Effect of Blast Vibrations on Dump Slope Stability in Opencast Coal Mines

Sathish Kumar Mittapally[1], E. Srinivas[1](✉), I. Satyanarayana[2], and K. Purushotham[3]

[1] Department of Mining Engineering, University College of Engineering, Osmania University, Telangana, India
e.srinub4u@gmail.com
[2] DGMS, Bangalore, India
[3] Department of Mining Engineering, Government Polytechnic, Bellampally, Telangana, India

Abstract. Mining activities are synonymous with the standard of life as well as the state of any nation. It results in both economic and uneconomic materials being generated. The uneconomic materials (wastes) are stacked at different places known as waste dumps. The stability of these dumps has been a major concern over the years. The problem becomes increasingly difficult with the reduced availability of land areas for dumping. The mechanized opencast mining methods have been extensively adopted by Indian mines to meet the increasing demand of coal which results into major disposal problem of large volume of waste material generated from mining operations in open -pit mines. The stability of dump slopes is influenced by a multiple of factors, including blasting vibrations. This research aims to analyze the impact of blast vibration on dump slopes through field investigations and parametric study by using numerical modeling, utilizing the Flacslope software. Our findings indicate that, no explicit dump failures were observed in the study area, an increase in peak particle velocity leads to a reduction in the slope's Factor of Safety, as evidenced by our parametric study.

Keywords: Blast vibrations · Dump stability · Monitoring · Opencast Mines · Waste material

1 Introduction

In India the total coal production in the year 2020–2021 is about 716.08 million tonnes and 778.19 million tonnes in the next year 2021–2022 with an positive growth of 8.67% [4]. As opencast mines continue to grow in size, the associated Stripping Ratio also increases, resulting in a substantial increase in the volume of overburden removal required. The global demand for energy continues to grow at a very high rate, driven by demand from both developed and developing countries. Coal has major role to play in meeting this demand and it must be ensured that it is available continuously but remains competitive with other energy sources. The increase demand of coal production in India can only be achieved through the mechanized surface method of mining. Now-a-days coal reserves from shallow depths are going to exhaust and surface coal mining has to

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 1298–1306, 2023.
https://doi.org/10.2991/978-94-6463-252-1_130

go deeper and deeper. At present there is a huge gap between supply and demand of coal to meet the energy needs of the country. The dominance of coal is likely to continue in the foreseeable future. The production from Open Cast Mining has seen unprecedented growth whereas Under Ground production remained stagnant at the same level during the last decade. This indicates that large number of opencast coal mines are going to start in the future years. Opencast coal mines will be increased to many folds. The advent of large earthmoving equipment has resulted in a tremendous increase in open pit coal mining at low cost. The increasing demand for coal, opencast coal mines are being planned to go to depths and sizes that never considered before. There has been a great need to substantially increase the coal production in the coming decade to meet our growing economy. In this decade few destabilizations of internal dumps have taken place in coal mines. It is necessary to study such cases and find out the cause of destabilization. Figure 1 show the dump slope failure occurred at Rajmahol OCP, ECL, CIL in 2016 that took almost 40 lives. Table 1 provides the details of dump slope failure accidents that occurred in las 5 decades. This study aims to evaluate the impact of blast vibrations and blast vibration acceleration on dump slopes through a combination of field investigations and analysis. The Factor of Safety of dump slopes is assessed using the Flacslope software, and a parametric study is conducted to examine the effects of peak particle velocity (PPV) in blast vibration. Kainthola [1] utilized the shear strength reduction technique in conjunction with a two-dimensional finite element code to assess the failure condition of the slopes and to determine a target factor of safety. The findings suggest that a sustainable and stable angle and height of the dump could be achieved, thereby ensuring smooth and safe disposal. In a related investigation, Haiwang Ye and Wen Li [3] conducted a stability analysis of the Malugou dump that has been subjected to constant blasting from a nearby mine. The authors employed geo-studio software to evaluate the impact of blasting on the stability of the dump. The results of the analysis indicate that the blasting activities did not adversely affect the stability of the dump. Moreover, Schmidt [2] conducted a slope stability analysis based on the generalized Hoek-Brown failure criterion using Phase 2 software in two case studies: the Barite mine and a coal mine located in western Turkey. The findings of this study suggest that the approach used by Schmidt is an effective means of assessing the stability of slope systems.

