Influence of Underground Workings and Dump Height on the Stability of Overburden Dumps

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Abstract
Coal is extracted using both underground and opencast methods of working. During the coal extraction process, opencast mining produces a significant amount of overburden. In opencast mines, the removed overburden material is dumped at significant heights to reduce ground coverage. But overburden dumps with great heights are at risk and sometimes lead to failure of dumps causing loss of men and machinery. Stability issues will become more complicated when the overburden is dumped above the old underground workings. Complication arises because of redistribution of pre-existing stresses from underground activities affecting the overburden dumps. This study uses a two-dimensional finite element (FE) analysis program to understand the stability analysis of overburden dumps above old underground workings. The factor of safety (FoS) is determined using the strength reduction technique which highlights the impact of underground excavations on overburden dump stability by highlighting the required strength reduction factor (SRF).

In order to analyse the overburden dumps with the presence and absence of old underground workings, numerical models were created for various dump heights. The overburden dumps with underground workings exhibited SRF values ranging from 1.78 to 2.05, while the dumps without underground workings had SRF values ranging from 1.81 to 2.55. The displacement of the overburden dump material, which results in 7 mm of horizontal displacement and 29 mm of vertical displacement, indicates a significant impact of underground workings on the stability of the overburden dumps. This study highlights the importance of considering underground workings in the design and management of overburden dumps to ensure safety and stability.

Keywords: Opencast mining, underground workings overburden dump, numerical modelling, stability analysis.

Introduction

Coal mining plays a significant role in global energy production and is the primary source for generating electricity, steel production and numerous other applications. India's coal production reached a record 997.4 million tonnes in fiscal year 2024 (FY24), reflecting 11.67% rise compared to the previous year. The coal ministry reported that in FY23, the production was 893.19 million tonnes[19]. Coal consumption is increasing day by day, due to the growing demands of various industries. Two methods of coal extraction are opencast and underground methods of working, generating substantial waste in the form of overburden material, especially in open-cast mining. The amount of overburden produced by different coal mining industries is illustrated in figure 1[20]. The composition of the overburden primarily includes shale, gravel, sandstone and loose sand in various sizes, ranging from boulder to clay size[23].

The generated overburden is deposited either as backfill within the mine or as external dumps outside the mine, as shown in figure 2[15]. The large volumes of overburden create expansive, loose dumps with significant mass[21,24,27]. With increased coal production and deeper mining, managing the large volumes of overburden dumps becomes challenging[9]. The rapid accumulation of overburden has led to taller dumps on limited ground cover, raising the risk of failures. The physico-mechanical properties of these dumps differ from the original material[8, 29].

Stability of coal mine overburden dumps is crucial in opencast mining. Assessing dump slope stability is essential to ensure safety and cost-efficiency. Key factors influencing dump slope stability include material properties, geometric configurations and external forces like seismic loading[3]. Large direct shear test apparatus have been developed to determine the shear strength of heterogeneous dump materials[9]. Comparative studies using software like slide, geoslope and phase 2 are used to calculate factor of safety (FoS) of dumps[28], optimizing dump design for long-term stability. Internal dumps help to reduce land usage, a critical need given the shortage of land due to population growth, forest cover and other challenges.

The Indian mining industry is increasingly concerned about slope failures in coal mines which have caused fatalities and equipment damage. Understanding the factors contributing to dump failures is crucial. Waste dump stability is generally analyzed similarly to slope stability defined with a unitless value, FoS[11], influenced by geological processes and physico-mechanical properties affecting soil shear strength.

The minimum FoS should be at least 1.50 for permanent slopes and at least 1.30 for other cases[6]. A parametric study shows that increasing shear strength parameters raises the

FoS linearly, while increasing dump slope height lowers the FoS[17].

The heterogeneous nature of dump material also introduces substantial variations in its shape, size, formation, physical and chemical properties and mechanical properties across different locations, making comprehensive material characterization essential for safe and optimal dump slope design[12]. Factors that trigger instability in dumps, are classified as either external or intrinsic. For example, a slope on the brink of collapse due to inherent susceptibility to shear failure may only fail when combined with an external factor such as rainfall or seismic activity[5].

A finite element (FE) approach was used to examine various factors affecting dump slope stability including floor inclination, dump slope height and inclination, geological and hydrological conditions and the physical and mechanical properties of materials. The study concluded that these factors are critical in designing a safe and economical dump slope to avoid catastrophic failures[26,32].

In response to recurring dump failures, mining companies have sought the expertise of research institutions to conduct stability studies and to enhance safety measures, particularly for dragline dumps[10].

