Study of modes of failure and impact of blast-induced vibration on slope stability

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Abstract: This study was undertaken to investigate past research. Slope stability is an essential consideration for open-cast coal mines or iron ore mines because mainly drilling and blasting techniques are used for extraction purposes. A failure of an incline or slope in the functioning or working area of a mine can cause critical financial misfortunes and safety considerations. The principal failure modes fluctuate and are complex. Such components are represented by designing the topography state of the distinctive rock mass, which is quite often exceptional for each specific site. In this paper, we will examine how the blasting parameters impact the stability of the slope because of the occurrences of high-frequency vibration due to blasting. In this paper, we will compare and analyze blasting parameters based on past research studies. This paper also explains the study of the different failures occurring on the slope after completion of blasting, which impacts the stability of the slope when vibration produces a shock wave.

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Keywords: Blasting, vibration, slope, stability, impact.

1. INTRODUCTION

In mining applications, especially in surface mine tasks, impact prompted blast-induced vibrations can be urgently dangerous for both structure designs and bench slopes. The most widely recognized type of blasting harm is brought about by ground vibration. The sudden speed increase of the rock by the explosion energy following up on the drill hole creates an exceptional stress wave of transverse and longitudinal wave movements in the surrounding rock. Other development vibration influences the integrity of the surface design and potentially slope stability. Blasting vibration is believed to be the most harmful factor of all hazards arising from blasting. When an explosive explodes in the rock, the blasting seismic wave produces disturbance in the rock mass and spreads in the form of a stress wave. In the near- and middle-field of blast source where the stress wave peak is higher than the tensile strength of the rock, the blasting destroys the rock, resulting in crushed zones, fracture zones, or blasting damage; in the far-field of blasting source where the stress wave peak is lower than the tensile strength of the rock, the blasting causes elastic stress waves, seismic waves, elastic vibration of rock particles which may cause the potential damage in the rock and earth mass to develop further, thus leading to slope instability, landslides, and other damages. The intense vibration caused by blasting load is very likely to trigger landslides, avalanches, etc. Therefore, the study of blasting vibration impact on slope stability is of more practical significance.

2. REVIEW OF LITERATURE

VK SINGH (2013): Controlled blasting program was adopted in an open-pit coal or iron mine to improve the stability of the resulting cut slope.The aim was to decrease over break and minimize damage to the final pit dividers from creation impact. The utilization of pre-splitting permitted extensively higher benches to be embraced with a lot more extreme, generally slope points. The extra cost of pre-splitting was fully justified by the improved face stability and the resulting reduction in overburden quality.

HAMID REZA (2014): Drilling and blasting are important mining technologies since they are required for the initial breaking up of rock masses. The actual shattering and displacement of the rock mass consume only a small portion of the explosive energy. The remainder of the energy is used to combat negative consequences, such as ground vibration**.** Rock engineers are concerned about predicting induced ground vibration across a fractured rock mass when assigning rock slope stability in open-pit mining.

T.N. SINGH(2009): Blasting stays as an economical and reliable uncovering procedure; however, some natural shortcomings, for example, the control of blast-induced vibration. The effects of vibration over encompassing networks in a blast region have been researched for quite a long time.This study focuses on using an Artificial Neural Network (ANN) technique and Geo-mechanical boundary connections**.** The possible extent of the development of any failure to the rear of the crests increases. It should be considered so that the ground deformation at the peripheral mine area can be avoided. The general overall slope angle of 45°is deemed safe by the Directorate General of Mines Safety (DGMS).

DHANANJAI VERMA (2011): The issues concerned the slope Stability in the open cast mines has come to the forefront of the mining operations due to increasing pit depth. A comprehensive study is necessitated to ensure stable slopes. These are aided by numerical, analytical, physical, kinematic, and empirical analyses. It has involved the classification and prediction of the probable failure mode of the slope.

3. METHODOLOGY

3.1. Maine factors affecting slope stability

Slope failures of different types are affected by the following factor.

A. Slope geometry

Slope geometry is the significant factor that influences slope stability. The fundamental geometrical slope plan parameters are bench height, overall slope angle, and failure surface area. The stability of any slope decreases with increases in height and slope angle. The overall angle increases the potential for any failure to develop to the rear of the crests, and it should be considered in order to avoid ground deformation near the mine's periphery. According to the Directorate General of Mines Safety, an overall slope angle of 45° is considered safe (DGMS). The curvature of the slope has a significant impact on the instability, so convex section slopes should be avoided in slope design. The less stable the slope becomes as it becomes steeper and higher in height.