2 Field Investigations

The dump slope of a Mine 'X' is selected as the study area in the research and rock core samples are collected sufficient enough for lab testing to find the properties of the dump slope. Figure 2 displays the collection of samples at the mine site.

From the results of lab testing, it is observed that the dump material having density in the range of 1756 to 2106 kg/m^3. Cohesion in the range of 25.4 kPa to 37.0 kPa and friction angle in the range of 26.5° to 31.5°. Floor is found to be having highest value of internal friction angle ad 31.5°. The cohesion of deck-3 is found to be 25.4 kPa but, the cohesion for floor is found to be 37.0 kPa. Presently maximum height of the dump at mine 'X' was about 100 m and the mine authorities are implementing an effective drainage system. Considering the fully drained conditions, the final properties of dump material at mine 'X' are summarized in Table 2 given below.

Table 1. Details of dump slope failure accidents that occurred in last 5 decades (Satyanarayana, 2019) [5]

Year	Incident	Lives Lost
1963	Italy, Vaiont Land Slide. The slide inundated a reservoir sending a wave over the crest of the dam that destroyed five villages.	2000
1998	Italian, Devastating mudslides destroyed parts of two villages	100
2000	Kawadi Opencast coal mine WCL due to slope failure of 31 m high over burden bench	10
2006	Tollem Iron Ore Mine, due to dump slope failure of 30 to 46 m high Dump bench in the mine.	6
2008	Jayant Colliery, NCL, Dump failure (dragline dump)	5
2009	Sasty Opencast, WCL, Dump failure due to height of 73 m dump failed and slided	2
2016	Rajmohal Opencast, ECL, Dump Slope Failure due in-stability of dump slide	40 (approx.)

Fig. 1. Dump slope failure at Rajmahol OCP, ECL, CIL, 2016

3 Experimentation Works

The details of drilling and blasting at the study area of one of the blasts are given in Table 2 & 3. The overburden blast was initiated by NONEL and coal blasts were initiated by detonating fuse. Blast vibrations data is recorded by installation of the Minimate on dumps. The sequence of firing blast holes with nonel is shown in the Fig. 3.

The blast is conducted in two location of the study area, Bottom bench (White medium hard sandstone) and Top bench (Soft brown sandstone mixed with sandy soil). The details of the blasting conducted in bottom and top bench is provided in the Table 4. To measure the vibration caused by the blasting a seismometer (Minemate) is installed at a location which is 40 m away from the blasting site. The details of vibration monitoring

Fig. 2. Sample collection at study area

Table 2. Dump slope properties obtained from laboratory tests

Sample	Sample Density (kg/m^3)	Cohesion (kPa)	Friction Angle, (Degree)
Floor	2106	37.0	31.5
Deck-1	1869	27.5	29.4
Deck-2	1756	26.8	28.8
Deck-3	1895	25.4	26.5

in bottom and top bench is provided in the Table 5. The maximum vibration recorded was 2.22 mm/sec. With dominant frequency of 30 Hz. The total explosive used in blast was 5319 kg and charge per delay was 120 kg. In other blast, the maximum vibration recorded was 5.14 mm/s. With dominants frequency of 13 Hz.

4 Analysis of Factor of Safety Using Numerical Modelling

Parametric studies were conducted through numerical models using “Slope Stability Analysis Software” (FLACSLOPE V 7.0) based on limit equilibrium method to study the effect of coefficient of blast acceleration (α) on dump slope stability at Mine ‘X’. The stability analysis was conducted considering circular failure surface passing through

Table 3. Details of drilling pattern at the study area

Bench Location	Depth (m)	Spacing x Burden (m)
Medium hard Sand Stone (steep gradient)	6.0 (1–2 rows)	5 x 4
	5.0 (3rd row)	5 x 4
	4.0 (4th row)	4 x 4
	3.0 (5th row)	4 x 3
Medium hard Sand Stone (Normal gradient)	6.0 (1–2 rows)	6 x 5
	6.0	6 x 5
	3.0–5.0	5 x 4.5
Coal	3.0–6.0	5 x 4
	<3.0	4 x 3