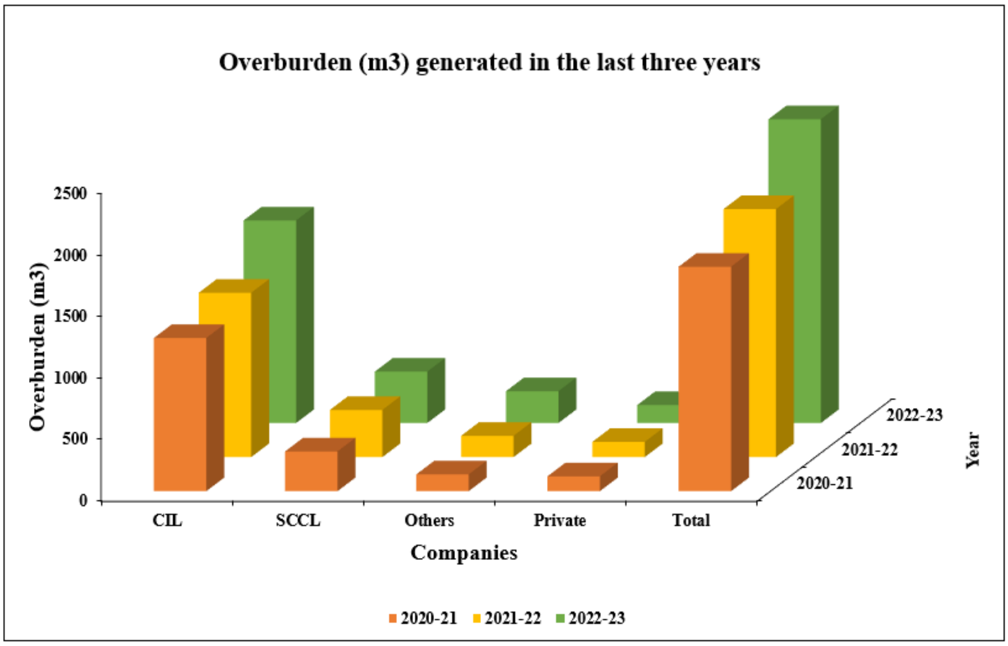

Figure 1: Generation of overburden in last three years[20]

Figure 2: An overview of coal mine dump slope[15]

Dump failures occurred due to over-height, rainwater infiltration, inadequate compaction and ground vibrations from blasting. These issues can be mitigated by implementing proper measures. Researchers have used analytical methods such as limit equilibrium analysis and FE modelling to assess dump stability and to develop safer dump disposal practices, aiming to prevent accidents and to enhance mining safety[16]. High-gradient slopes and vertical extents of 100-120 m are increasingly common in overburden dumps to maximize storage and reduce ground space[3,18]. However, these dumps are prone to slope failures due to improper geometry and inadequate shear strength. Factors like precipitation, site hydrology[31], external loads or blast vibrations[21,33], weak foundations[4] and low bearing capacity further exacerbate instability.

Among these, weak foundations are particularly critical, as they can lead to severe dump failures[4]. Placing overburden material on weak foundations emphasizes the need for stable surfaces to ensure structural surface and lifespan[25]. Irregular topography and sloping floors also worsen dump instability[22]. A review focused on the stability challenges of coal mine overburden dumps, especially in opencast mining, considering the impact of old underground workings on dump slopes[13]. Stability analysis, particularly for dumps with weak man-made sludge bases, shows that these foundations are critical[1].

To improve stability, constructing trenches filled with rocks around the dump base has been proposed. Numerical studies indicate that wider underground galleries increase stress and strain, reducing the FoS and impacting dump stability[2]. Both physical and numerical simulations are used to assess the influence of old underground workings on surface slope stability in Jharia Coalfields[30]. Weak foundations, low bearing capacity floors and uneven slopes can cause significant material displacement and deformation, leading to dump failures.

Stability and deformation of overburden dump slopes are critical in opencast coal mining. A study on longwall workings revealed a 56 mm displacement in overburden dumps, highlighting a significant issue[14]. Numerical simulations and model tests show that coal seam mining affects deformation characteristics of overlying rock masses, with maximum displacement near inner dumps[7]. A study shows that dump stability decreases as the joint dip angle increases, which lowers the FoS and increases displacements.

In this research study, the stability of overburden dumps located above old underground workings is investigated using two-dimensional finite element modelling. This study focuses on understanding how underground workings and varying dump heights influence the stability of the overburden slope. Numerical models were developed to evaluate FoS under different scenarios including cases with and without underground workings. The study also examines the impact of variations in the depth and gallery width of underground workings on the stability of overburden dumps. Key findings indicate that the FoS decreases with increasing dump height and gallery width while it increases with greater depth of underground workings.

Material and Methods

In this study, to carry out field investigations and laboratory experiments for further research, the following mine in South India has been selected as a case study. In this mine, the overburden dumps are situated directly above the underground workings. The field investigations, sample collection and necessary information for the research work have been conducted.

