Journal of Rock Mechanics and Tunnelling Technology (JRMTT)
28 (1) 2022 pp 5-16

Available online at www.isrmtt.com

Slope stability Analysis of Waste Dumps for Mining Sites - A Case Study

*S. Handa**
R. D. Dwivedi
Anil Swarup
Divyansh Pandey
M. K. Meena

**GEODATA India Private Limited, New Delhi, India*
CSIR-CIMFR Regional Centre, Roorkee, India

***E-mail: shubhamhanda40@gmail.com*

ABSTRACT

A mine premises with many working faces, roadways and workshops should have separate designated locations for mined-out mineral/ore storage. Waste or reject material obtained after screening the raw material needs to be dumped in a separate location so that it should not cause any danger to nearby infrastructures, working places and flora & fauna. With this view, a stable waste dump having a large height along with less land area has been of great importance for any mining project in terms of optimized land utilization. Hence, dumps need to be designed carefully to make them stable for a long period of time.

The present paper discusses a case study wherein two unstable dump slopes of face reject material and one screen reject material located near a limestone mine have been optimally designed.

Keywords: Slope stability; Dump stability; Shear strength reduction; Sirohi

1. INTRODUCTION

Slope stability plays a major role in the case of waste dumps especially near the working opencast mine because its failure may cause damage to the men and machinery deployed nearby and thus mineral/ore production may seize for a longer period of time. Low height dumps acquire large land areas therefore high dumps are designed to manage the waste material in a comparatively smaller land area. This requires proper geotechnical investigation to design the dumps, which stands stable for a longer period of time without affecting the surroundings. Mismanagement of dumps may lead to failure, which in turn results in a threat to human safety and increase in the overall cost of maintenance (Poulsen et al., 2014).

Till date, many researchers have studied slope stability of mine waste dumps. For instance, Behera et al. (2016) studied a waste dump near Basundhara mines of Mahanadi Coalfields Limited (MCL), Odisha and found pore pressure and water seepage as major factors for triggering continuous mass movement, particularly in the rainy season. Singh et al. (2013) and Cho & Song (2014) also observed water pressure as a major parameter responsible for waste dump failures. Kainthola et al. (2011) conducted dump failure analysis using shear reduction technique for Western Coalfield Limited, Nagpur, India where a huge dump of 75 m height with a slope angle of 43° had slipped forward by 18m and redesigned it with a safety factor of 1.3. Gupta et al. (2018) used fly ash layers to improve stability and thus increased the factor of safety of the dump slopes. Zevgolis (2018) characterized some limestone waste dump properties in Evia, Greece, and compared the result with that obtained using Kuz- Ram empirical model.

In the present study, stability of three existing limestone dumps in the area of Ultra Tech Nathdwara Cement Limited (UNTCL) has been analyzed. UNTCL is operating an existing integrated cement plant with an installed capacity of 4.8 MTPA Clinker, 4.85 MTPA Cement and 70 MW CPP at Amli in Sirohi (Rajasthan). The limestone mine waste dumps are located nearby Amli mines. The sources of raw material for the cement plant are two captive lime stones mines namely Amli limestone mines of capacity 6.35 MTPA and Thandiberi limestone mines of capacity 1.065 MTPA. These mines are located in the vicinity of 7.5 km from the plant area.

There are three face reject dumps with sizes (length x width x height) 392 m x 302 m x 65 m, 265 m x 142 m x 52 m, and 350 m x 328 m x 55 m and screen reject dump of size 900 m x 220 m x 55 m. Currently, the bench height of the face reject material dump and screen reject material are about 10 m and 8 m respectively. The dump height restrictions for the face reject material and screen reject material are 60 m and 40 m respectively. The dumps are highly unstable due to erosion and washed-out material all along the dump slopes (Figs.1 & 2).

There was no berm in the existing screened-out dump (Fig.1). Multiple traces of wide erosion along the dump slopes were observed during the visit (Fig.1). Water flowing along the slopes especially in the case of screen reject dump has been the real culprit for slope mass erosion at large. On the top of the dump, cracks were also observed at places (Fig.2), which might have given passage to percolate water into the dump mass resulting in its failure. Such cracks were also observed on the benches of the face reject dumps. Keeping in view the aforementioned instances of erosion and cracks, the dumps slopes need to be analyzed and properly designed. CSIR-CIMFR conducted the study and designed the dump slopes using Rocscience numerical code SLIDE2 based on finite element method.

