accident categories, where the primary cause of the accident was unanticipated movement of the ground. This includes fatalities resulting from bench and highwall failures, rock falls, waste dump and stockpile failures, and the collapse of unknown underground workings.

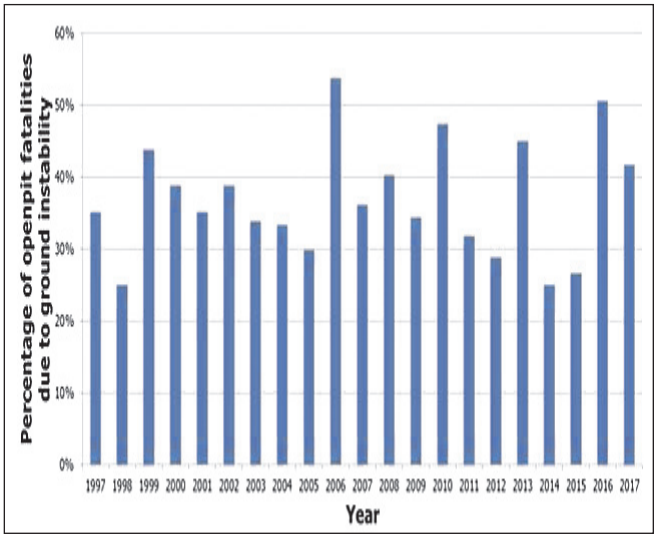


Fig.1: Percentage of open pit mine fatalities that were caused by unstable ground conditions

The fatalities occur most often at metal mines followed by coal. 482 out of 605 fatalities due to ground instability were occurred in open pit metal mines (Fig.2). The number of open pit metal mines are around 8400 where as the number of open pit coal mines are around 200. DGMS is striving for reducing the number of injuries and fatalities resulting from ground instability at open pit mines.

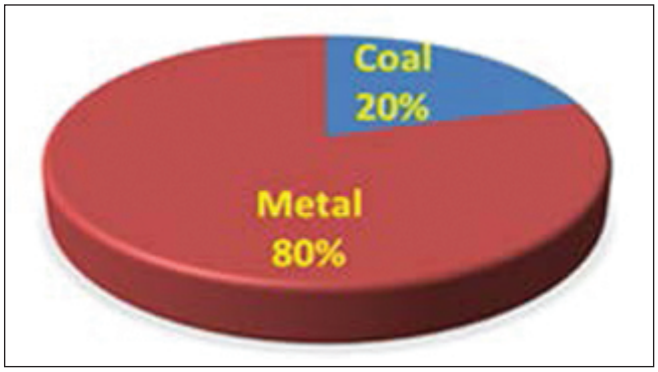


Fig.2: Per cent distribution of 605 fatalities from 1997 to 2017 at open pit operations

There are several ways to reduce hazards associated with slope failures: (1) safe scientific design of slope; (2) secondary supports, controlled blasting, depressurization or adequate drainage systems; (3) monitoring devices for adequate advance warning of impending failures; and (4) proper and sufficient scaling of loose material from highwalls. At any open pit operation, some instability can be expected – from minor bench failure to massive slope failures (Figs.3 and 4).



Fig.3: Local failure of bench at Dorli OCP-1 of SCCL

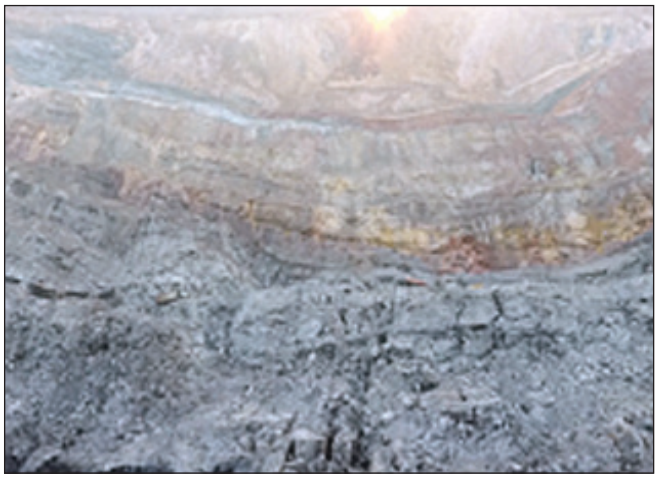

Fig.4: Massive slope failure at Juna Kunada OCP of WCL did not cause any injuries but cause closure of mine