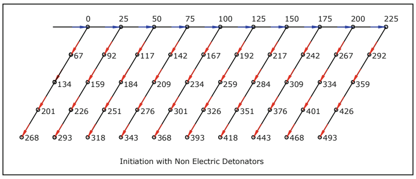

Fig. 3. Sequence of firing blast holes with nonel at the study area

Table 4. Details blasting conducted in bottom and top bench

Bench Location	Bottom bench (White medium hard sandstone)	(Top bench) Soft brown sandstone mixed with sandy soil
No. of Holes	99	255
Average Depth	5.6 m	5.2 m
Hole Diameter	150 mm	150 mm
Length x Width of patch	–	240 x 50 m
Spacing x Burden	6 m x 5 m	6 m x 5 m
Explosive Used	SME-5319 kg, Booster-9.9 kg	SME-11625.5 kg, Booster-25.5 kg
Average charge/hole	53.7 kg	45 kg
Maximum charge/delay	120 kg	100 kg

the ultimate slope. Bishop's method of multiple analyses was used for circular failure conditions. The heights of dump slopes were considered at 30 m, the slope model was constructed for stability analysis to investigate blasting effect. Fully drained conditions of the dump slopes have been considered presuming that effective drainage measures under

Table 5. Details of vibration monitoring in bottom and top bench

Location of Minimate	Distance (m)	PPV (mm/sec)	Dominant Frequency (Hz)
Bottom bench	1230 m horizontal 40 m vertical	2.22	30
Top bench	200 m horizontal 50 m vertical	5.14	13

implementation by the mine management. The input parameters for stability analysis i.e. unit weight (Ɣ), cohesion (c) and angle of internal friction (Φ) were considered for input parameters for stability analysis. The coefficient of blast acceleration (α) values considered for this study ranges from 0 to 0.45g. Some models developed by "Slope Stability Analysis Software" (FLACLOPE v 7.0) with varying coefficient of blast acceleration (α) are given below Figs. 4, 5, 6, 7, and 8.

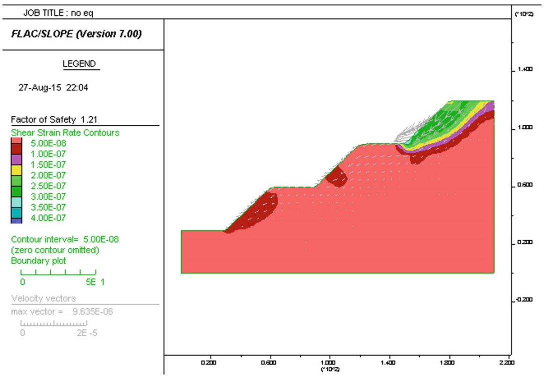

Fig. 4. Stability analysis of dump slope with coefficient of blast acceleration (α) = 0g

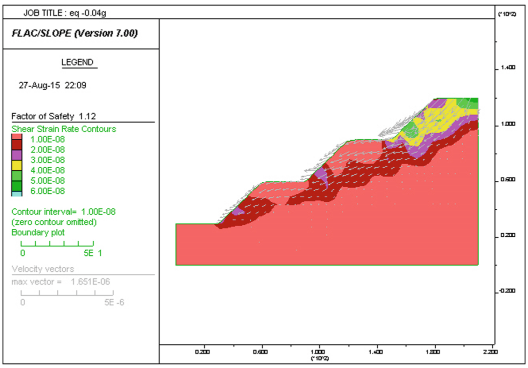

Fig. 5. Stability analysis of dump slope with coefficient of blast acceleration (α) = 0.04g

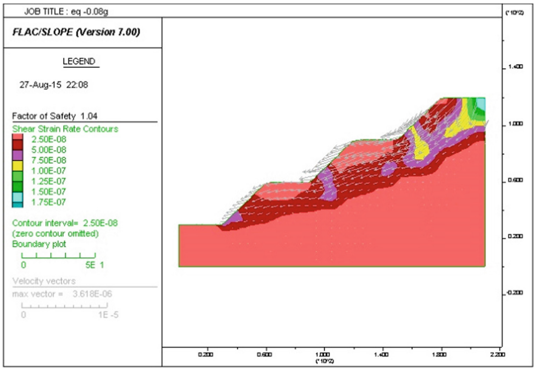

Fig. 6. Stability analysis of dump slope with coefficient of blast acceleration (α) = 0.08g