Fig. 1 - Traces of erosion on dump slopes

Fig. 2 - Tension cracks present on the dump

The waste material mainly consists of calcic rock overlain by the calc-silicates followed by quartzite with a cohesion value of 50 kPa for face reject material and from 0 to 25 kPa in case of screen reject material. The case study is mainly focusing on the study of existing face reject and screen reject dump slopes stability and designing the stable slopes for the existing dumps within the limited available space at the site.

Keeping all existing conditions and parameters in consideration, a general method of slices for slope stability is adopted. Stability analysis has been carried out considering the following cases: (i) static saturated and (ii) dynamic saturated conditions with berms.

2. GEOLOGY OF THE AREA

Sirohi with an area of 5136 km^2 is bordered by Jalor district from the west, Pali district from the north, Udaipur district from the east, and Banas Kantha district from the south as shown in Fig 3. Geology of the area consists of most of the lowermost calcic rocks overlain by the calc-silicates, followed by quartzite. Younger granite, pegmatite, amphibolite and quartz veins intrude all these rock units. This area mostly consists of long and high hills. The hillocks are isolated and scattered in a long continuous belt and on both sides of the hill having gentle slopes.

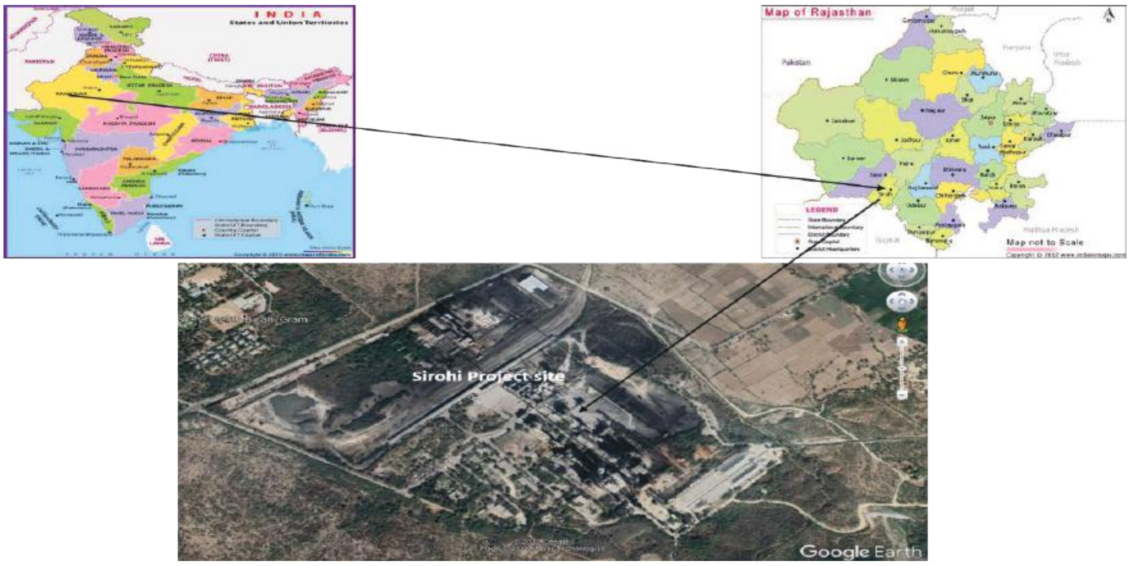


Fig. 3 - Location of the project site

Total plant area of about 230 ha is located between latitudes 24º48'57.66" to 24º49'54.69" and longitudes 73º4'36.77" to 73º6'4.82". Figure 4 shows the geological plan of face reject and screen reject dumps. The various cross-sections of the screen reject dump along the planes S_1-S_1, S_2-S_2, S_3-S_3 and various cross-sections of the face reject dump along the planes DU_1-DU_1, DU_2-DU_2, DU_3-DU_3 are shown in Fig. 5.

Along Section S1-S1 the maximum elevation of the screen reject dump is 480.2 m and the elevation of the slope is increasing from 430.2 m to 460 m. Along section S2-S2, the maximum elevation of the screen reject dump is 478.8 m and the slope is increasing from 423 m to 426 m, whereas the section along S3-S3 the maximum elevation is 474.8 m with varying slope.

Along section DU1-DU1, varying slope is observed with the maximum elevation of 579.5 m. Along section D2-D2 the maximum elevation is 544.18 m with varying slope, whereas the maximum elevation along section D3-D3 is 513.26 m.