Fig.5: Fatality and loss of equipment caused by unexpected massive slope failure at Rajmahal opencast mine of ECL

Diligent monitoring and examination of slopes for warning signs is imperative for protecting work persons and equipment. Geotechnical designs can be improved to increase factors of safety and proper bench designs can be improved to minimize slope failure hazards. However, even slopes with conservative designs may experience unexpected failure due to the presence of unknown geologic structures, improper drainage systems, or absence of monitoring. Unanticipated movement of any amount of rock may cause severe disruptions to mining operations, pose major safety concerns, or contribute to large financial losses for companies (Fig.5).

3.0 Determination of potential failure geometry

The first step in determining the basic failure mode is geotechnical mapping [1, 2, 3, and 4]. By plotting the orientation of the discontinuities and the cut face of the slope on a stereo net, potential slope stability problems can be recognized.

4.0 Recognizing hazards

Even the most carefully designed slopes may be subjected to instability. Acknowledging that slope failures may occur and knowing what the warning signs are, will contribute to the safety of the operation. Some of the more common warning signs of slope instability are:

4.1. Tension Cracks

The formation of cracks at the top of a slope is a sign of instability (Fig.6). Cracks form when slope material has moved toward the pit. Since this displacement cannot be detected from the pit floor, it is extremely important to frequently inspect crest of highwall above active areas. Safe access should be maintained at all times to the regions above active mining. Frequent inspections are necessary during premonsoon and rainy seasons and also after heavy blasts.

4.2. Vertical Displacements

These occur where rock or soil or bench has moved down in a vertical or nearly vertical fashion due to local geological

disturbances like joints, faults etc. (Fig.7). Both the rock mass that has moved vertically and the face of freshly exposed rock may be unstable and should be monitored accordingly.