About Mine: Mine involves the conversion of parts of the abandoned underground mines into an opencast project. The project is located on the western side South India. Field visits were carried out at mine to collect the dump samples and other necessary information such as dump configurations and dimensions of the old underground workings. Figure 3 shows a view of the mine overburden dumps.

Figure 3: A view of location of opencast coalmine and dumps

Various geotechnical tests were performed on the overburden material in order to identify the physical parameters of material. The collected samples from mine along with grain size distribution, proctor compaction and direct shear test conducted are shown in figure 4. The material properties from the case studies in this chapter are used as input for numerical modelling to analyze the stability of overburden dumps affected by old underground workings.

Table 1 shows the laboratory test results from samples collected from decks 1, 2 and 3 which were used in the numerical modelling. The varying thicknesses of rock formations below the surface were also considered, with material properties provided by the Geology department of the mine.

Numerical Modelling: Limit equilibrium analysis can be used in many applications having simple slope geometries and basic loading conditions. However, in many cases, slopes involve complex geometry, non-linear material behavior, *in situ* stresses and the presence of pore pressures, seismic loading etc. FE method has been successfully used in many complex problems and applications. The FE software RS2 is used to simulate the impact of old underground coalmine workings on the stability of overburden dumps in terms of strength reduction factor (SRF) using the shear strength reduction technique to calculate the SRF of the dump slope.

Case Study - Stability Analysis of Coal mine Overburden dump of Mine: The mine dump design parameters for the model include a width of 30 m, a height of 30 m and a slope angle of 37.5° for each deck. The working depths of panels IIIA and IV are 239 m and 257 m respectively, partially developed/depillared by underground mining methods. The roadway dimensions are 2.4 m high by 3.5 m wide for seam IIIA and 3.4 m high by 3.6 m wide for seam IV. The numerical models were developed considering the dump height 30 m to 90 m above the old underground workings. The impact of underground workings on the overburden dumps is analysed with the increase of load in the form of overburden dumps. Numerical models were created for the 30 m, 60 m and 90 m dump height considering the old underground workings and without underground workings.

Figure 4: Collection of dump samples and geotechnical tests conducted
a. collection of samples b. Sieve size analysis c. Proctor compaction d. Direct shear test.

Table 1
The average geo-mechanical strength of the dump material

S.N.	Laboratory test	Value obtained
1	Maximum dry density (g/cc)	1.54
2	Optimum moisture content (%)	9.83
3	Unit weight (kN/m3)	15.1
4	Cohesion (kPa)	44
5	Friction angle (°)	23.8

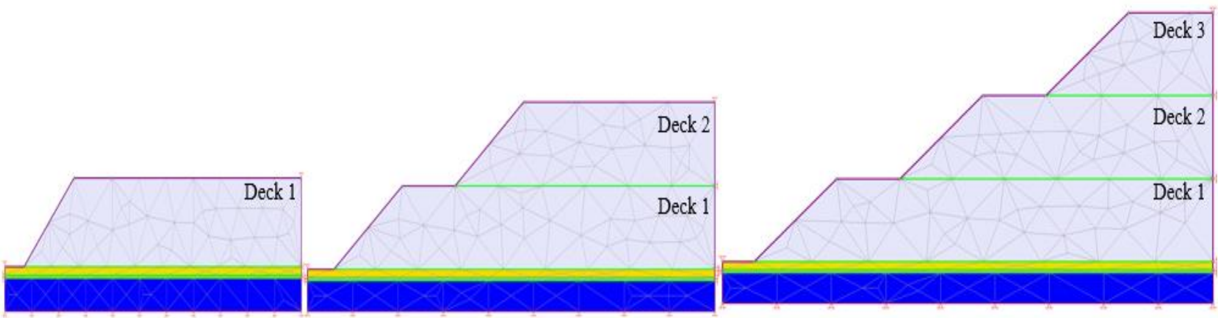

Figure 5: Discretized FE model of overburden dumps of Mine with boundary conditions

https://doi.org/10.25303/185da1040113

It helps in understanding the influence of underground workings on the overburden dumps along with the increase of overburden above the workings. Mine overburden dumps as also developed with both without underground workings (Figure 5) and with underground workings (Figure 6) with the increasing dump height. A combination of depth of underground workings, gallery width and dump slope height was considered to construct a set of 112 numerical models for a constant gallery height of 3 m as shown in table 2. The dataset of 112 dump models was developed and analysed to understand the parametric effect on the overburden dump slopes.