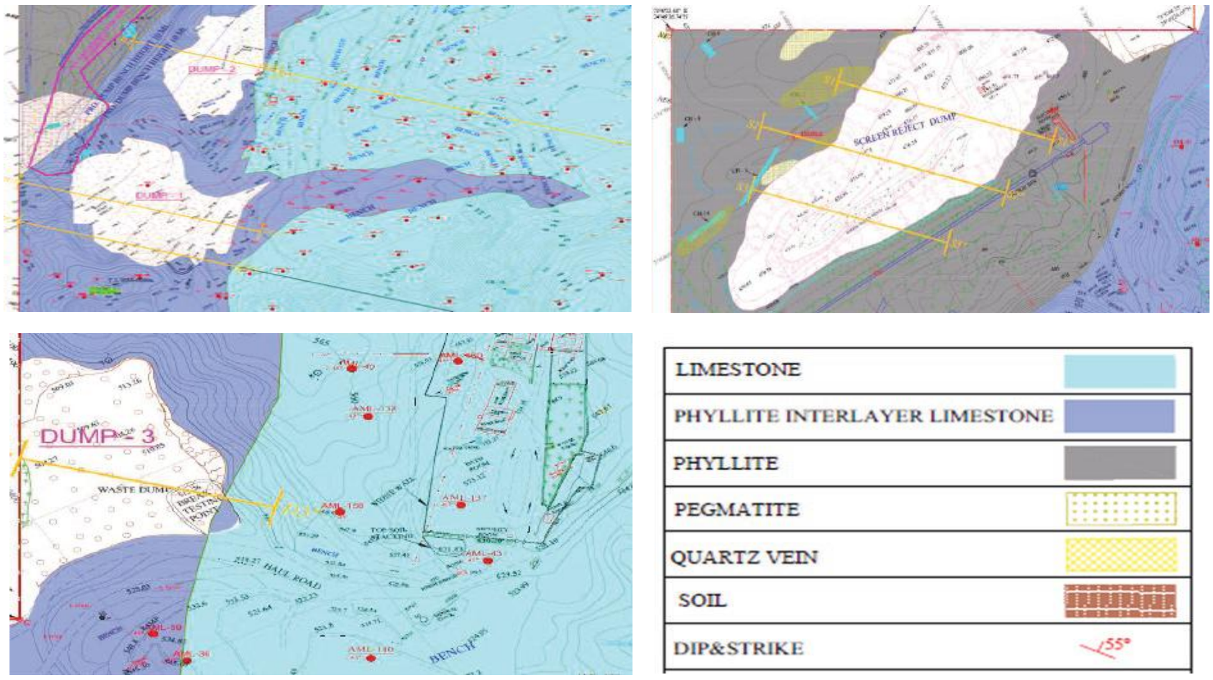


Fig. 4 - Geological plan of face reject and screen reject dumps

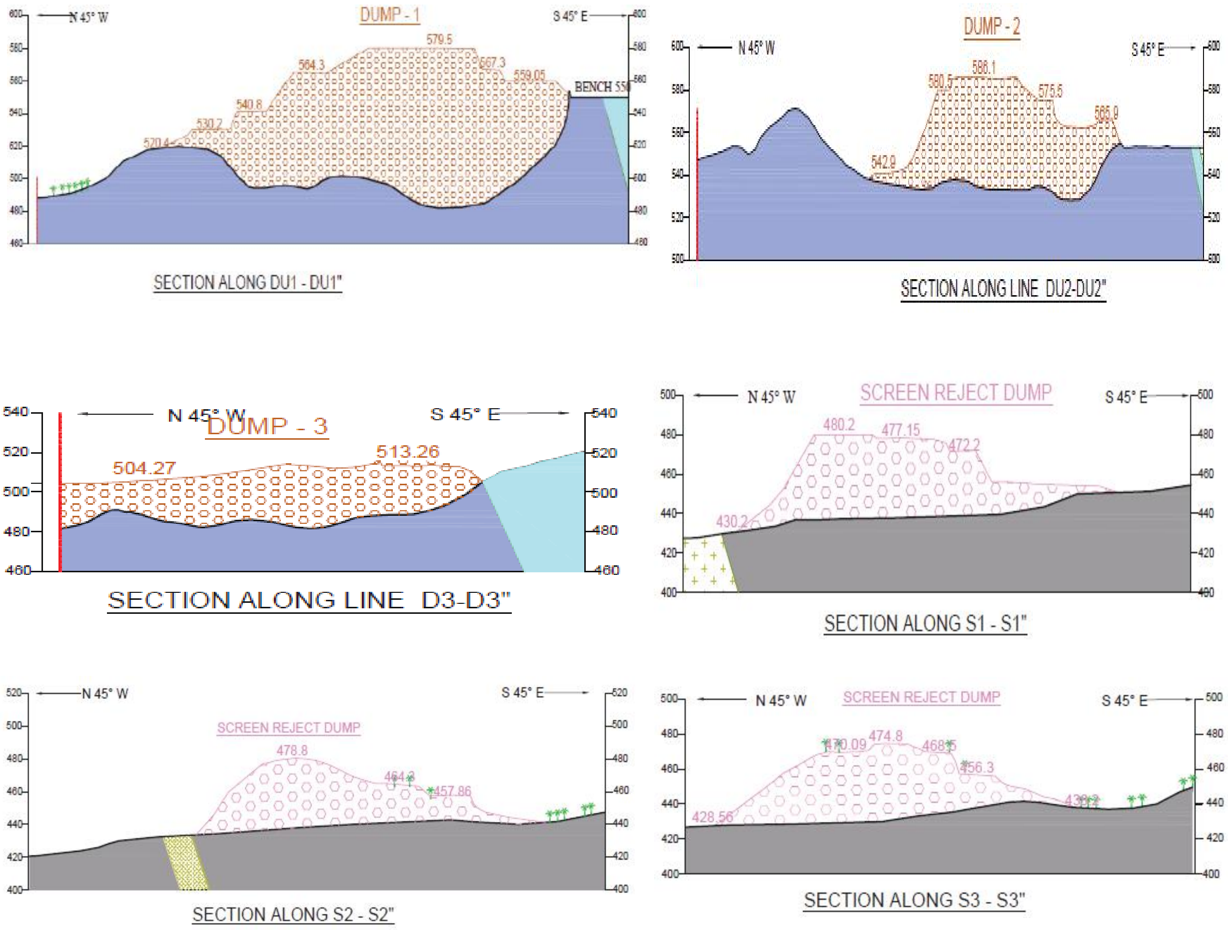


Fig. 5 - Elevations and cross-sections of the dumps

As shown in the above cross-sections (Fig. 5), the slope of the face reject and screen reject material is found unstable, hence proper analysis of these dumps is required to have a stable slope.

3. METHODOLOGY

Generally, Limit Equilibrium approach is extensively used for stability analysis of hill/dump slopes. The most commonly used method pertaining to limit equilibrium is method of slices. In this method, a particular slip surface is divided into a number of slices, and the equation