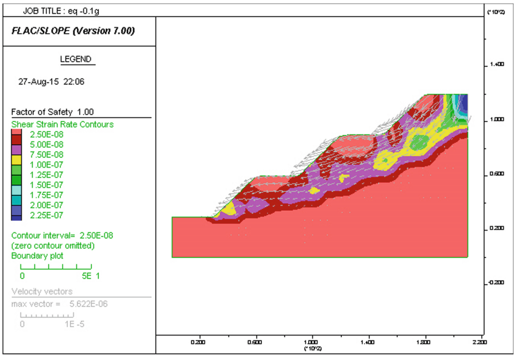

Fig. 7. Stability analysis of dump slope with coefficient of blast acceleration (α) = 0.10g

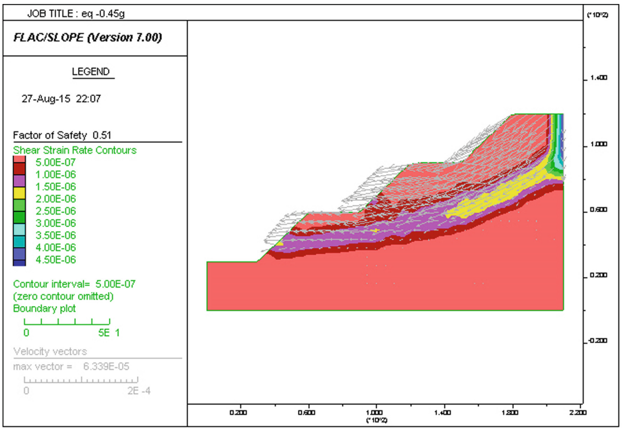

Fig. 8. Stability analysis of dump slope with coefficient of blast acceleration (α) = 0.45g

Table 6. Parametric study results of dump slope stability

Sl. No	Blast Acceleration (a) (in terms of g)	Factor of safety (FOS)
1	0	1.21
2	0.04	1.12
3	0.08	1.04
4	0.1	1.00
5	0.45	0.51

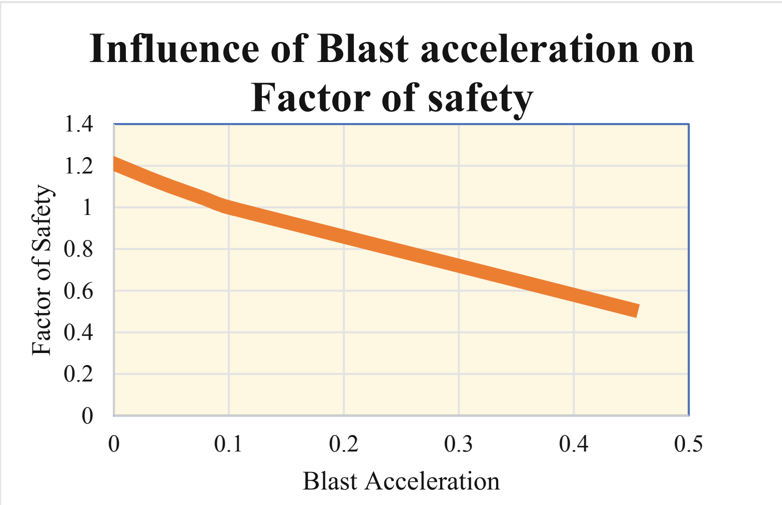

Fig. 9. Graph showing variation in FOS with increasing blast acceleration.

The results of software study are shown in the Table 6 and the variation in factor of safety with change in blast acceleration is shown graphically in Fig. 9. The analysis of slope stability has indicated fairly stable condition for the slopes with factor of safety ranging between 0.51 and 1.21 when the blast acceleration was 0 to 0.45 g. It may be concluded from Fig. 9 that factor of safety of slope decreases with increasing blast acceleration.

5 Conclusion and Recommendations

At mine 'X' monitored for a considerable duration, however, no explicit dump failure was noticed in this mine. Further it may trigger dump slope failure when it was at the verge of failure. Based on the experimentations, results and discussions the following secondary conclusions and precautionary measures are suggested.

- During blasting, attention should be given to induced vibration that to especially minimum displacement in dumps and in the high dominant frequency range.
- From the results of production blast monitoring, the highest vibration amplitude originates from the blast holes closest to the dump slope. Decrease charge weight along the two lines of blast holes closest to the dump slopes will reduce damage to dumps. This should be co-coordinated with similar reduction in spacing to maintain same fragmentation.
- With increasing PPV displacement will be taken place in a dump which ultimately reduces FOS, sometimes it has been observed that higher PPV act as triggering factor for failure of circular dump slopes. Hence see that maintain always low PPV values in every blast.

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