Dump Susceptibility Analysis Under Earthquake Conditions Using Numerical Modelling

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Abstract. The majority of coal mines in India use open-cast mining method to extract coal. The amount of overburden produced by the mine is increased as a result of the increased working depth and higher stripping ratio. Land scarcity is the major problem of the overburden management with stability in the mine area. Optimizing the dump geometry is an alternative way of overburden management in the mine area with stability. This investigation addresses the effect of seismic loading on the dump with the different geometric configurations. This study used the finite difference method-based numerical solver (FLAC2D software). The numerical model results show that the dump is stable under static conditions. The investigation results show that the dump slope toe is sensitive to dynamic conditions. This investigation results will be helpful for the identification of susceptible zone in the dump slope. And based on this investigation results can make decisions for real-time slope monitoring sensor installation in the critical zone.

Keywords: Mine dump · Numerical modelling · Factor of safety · Seismic loading · Dump susceptibility

1 Introduction

As a result of increasing coal production, a large volume of overburden material is generated from the open-cast mines, forming a huge overburden dump inside and outside the mine land. The limited leasehold area availability is a major issue for the overburden management with stability. Without slope stability analysis, dump construction may be a reason for failure, so the scientific dump parametric study is significant for dump stability [1]. The main reason of slope failures is unplanned dumping, heavy rainfall, and earthquake conditions [2]. Numerous studies have identified associations between surface geometry, local geology, increased dynamic wave propagation, and landslide incidence [3]. Therefore, this study includes the dynamic load on dump slope stability analysis.

In the past, many mine slope failure accidents have occurred. Resulting in the loss of human life and machinery. And it also hampered production operations [4]. So, the mine slope stability is essential for miners and machine safety. In this investigation, the

B. Raj et al. (Eds.): ICETE 2023, AER 223, pp. 1247–1255, 2023.
https://doi.org/10.2991/978-94-6463-252-1_125

impacts of the earthquake were analysed on the mine dump. This investigation is based on 2D modelling of ground motions using the finite difference approach.

Many researchers use a pseudo-static condition for slope stability analysis [5, 6]. This approach is based on the limit equilibrium method (LEM) and evaluates the slope factor of safety with the horizontal loading condition (k_h = horizontal seismic coefficient). This study determines the slope factor of safety only, which is the limitation of this study. Therefore, researchers used robust numerical modelling tools for displacement analysis [7]. The effect of the earthquake on the dump slope stability was analyzed by Koner [6, 8]. Internal dump displacement was analyzed under the seismological condition [5]. Hence, this study uses FLAC^{2D} software for the dump slope stability estimation with dynamic loading.

Geotechnical engineers utilize the slope factor of safety to measure slope stability using LEM. The LEM is widely used for soil and rock slope stability analysis. Due to some limitations of LEM, researchers use numerical modelling tools for slope stability analysis. Engineers must grasp the benefits of numerical modelling approaches due to the wide range of numerical applications accessible nowadays. However, with the help of recent significant advancements in computing facilities, geotechnical engineers, with low-cost implications, have found the finite difference method (FDM) as a powerful tool and valuable technique as a viable alternative for all pre-field applications [6]. This method is robust for solving complex geometry problems.

This study has been done in two parts. The first part identifies the optimum dump geometry parameters of the stable dump. Analyzing the effect of seismic vibration on the dump slope is the second part of the present investigation.

2 Material and Methodology

This study involves continuum numerical modelling for the dump stability assessment. Dump parametric studies are numerically simulated using FLAC^{2D} software. Implementing the shear strength reduction (SSR) method in the FDM for the dump stability analysis. In the study, all numerical models are solved under gravitational loading. Dump optimum configuration identification, this study focused on the dumping approach, single, double, and triple-stage dumping. Each bench height is 30 m, the bench slope angle varies from 25° to 41°, and the bench width is 30 m. For the dump slope susceptible zone analysis, we input the dynamic loading in the numerical modelling. This investigation focuses on the dump geometry parameters, which have probably caused the failure. Figure 1 presents the study flow chart.

2.1 Boundary Conditions

In the numerical modelling, we are creating an artificial boundary condition for the model stability analysis. Static and dynamic loading boundary conditions are different because these depend on the applying loads. Slope factor of safety analysis, we use mechanical boundary conditions. Dump model bottom surface fixed in x and y direction velocity using the fixed command and dump both side x-direction movement control by roller boundary condition as seen in Fig. 2(a).