of equilibrium investigates each slice. The ratio of the summation of resisting forces to the summation of the driving forces is known as the factor of safety (FoS).

$$\text{FoS (Factor of safety)} = \frac{\sum_1^N \text{Resisting forces}}{\sum_1^N \text{Driving forces}} \quad (1a)$$

where N is the number of slices.

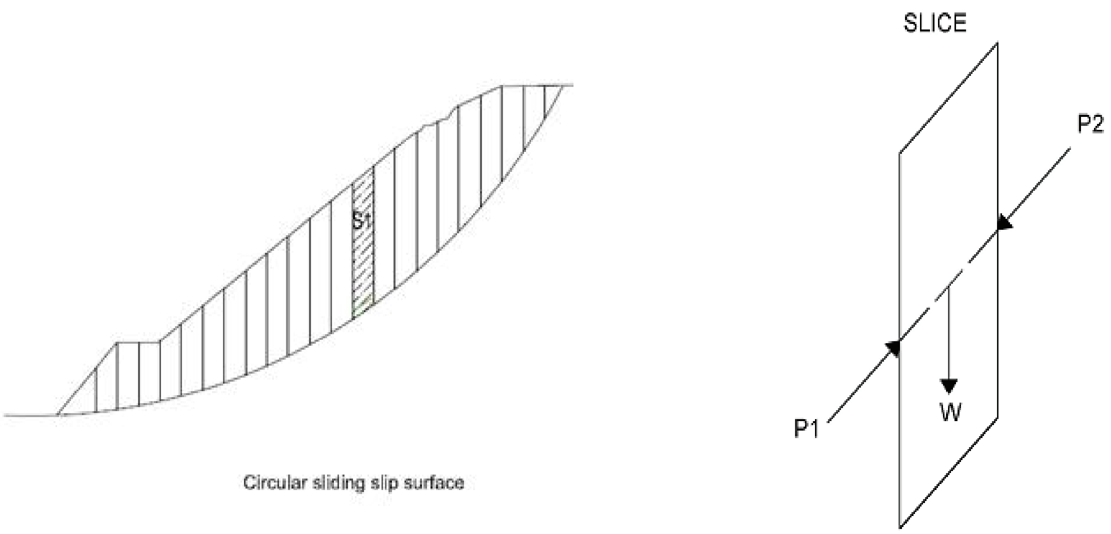


Fig. 6 – Typical circular sliding surface

.

$$FoS = \frac{Shear\ Strength}{Shear\ Stress} = \frac{c+\sigma_n tan\emptyset}{(P_1-P_2)/A} \quad (1b)$$

where

P_1	= force resisting slope failure,
P_2	= force causing slope failure,
c	= cohesive strength,
σ_n	= normal stress,
ϕ	= angle of internal friction, and
A	= failure area.