The set of models was developed as per Coal Mines Regulations, of which the overburden dump configuration is considered according to the Regulation 108 of CMR, 2017 i.e. slope angle of 37.5°, a height of 30 m and a width of 30 m. The dumps were placed above old underground workings developed using the bord and pillar method. The models evaluated the stability of overburden dumps, factoring in the dimensions of the underground workings, including gallery width, seam depth and pillar spacing. The gallery heights used 3m, in line with Regulation 111 of the CMR (2017), as shown in table 3. Based on the obtained information, the models were created using RS2 software as shown in figure 7. The left and right extremes of the dump models have been restrained in horizontal direction and the top surface of the dump has been left open to allow the excess material to flow freely and the models are interpreted in terms of SRF and displacement.

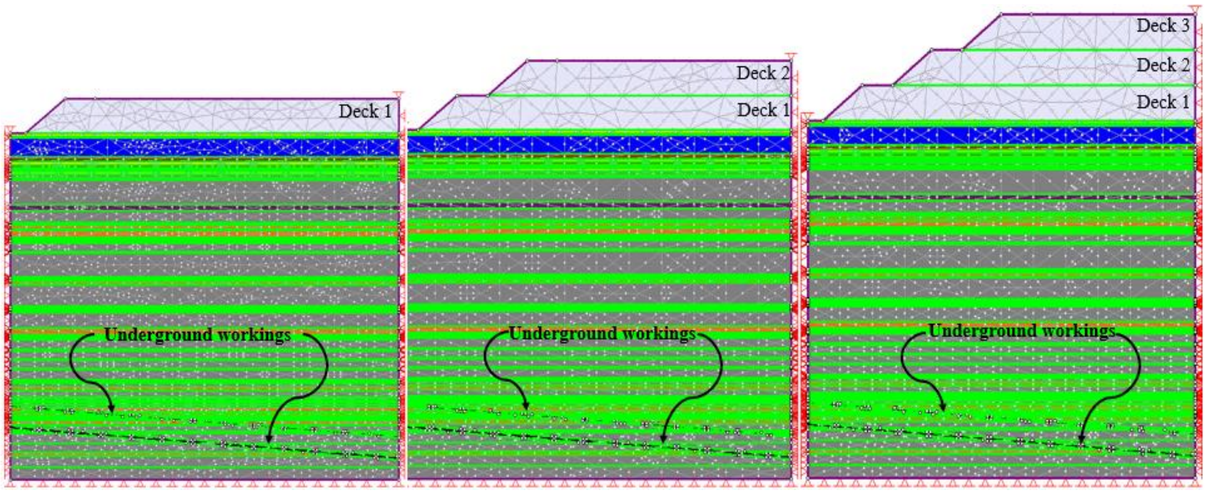

Figure 6: Discretized FE model of overburden dumps over underground workings of Mine with boundary conditions

Table 2
Numerical modelling design matrix

S.N.	Input variables	Range of input variables	No. of models
1	Overall dump height (m)	30, 60, 90, 120	4
2	Depth of working (m)	60, 90, 150, 200, 240, 360, 400	7
3	Gallery width (m)	3, 3.6, 4.2, 4.8	4
Total number of models = (4*7*4*)			112

Table 3
Pillar and gallery dimensions (Reg. No. 111 of CMR 2017)

Depth of seam from the surface	Gallery width (≤ 3 m)	Gallery width (3-3.6 m)	Gallery width (3.6- 4.2 m)	Gallery width (4.2- 4.8 m)
	The distance between centre of adjacent pillars shall not be less than (m)			
Not exceeding 60 m	12.0	15	18	19.5
Exceeding 60 m but not exceeding 90 m	13.5	16.5	19.5	21.0
Exceeding 90 m but not exceeding 150 m	16.5	19.5	22.5	25.5
Exceeding 150 m but not exceeding 240 m	22.5	22.5	30.5	34.5
Exceeding 240 m but not exceeding 360 m	28.5	34.5	39.5	45
Exceeding 360 m	39.5	42	45	48

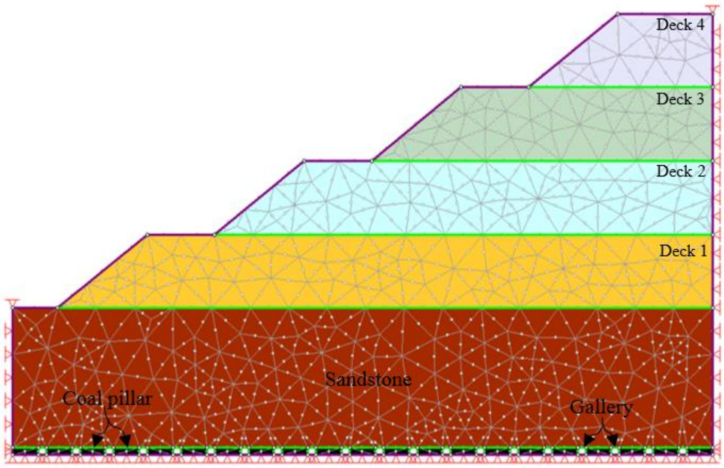

Figure 7: Illustration of a numerical model of overburden dumps over underground workings