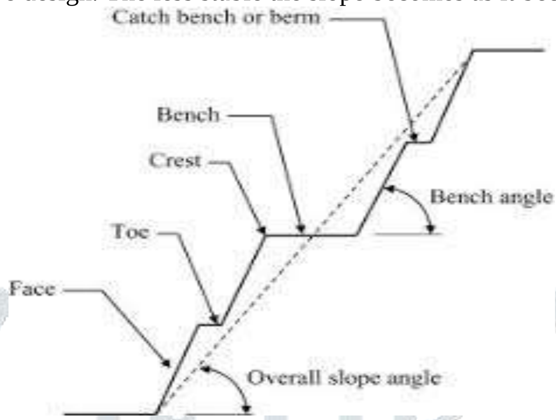

Figure 3.1: Diagram indicating bench angle, face, slope angle, toe, and crest

Source (https://www.google.com/search?q=Diagram+indicating+bench+angle,+face,+slope+angle,+toe+and+crest)

B. Rock blasting

Drilling and blasting is a ubiquitous method of excavation in open-cast mining. Blasting carried out in the mine, and dynamic load generated due to earthquake/movement of heavy earth moving reduces the stability of slopes in several ways.

- Shear stresses in the rock are increase by seismic acceleration forces
- Discontinuities are opened and weakened, and new fractures are developed
- Heavy blasting generally increases rock fall potential from benches

4.GENERAL MODES OF SLOPE FAILURE

There are four primary modes of slope failure in rock masses. These are

- Planar failure
- Rotational failure
- Wedge failure
- Toppling failure

4.1. Planar failure

In planar failure, simple plane failure is the easiest form of rock failure to analyze. It occurs when a discontinuity that runs roughly parallel to the slope face and dips at a lower angle hits the slope face, allowing the discontinuous material to slide. It is commonly controlled structurally by surface weaknesses, such as faults, joints, bedding planes, variation in shear strength between layers of bedded deposits, or the contact between the firm bedrock and overlying weathered rock.

The following conditions must be met for planar failure

- The strike of the plane of weakness must be within ± 20º of the strike of the crest of the slope.
- The toe of the failure plane must be daylight between the toe and the crest of the slope.
- The dip of the failure plane must be less than the dip of the slope face, and the internal angle of friction for the discontinuity must be less than the dip of the discontinuity.

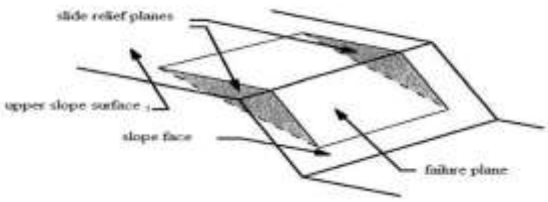

Figure 4.1 Planar failure modes

Source (https://www.google.com/search?q=Planar+failure+modes+diagram)

4.2 Rotational failure

Little-deformed slopes, which slide along the rupture surface that is curved concavely upward, are the most prevalent forms of rotational failure. Slump movement rotates, more or less, around an axis parallel to the slope. In the head area, movement may be almost wholly downward, forming a near-vertical scrap, and have a bit of apparent rotation. However, the top surface of the slide commonly tilts backward away from the pre-existing slope face, thus indicating rotation. A purely circular failure surface on a rotational failure is quite rare because, frequently, the shape of the failure surface is controlled by pre-existing discontinuities such as faults, joints, bedding, shear zones, etc.

Conditions for rotational failure:

- Rotational failures occur most frequently inhomogeneous materials, such as soil or soil-like material such as excavated overburden rock, waste dumps, fills, tailings dams, etc., and highly fractured or jointed rock slopes.
- Either circular or non-circular failure surfaces are generated.

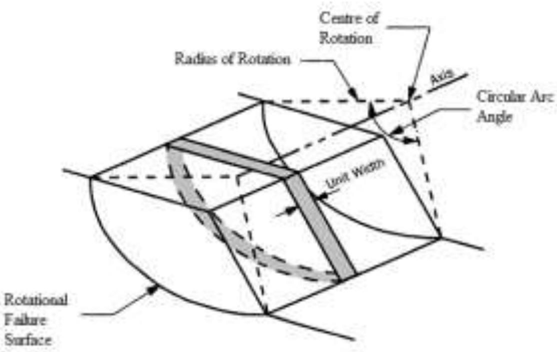

Figure 4.2 Rotational failure modes

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4.3 Wedge failure

The three-dimensional wedge failure occurs when two discontinuities intersect in such a way that the wedge material, formed by the discontinuity, can slide in a direction parallel to the line of intersection of the two discontinuities. The wedge of rock resting on these discontinuities will slide down the line of intersection provided that:

- The inclination of the line of intersection is significantly greater than the angle of internal friction along the discontinuities.
- The plunge of the line of intersection daylights between the toe and the crest of the slope.