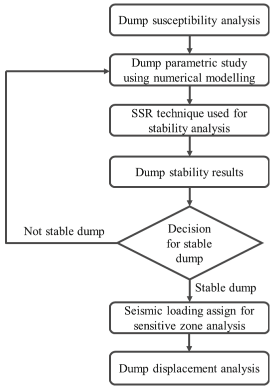

Fig. 1. Work methodology flow chart.

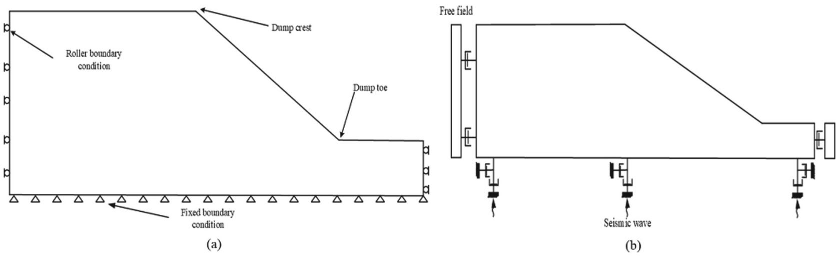

Fig. 2. The boundary condition of a numerical model (a) for static condition (b) for dynamic condition.

For dump model displacement analysis under dynamic loading, we are using a free field condition and applying it by ff command. This boundary condition controls the unwanted seismic wave reflection on both sides of a dump. Figure 2(b) illustrates the dynamic loading boundary condition.

2.2 Dump Material Property and Dump Parameters

Dump material properties are taken from the previously published literature. Table 1 illustrates the material properties [9]. In this investigation, we are using multiple-steeping dump models, as seen in Table 2. Each bench height is 30 m, an overall dump height is 90 m is taken for the parametric study, and two benches between bench width are taken equal to bench height (30 m). Figure 3 is shown the dump schematic diagram.

2.3 Dump Stability Analysis

The analysis of a slope is based on the computation of a safety factor. A safety analysis in FLAC^{2D} may be done by decreasing the strength characteristics of the dump material (cohesion and friction angle). This process is called the shear strength reduction (SSR) technique. In this technique, the dump material strength parameters (c and ϕ) decrease

Table 1. Mine overburden material property.

S. no.	Property	Value
1.	Density (kg/m^3)	2300
2.	Cohesion (kPa)	50
3.	Friction angle (°)	30

Table 2. Combination of dump geometry parameters used for stability analysis.

S. no.	Stepping of dump	Slope angle (°)	Safety width (m)	Height (m)
1.	Single stage	25 to 41	20	30
2.	Double stage	25 to 41	30	60
3.	Triple stage	25 to 41	30	90

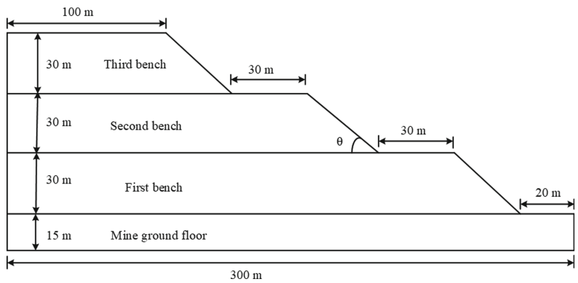

Fig. 3. Schematic diagram of dump parametric study.

until the slope collapses. Thus, the strength parameters of dump material are decreased automatically and incrementally. The following equations are used in the factor of safety analysis.

$$c^{trial} = \frac{c}{F^{trial}} \tag{1}$$

$$\phi^{trial} = arctan\left(\frac{\tan\phi}{F^{trial}}\right) \tag{2}$$

The numerical modelling tool is very robust for slope stability analysis. In this modelling, we are using rectangular and square shape meshing for the numerical models. The mesh size ratio is 1:1 for each zone except the slope surface region.