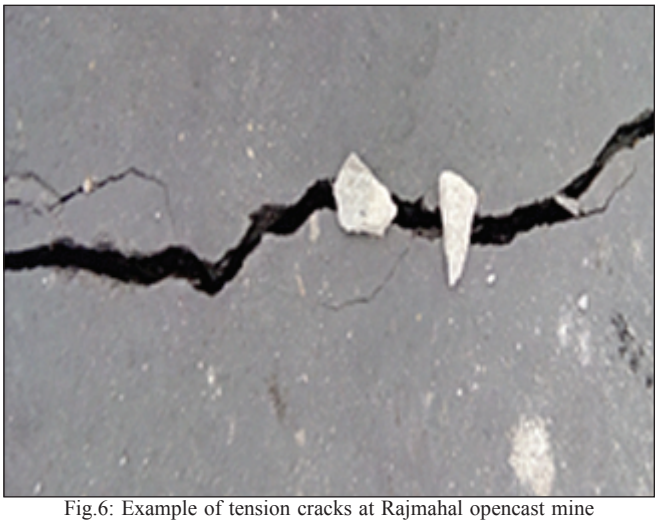


Fig.6: Example of tension cracks at Rajmahal opencast mine of ECL



Fig.7: Example of vertical displacement at Dorli OCP-1 of SCCL

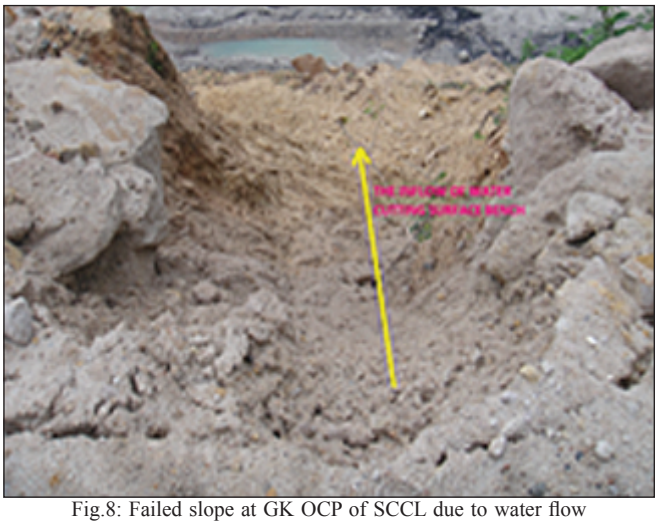


Fig.8: Failed slope at GK OCP of SCCL due to water flow

4.3. Abnormal Water flows

Sudden changes in seepage or water flow from benches may also precede slope failures. Fig.8 illustrates a saturated plane in a failing slope.

However, changes in steady flow from dewatering/ piezometric wells or unexplained changes in piezometer readings may also indicate subsurface movement that has cut through a perched water table or intersected a water bearing structure. Changes in water pressure resulting from the blockage of drain channels can also trigger slope failures. Water can also penetrate fractures and accelerate weathering processes. Freeze-thaw cycles cause expansion of water filled joints and loosen highwall material. While most mines do not have vegetation on the slope faces, movement of trees at the crest of a slope can be an indicator of instability.

4.4. Overhangs

An effort must be made to determine which portion of the slope failed, and whether more material may fail. One of the most dangerous situations that can occur is an overhang. If workers are not aware that a portion of the material below them has failed, they may unwittingly venture out onto an unsupported ledge. Remedial measures such as scaling, supporting, or blasting the overhang or other hazardous rock may be necessary.

5.0 Monitoring equipment

Because of the unpredictability of slope behaviour, real-time 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. Several new technologies like laser monitoring, imaging spectroscopy, interferometric synthetic aperture radar (SAR), and digital image change detection, slope stability radar (SSR) [5, 6, 7, 8, 9] have been evolved. A suitable slope monitoring plan should be developed, implemented and reviewed quarterly by mine management.

6.0 Data reduction and analysis

All slopes will deform in response to mining. The deformation will vary depending on the slope geometry, the geology, the rock mass properties, and the groundwater conditions. Monitoring instruments are useful for collecting a large amount of data, but knowing what data is pertinent will guide the necessary course of action.

7.0 Slope stabilization methods and pre-planned response to movement

Even with diligent planning, careful geotechnical designs, and adequate monitoring programmes, the chances for instability still exist. If the failure is in a non-critical area of the pit, the easiest response may be to leave the material in place. If the failure is in a non-critical area of the pit, the easiest response may be to leave the material in place.

To prevent small-scale failures from reaching the bottom of the pit, both the number of catch benches and the width of catch benches can be increased. Catch fences are to be used to contain falling material. If allowing the instability to fail is not an option, artificially supporting the failure by bolts, cables, mesh, and shotcrete may be a solution.

8.0 Conclusions and recommendations

Slope failures and ground instability at surface mining operations contribute to nearly 38% of open mining fatalities. The fundamental problems with investigations for pit slope design are: the designs are based on quantitative observations from a very small percentage sampling, there are always gaps in knowledge and always uncertainties. Knowing how to properly design slopes with respect to geologic structures will help minimize slope failures.

It is recommended to include scientific stability analysis, design and real-time monitoring as an integral part of the open pit mine during the planning stage itself. Carefully designed real-time monitoring programmes integrated with Safety Management Plan (SMP) are very useful for supplementing safe operational practices and to detect any instability well in advance. The new benches should always be formed, in the failed zone, by pushing back the existing pit crest from top to downwards. The fresh benches should be formed in undisturbed slope material. The toe of the failed material should not be touched before reforming the benches from top to bottom. The systematic benching from top to bottom would only provide long term safe conditions at pit bottom. The mine management should increase the mine inspections in and around the mine during premonsoon period and focus on measures taken for diverting of rain water, drainage system, abnormal flow of water, development of any tension cracks on surface, displacement of benches, etc. The ultimate highwall should be formed by controlled blasting.

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