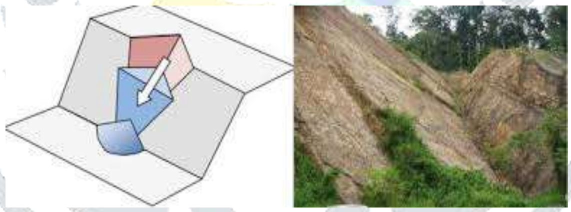

Figure 4.3 Wedge Failure Modes

Source (https://www.google.com/search?q=Wedge+Failure+Modes+diagram&oq=Wedge+Failure+Modes+diaram)

4.4 Toppling failure

When the weight vector of a block of rock lying on an inclined plane falls outside the base of the block, toppling failure occurs. Undercutting beds are prone to this type of failure. The system may collapse if they are disturbed, or this failure has been blamed for a variety of failures ranging from minor to major. When the hill slopes are v-shaped, this form of failure is more likely to occur.

Figure 4.4 Toppling failure modes

Source (https://www.google.com/search?q=+Toppling+failure+modes+diagram)

5.EFFECT OF BLAST VIBRATION ON SLOPE STABILITY

It recommends that the impact of blasting vibration on slope stability is complicated. Existing design experience shows that when the value is under 15%, it has no effect on the strength of the slope, and the value of k dynamic/k static is, for the most part, needed to be greater than 0.9. The impact of the blast produces ground shock and vibration, which may cause damage to the surrounding structure. In recent years, blasts have prompted ground shocks, and their propagation in rock mass has been drawing increasingly more consideration. The blast impact includes a change in rock conduct, having suggestions on the stability and integrity of designs.

5.1. Blast induced ground vibration

Geography and geo-mechanical parts of the rock mass influence the characteristics of ground vibration as waves move away from the blasting region. This dissipation or geometric spread happens when a finite measure of vibration energy needs to fill an expanding measure of rock mass volume as it advances toward the farthest point of detonation. The most utilized parameter to address ground vibration is the peak particle velocity (PPV). It fundamentally relies upon two principal factors: the mass of the detonated explosive charge and the distance between the detonation point and the estimating point. The most utilized is the one that relates the peak particle velocity to the "scaled distance" used to predict the impacts of ground vibration on designs and humans. The parameters that affect the characteristics are basically of two types: controllable and uncontrollable. The parameters linked to blast design are those that can be controlled. Uncontrollable parameters are properties of the rock mass that are influenced by the surrounding local geology and geo-mechanical characteristics. Some of the most important include those from USBM in 1959, Langefors-Kihlstrom in 1963, Ambraseys-Hendron in 1968, Nicholls *et al.* in 1971, Siskind *et al.* in 1980.

5.2. Types of waves produced after blasting

Generally, there are three types of seismic waves: P-wave (Primary wave), S-wave (secondary wave), and surface wave. These kinds of waves generally occur after the blasting is produced. They also generate vibration and affect the stability of the slope in open-cast mines. The nature of the vibration at any given site might be extremely complex, and many different wave types will likely be compared. The ground compresses and expands or moves back and forth, in the direction of motion, as a result of P waves. Because primary waves are the first to arrive at seismic recording sites, they are primary waves. Solids, liquids, and even gases can carry P waves. The earth is shaken by S waves in a shearing, or crosswise, an action perpendicular to the travel direction. These are the swaying waves that cause the ground to move up and down or side to side. Because S waves always arrive after P waves at seismic recording stations, they are secondary waves. S waves can only go through solid materials, unlike P waves. Surface waves travel along the earth's surface after both P and S waves have passed through the planet's body. Only solid.

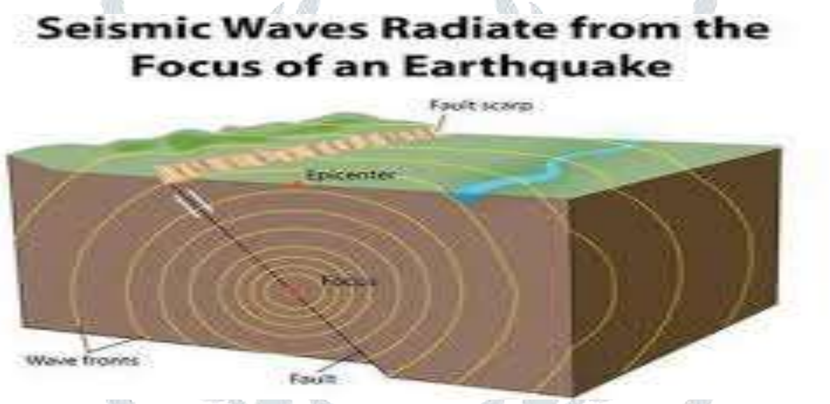

Figure 5.2: - Seismic wave
Source (https://www.google.com/search?q=Seismic+wave+diagram)