3 Results and Discussion

Initially, the stability of the slope is examined under the assumption of homogeneity within each bench composing the slope, the geotechnical parameters are obtained from Table 1, and numerical simulations are used to assess the dump slope factor of

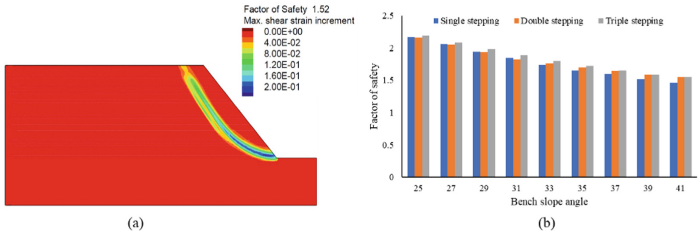

Fig. 4. Dump stability analysis results (a) Numerical model with FOS and (b) FOS variation with bench stepping.

safety. Before the model solving, we apply a gravitational loading condition. Under static conditions, the slope is stable, as seen in Fig. 4(a). For slope profiles shown in Fig. 4(a), this failure surface appears circular. The obtained safety factor is above 1.4 for all numerical models. The results of the static condition indicate that the dump will be stable. All numerical model results are shown in Fig. 4(b). For the stable dump, the multiple-stepping construction method is favorable for the open-cast industry.

3.1 Dump Susceptible Analysis

It is essential to study the role of earthquakes in slope behavior analysis. Such as the behavior of the dump mass during and after seismic loading. A 2D cross-section of the dump was used for numerical simulations. This numerical research did not include any studies of the impacts of ground failure/settlement. The slope displacement is measured in this study for the ground motion condition, as seen in Fig. 5(b). The EL earthquake acceleration history data was used for slope displacement prediction.

The reason for dump failure would be rainfall and seismic activities. This study focuses on dump slope stability analysis under seismic loading. The stability of dumps for the different dynamic periods (1 to 10 s) was analysed with input ground motion conditions. The analysis used the El Centro time history recorded at 117 (USGS) station during the Imperial Valley earthquake (Fig. 5(a)). The study considered the one acceleration time history of the 1941 Imperial Valley earthquake. Incrementally, the model applied the acceleration time histories to all nodes along the bottom boundary of the finite difference models. The low-frequency components of an earthquake motion generally dominate the displacement response in the dump slope.

This research studied the influence of dynamic loading on dump slope displacements. In this investigation, the dump slope toe region in maximum displacement is found. For the single bench stepping, we observed that dump slope toe in maximum displacement. Figure 5(b) presents the displacement history results for the dump crest points. The results indicate that the dump bench toe is susceptible to dynamic loading. The dump slope displacement depends on the dynamic loading time. Figure 5(b) is shown the first bench crest point in maximum displacement found compared to the second and third bench crest points for the stable dump design parameters.

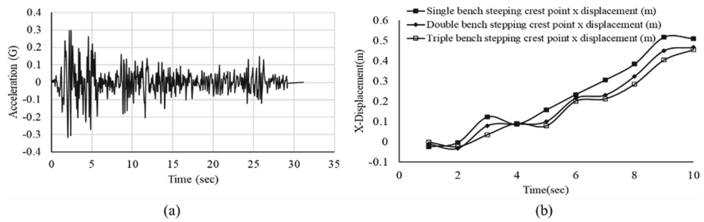

Fig. 5. (a) EL Centro earthquake history data, and (b) Dump slope crest x—displacement.

3.2 Along the Dump Slope Surface Susceptibility Analysis

Case-I When dump height is 30 m and slope angle 39° (single stepping dump).

The plots of x-displacement for the 10 s time are shown in Figs. 6, 7, and 8 for the single, double, and triple stages of dumping. For single-stage dumping, the maximum values for displacement are observed to be 0.57 m for 10 s, respectively, for the monitoring points mentioned in Fig. 6.

Case-II When dump height is 60 m and slope angle 39° (double stepping dump).

For the double-stage dumping, the maximum value for displacement is observed to be 0.53 m for 10 s, respectively, for the monitoring points mentioned in Fig. 7.

Case-III When dump height is 90 m and slope angle 39° (triple stepping dump).

For the triple-stage dumping, the maximum value for displacement is observed to be 0.52 m for 10 s, respectively, for the monitoring points mentioned in Fig. 8.