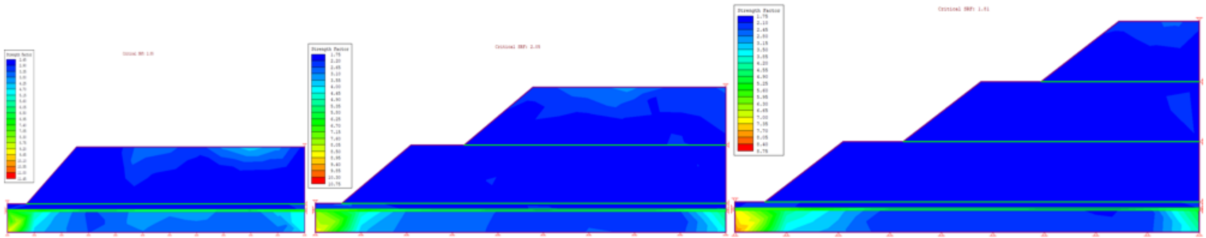

Figure 8: Contour of critical SRF of mine opencast dump model without underground workings

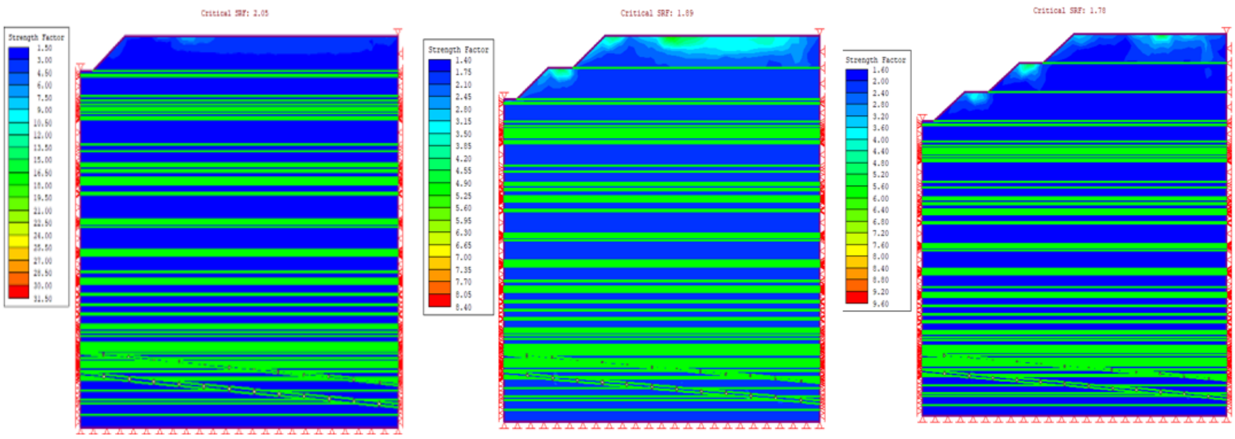

Figure 9: Contour of critical SRF of the Mine opencast dump model

Results and Discussion

The results from numerical models of mine overburden dumps deal with both without (Figure 8) and with (Figure 9) old underground workings, along with stability assessments of the dump slopes. The SRF values, computed using the RS2 model, are discussed in relation to site-specific conditions. For a 90 m dump height, the SRF values are 1.81 and 1.78 for the cases with and without underground workings respectively. Similarly, for a 60 m dump height, the SRF values are 2.05 and 1.89 and for a 30 m height, the SRF values are 2.55 and 2.05.

From figure 8, as height of the overburden dump increases the SRF of the overburden decreases. For each deck height of 30 m, 60 m and 90 m, the SRF decreases falls from 2.55 to 2.05 then to 1.81. This indicates the height as an influencing parameter towards the SRF. The stability of the overburden dump is decreased more than the dumps on the normal surface. Table 4 shows the SRF values for considering both with and without underground workings.

The SRF of the overburden dumps above the old underground workings (Figure 9) with single deck is 2.05, 1.89 for 2 decks and 1.78 for decks. The decrease in the SRF is due to the prior failure of the underground pillars, due to the load exerted by the overburden dumps. As the pillars failed to withstand, the rock layers above the pillars started bending downwards due to stress redistribution. This causes the foundation of the overburden dumps failure, ultimately leading to the failure of the overburden dumps. Figure 10 shows the horizontal and vertical displacement outputs of the overburden dump material.