5.3. Propagation of wave in large-scale bedding rockslide

Large-scale landslides, a typical geological danger, can be easily initiated by natural influencing factors such as tectonic activity or excessive precipitation during flood season, but anthropological blasting operations are extremely difficult to provoke directly.To look into the effects of a blasting wave on the state of a multi-layer interface to evaluate the accuracy of the analytical model and the deteriorating features of the weak interlayer, a comprehensive examination of P wave propagation in the filling joints was carried out. When P waves propagate from the basalt through the interlayer, the results show that a tensile reflection wave can arise. A theoretical equation for assessing the damage of soft rock interlayer is proposed, which may be used to calculate the increased stress of soft rock mass during blasting. The material density is discovered to be the most important determinant in attenuation rate. Furthermore, the longitudinal wave velocity of materials and the time of incident waves have the same influence on the attestation.

5.4. Propagationof blast vibration on slope during the shift from an open pit to underground mining

Surface mining of mineral resources continues to raise and steepen open pit slopes, potentially causing instability. Furthermore, once near-surface mineral deposits are depleted, surface mining becomes more expensive. Underground mining is obviously a viable option for ensuring mining safety and efficiency. Blast-induced seismic waves, on the other hand, propagate through open-pit slopes during the shift from open pit to subterranean mining. This type of disturbance is frequently the catalyst for the instability of high and steep open pit slopes. It is critical to examine the effects of blasting vibration on the slope and understand the propagation and attenuation of blasting vibration in rock slopes in order to effectively analyze the seismic effect of underground mining on open pit slopes and control the possible risk of instability.

6. REVIEW OF EFFECT OF BLAST-INDUCED VIBRATION ON STABILITY OF SLOPES

In the study, it is determined and observed that blast-induced vibration is highly dependent on vibration frequency, the frequency characteristics, and at the point when millisecond delay blasting is utilized in excavation, a worldwide frequency value of the entirety of the delays of vibrations neglects to introduce an actual image of the vibration characteristic. A limited scale blasting test and the connected mathematical simulation were subsequently to demonstrate this conviction. It is tracked down that the vibration recurrence from the openings in the free-face blast is higher than that in the confined blast.The vibration of breaking blast is less destructive than that of cutting impacts for a specific PPV.Empirical models were likewise utilized for predicting blast incited ground vibration for comparison with the Sadovsky model. Blast plan parameters for a most extreme charge per delay and distance were considered input parameters to predict blast impact-initiated vibration.The correlation of damage actuated by smooth blasting and pre-split blasting is dependent on the uncovering of high rock slopes. The final harm of rock slope is essentially prompted by pre-split blasting itself; the result shows that pre-split blasting high impact on the slope than smooth blasting. A thorough investigation of P wave propagation in filling joints was conducted. When P waves travel through the interlayer from the blast, a tensile reflection wave can occur, according to the findings. It is proposed a theoretical equation for calculating the damage to soft rock interlayer.

Excavation engineering or explosive blasting can impact local collapses or small-scale earth slides on slopes; it is widely acknowledged in valleys, however generating large-scale landslides involving millions of cubic meters of sliding mass is difficult. The shaking effect of production blasting, for instance, is minor when compared to tectonic activity's seismic consequences.

For many years, researchers have been concentrating their attention on two aspects of the dynamic response of open-pit slopes under the impact of seismic waves caused by blasting activities. The first is to use an instrumental monitoring approach to analyze the vibration velocity of mass particles in far-fields. Another option is to use the pseudo-static approach to assess slope stability. However, it has been discovered that earlier research was unable to adequately describe the complex behaviors and failure mechanisms of rock slopes subjected to dynamic stresses caused by blasting operations.

7. RESULTS AND CONCLUSION

In general, understanding how blast-induced vibration affects slope stability is essential. The seismic waves produced two types of waves: body waves and surface waves. By contrasting the two forms of seismograph comparison with respect to the advanced methodology of the conventional method, the data evaluation is not solely based on peak particle velocity, as for the traditional way. Seismic waveforms, their frequency content, and time duration are accounted for. It is the analysis that the seismic wave result indicates if the blast-induced acceleration of vibration converted into the earthquake sharply amplified at the top of the slope. The result shows that instantaneous tension stress causes tension cracks and, therefore, a reduction in tensile strength at the top of the slope.

- It is observed in a comparison of blast-induced vibration have a most relevant effect on the slope by the seismic wave produced by effectively surface wave method.
- In another parameter blast-induced vibration, comparison the between pre-split blasting method and smooth blasting method it is observed that pre-split blasting method is considered as high impact on the slope.
- A PPV prediction model suitable for open-pit slopes subjected to underground mining is built by theoretical research, considering mining depth and the elevation difference between the explosion source and monitoring site.

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