Dump slope stability is a challenging issue for the mining industry. Before dump construction, dump parametric scientific study is essential for dump stable dump construction in the mine area. The external force triggers the dump slope for failure. Therefore, dynamic loading has included in this study. This study methodology can use in the application of high-way rock slopes, tailing embankment slopes, and mine slopes for stability and susceptible analysis.

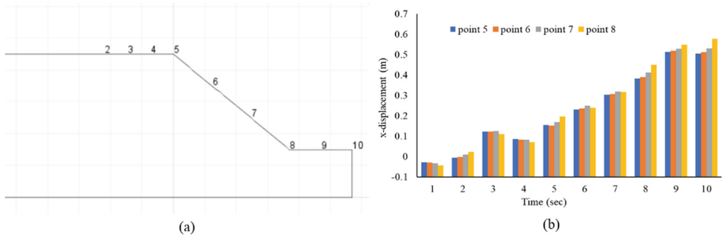

Fig. 6. Dump slope x-displacement with dynamic loading for 30 m bench height.

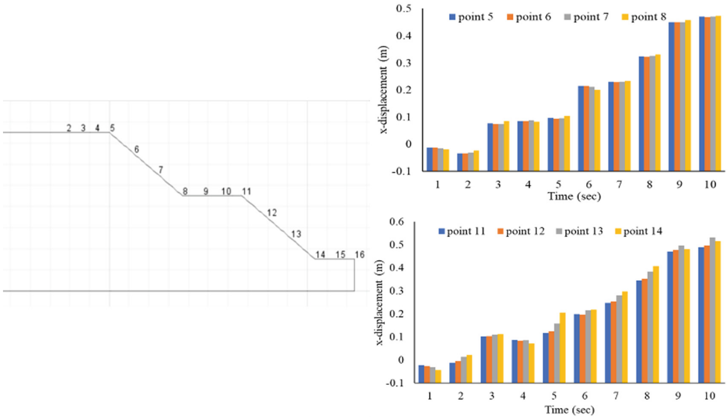

Fig. 7. Dump slope x-displacement with dynamic loading for 60 m bench height.

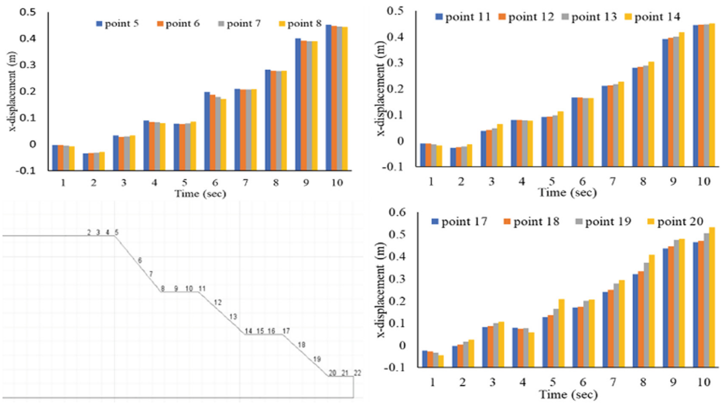

Fig. 8. Dump slope x-displacement with dynamic loading for 90 m bench height.

4 Conclusion

The mine dump failure occurs under an earthquake, and displacement of the slope depends on the dynamic loading time. The numerical simulations of the dynamic analysis gave promising results for the dump. The dump design parameters are an effective way to stable dump construction. The circular failure surface was observed in the dump slope. Dump loose material is very sensitive to dynamic activity, and loose material slope toe in maximum displacement found. The dump slope toe and above-toe area are very susceptible. The main conclusion of the numerical simulation results is shown below.

- The dumping pattern affects the stability and performance of overburden dumps. Triple-stage dumping has a higher safety factor than single-stage and double-stage dumping. Triple-stage dumping is feasible for dump construction without compromising stability because the overall slope angle decreases in triple-stage dumping.

- Due to the dynamic loading, maximum displacement was observed in the dump slope toe point compared to the crest point.
- The duration of dynamic loading will have an adverse impact on the dump slope stability because the slope displacement is time-dependent.
- The dump slope toe and toe above region is very susceptible under dynamic loading for the loose material slope.

Acknowledgment. The author would like to sincerely thank the Coal India R&D Board for providing the necessary funding (Grant no. CIL (21)/2021–2022/854/ME) for this research work.

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