From table 4, it is observed that the rate of decrease of the SRF from 1 deck to 3 decks (i.e., 2.05 to 1.78) as load on the underground workings is 13.1%. The effect of old underground workings gave 13.1% error on the overburden dump critical SRF indicating an effective impact on the overburden dumps. Figure 10 shows that the lowest Critical SRF observed for the 90 m overburden dump is 1.78, with old underground workings. In this case, the horizontal displacement of 7.00 mm and the vertical displacement of 29 mm are caused by the presence of two partially excavated underground voids, below overburden dump. The boundary deformation shown in figure 10 indicates differential movement, leading to instability in the overburden dump and adjacent areas.

Table 4
SRF values of the overburden dumps

Dump	With underground workings	Without underground workings
1 deck	2.05	2.55
2 decks	1.89	2.05
3 decks	1.78	1.81

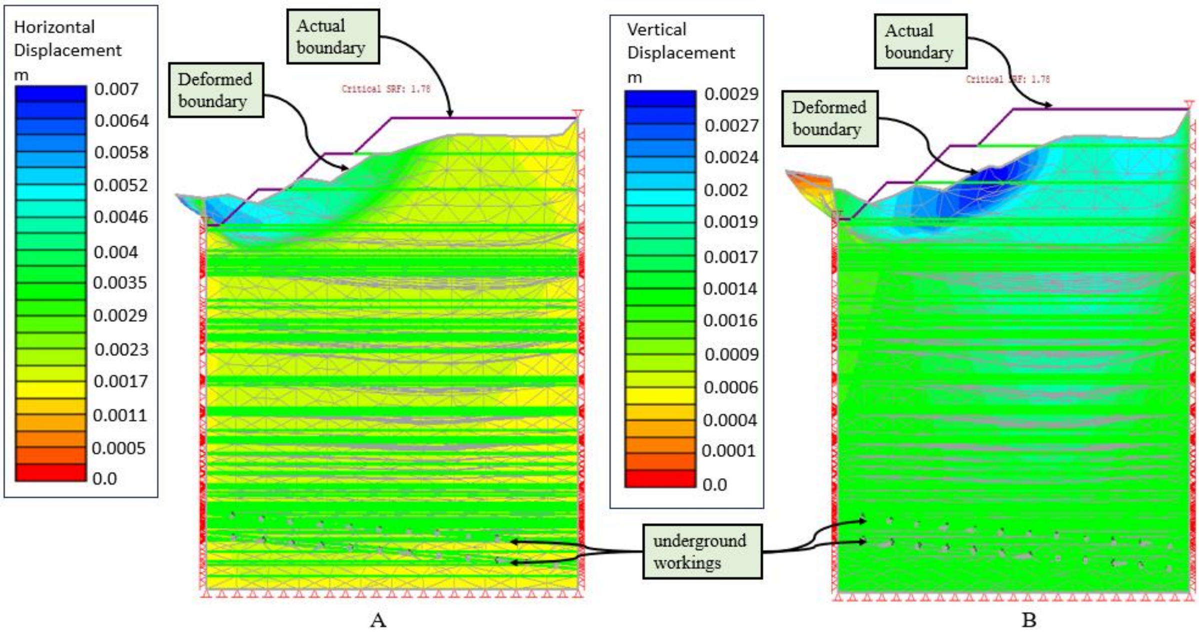

Figure 10: Showing (A) horizontal and (B) vertical displacements for Mine-B opencast dump model

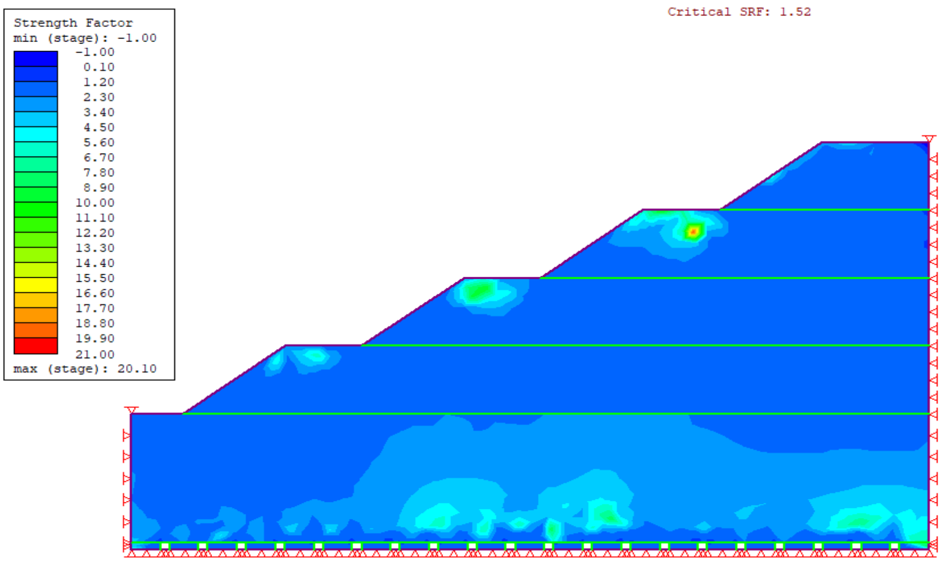

Figure 11: Critical SRF of the overburden dumps over underground workings

These voids contribute to stability issues. The rock layers below the overburden dumps exhibit increasing displacement values towards the surface, caused due to redistribution. The displacements from the numerical model of the case study support the SRF, indicating that the observed displacement at the lowest critical SRF level demonstrates the impact of underground workings on the stability of the overburden dumps.

As similar to case study, the numerical set of models is developed for varying depth of underground workings, gallery width and dump height. The critical SRF of the model over underground workings is shown in figure 11. Based on the outcomes of the developed models, plots were drawn for SRF vs depth of working and gallery width for which parametric analysis is required.

Effect of depth of underground workings: To understand the effect of underground workings on the overburden dumps, a plot has been drawn between depth of underground workings and SRF of the dumps as shown in figure 12. The graphs were drawn for each dump height of 120 m 90 m 60 m and 30 m for varying depth from 60 m to 400 m. Figure 12 shows that as the depth of underground workings increases, the SRF of the overburden dumps also increases. This indicates that deeper workings experience higher confinement in the rock strata below the overburden dumps. For a 120 m dump height at a 60 m depth with a 3 m gallery width, the SRF is 1.46, while for a 400 m depth of workings, it increases to 1.57. A similar pattern is observed for gallery widths of 3.6 m, 4.2 m and 4.8 m.

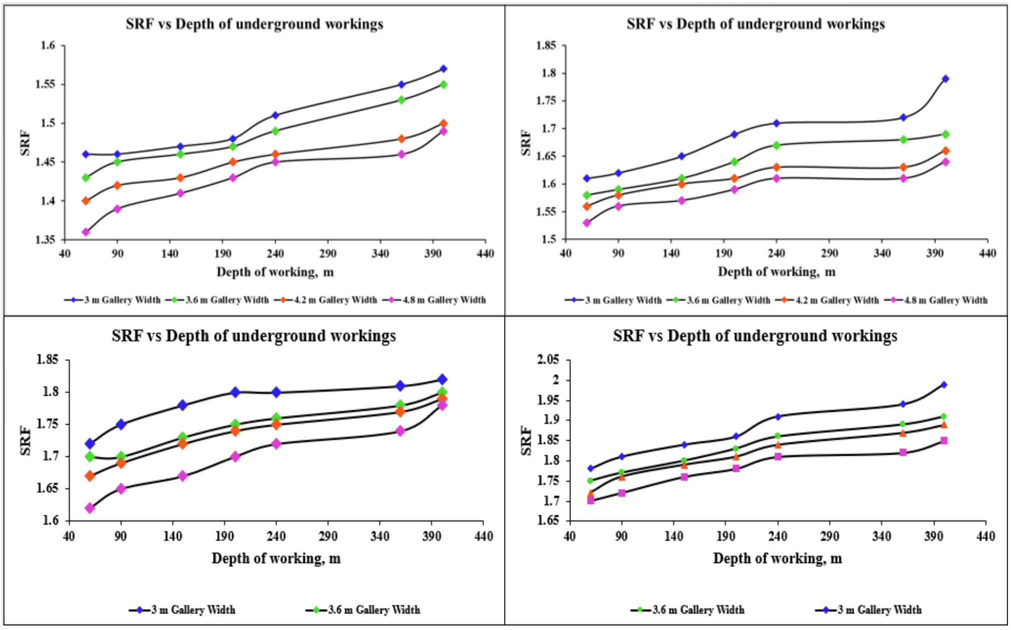

Figure 12: Comparative analysis of SRF for varying depth of underground workings

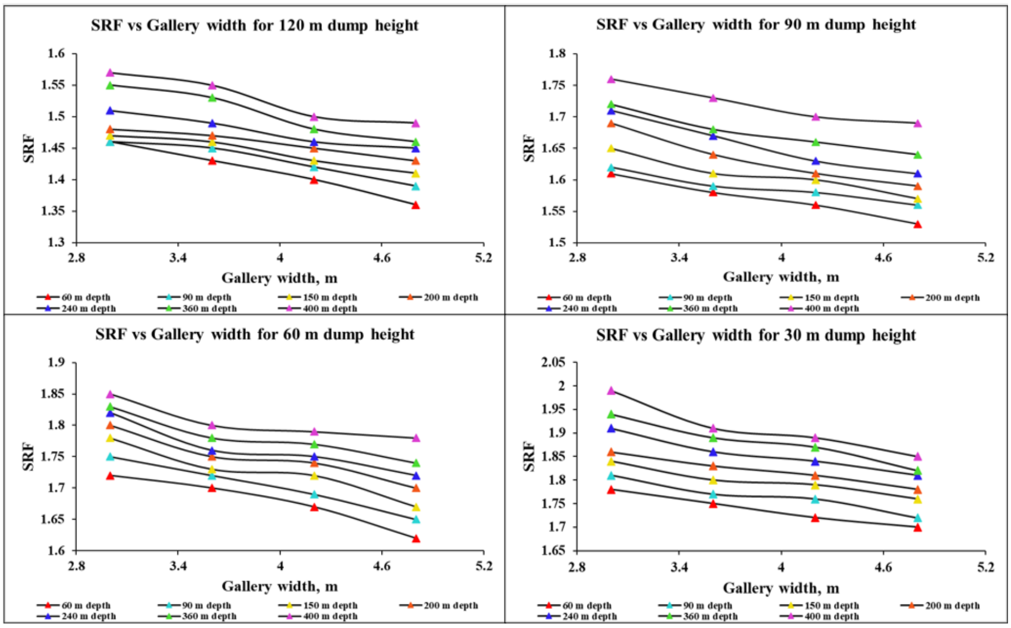

Figure 13: Comparative analysis of SRF for varying gallery width

Similarly, for a 30 m dump height at a 60 m depth and a 3 m gallery width, the SRF is 1.78 which increases to 1.99 for a 400 m depth of workings. This increase in SRF is attributed to the confinement of rock layers and the redistribution of stresses as depth increases. However, as the depth increases, stress redistribution occurs, leading to dissipation of stresses and consequently an increase in the SRF of the overburden dumps.

Effect of gallery width: The effect of gallery width on the SRF of the overburden dumps is shown in figure 13. The plots are drawn at gallery widths 3 m, 3.6 m, 4.2 m and 4.8 m for varying depths from 60 m to 400 m. From figure 13, wider galleries with a 4.8 m width exhibit lower SRF values compared to narrower galleries with a 3 m width. For a 120 m dump height at a 60 m depth of working, the SRF is 1.46 for a 3 m gallery width and 1.36 for a 4.8 m gallery width under the same conditions.

Similarly, for a 30 m dump height, the SRF for a 3 m gallery width is 1.78, while it is 1.7 for a 4.8 m gallery width at a 60 m depth of workings. Narrower galleries (3 m) exhibit higher SRF values than wider galleries (4.8 m) indicating better stability. At a constant depth of 60 m, the SRF increases from 1.46 to 1.78 as the dump height changes from 120 m to 30 m. This is due to the load exerted by the overburden dumps. The load from the overburden dumps impacts the underground workings before stress redistribution can occur.

This leads to the collapse of underground workings and the effect is transferred to the surface, thereby affecting the foundation of the dumps and causing dump instability.

Conclusion

A detailed study was carried out to assess the stability of the overburden dump slopes on the old underground coalmine workings. The case study was considered to assess the stability of the coal mine dumps present above the old underground workings. Laboratory studies provided the necessary data to perform numerical models of the mine which were used to determine dump stability. By investigating various depths, gallery widths and dump heights, the research provides a comprehensive understanding of the factors affecting dump stability. This study has drawn the importance of considering underground dimensions when designing overburden dumps above underground workings. The study has drawn the following conclusions:

- The material properties of mine dumps were determined in the laboratory as per IS codes. The test results of the dump material are: dry density = 1.54 g/cc, water content = 9.83%, cohesion = 44.0 kN/m² and friction angle = 23.8°. These values were used as inputs for the numerical models.
- The SRF for 1-deck, 2-deck and 3-deck overburden dumps without underground workings is 2.55, 2.05 and 1.81 respectively. This shows that increasing dump height decreases the SRF, indicating reduced stability with height.
- The SRF for 1-deck, 2-deck and 3-deck overburden dumps with underground workings is 2.05, 1.89 and 1.78 respectively. The greater rate of SRF reduction in this case highlights the destabilizing effect of underground workings.
- A decrease in SRF from 2.05 to 1.78 (13.1%) is observed when considering underground workings, emphasizing their critical influence on dump stability. This factor indicates further investigation as a key parameter in future studies.
- The presence of old underground workings causes displacement in the dump material, with horizontal and vertical displacements of 7 mm and 29 mm respectively, at the lowest SRF of 1.78. This highlights the mechanical response of the dump material to underground workings.
- The SRF of overburden dumps increases with the depth of underground workings due to higher confinement and effective stress redistribution, enhancing dump stability.
- Narrower gallery widths exhibit higher SRF and greater stability compared to wider galleries, indicating the critical role of gallery width in stability assessments.
- Shallower depths and higher dump heights impose greater loads on underground workings, leading to potential instability. Conversely, deeper workings improve stability through stress dissipation and reduced surface impact.

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(Received 22nd January 2025, accepted 20th February 2025)