Mohr-Coulomb failure criterion is used for analysis in limit equilibrium method. During the critical state along the failure surface, the force driving to instability is equal to the force which resists the instability. A free body of soil/rock mass (S1) above the assumed slip surface will be considered for analysis. The equation of static equilibrium is used to compute the FoS with respect to the shear strength.

Factor of safety greater than one indicates the larger resisting capacity and hence the slope will be stable against sliding along the assumed slip surface. In the present analysis, factor of safety 1.5 for static loading condition and 1.2 for seismic loading condition have been considered (IS 14243). Figure 6 shows the typical circular sliding surface indicating the forces acting on each slice. Factor of safety can be determined using Eqs.1a & 1b.

4. DUMP CHARACTERISTICS AT SITE FOR ANALYSIS

There are two types of dump material at site, which are as follows:

i) Face reject material
ii) Screen reject material

Slope stability analysis has been carried out using numerical code (SLIDE2) for both the materials as discussed below:

4.1 Face Reject Material

The dump material of face reject comprises of rock fragments of size about 50-250 mm (Fig. 7). Cohesive strength and angle of internal friction have been considered as 50 kPa and 30° respectively for the analysis as provided by the project authority. Dump slope for this material has been designed (Figs. 9 to 11).

4.2 Screen Reject Material

It is found that fresh screen reject material is cohesionless (c = 0), but this material lying on the pre-existing dump since last 20 years, has progressively consolidated with course of time due to its self-weight and thus its cohesive strength has been taken as 25 kPa for analysis as provided by the project authority. Its natural slope angle (angle of repose) is about 38° observed in the field and hence this value has been considered for analysis.


Fig. 7 - Face reject dump

Fig. 8 - Screen reject dump

5. FACTORS CONSIDERED FOR SLOPE STABILITY ANALYSIS

Basic factors influencing the dump slopes like cohesive strength and angle of internal friction (i.e., shear strength parameters), pore pressure of water present within the dump mass and berm width are considered while designing the dump slope. These parameters are discussed as follows:

5.1 Shear Strength Parameters of the Material

According to the Mohr-Coulomb failure theory, the shear strength parameters of the material include cohesion value and the angle of internal friction. Shear strength of the material increases with an increase in cohesive strength and angle of internal friction.

$$\tau = c + \sigma_n \tan(\phi) \quad (2)$$

where

τ = shear strength,
c = cohesive strength,
σ_n = normal stress, and
ϕ = angle of internal friction of material.

Table 1 - Values of shear strength parameters at sites

Material		c, kPa	ϕ
Face reject material (fragment size 50-250 mm)		50	30°
Screen reject (fragment size 12-15 mm)	Old compacted	25	38°
	New cohesion less	0	38°
	Material with little compaction	20	38°

The stability analyses are carried out to check the global stability (at slope, at toe and at base) of the embankment for assessing the adequacy of the side slopes. Stability analysis has been carried out considering the following cases: (i) saturated condition and (ii) saturated under dynamic condition. The second case is considered for the final design of dump slopes as both conditions i.e., saturation and seismicity have been considered for ensuring its stability in rainy season.

5.2 Berm Width

A berm is defined as a shelf that breaks the continuity of the slope. A berm provides resistance to sliding of slopes. Berm width plays an important role in the stability of the slope in controlling erosions by intercepting and diverting rainwater downstream. A sample data is shown in Table 2 and Figure 9 shows an increase in factor of safety (FoS) value with an increase in berm width.

Table 2 - Change in FoS with berm-width

Slope angle	Berm width (m)	Bench height (m)	Factor of safety (FoS)
43^o	2.5	8	1.546
	3	8	1.597
	3.5	8	1.648
	4	8	1.7

For stability, the overall angle of the slope must be less than the angle of internal friction. But larger berm width leads to an increase in the cost of cutting of slope.

Therefore, optimum berm width is always required for the design of the slope. Slope stability analysis is done to find the optimum slope at which the factor of safety reaches the desired value.

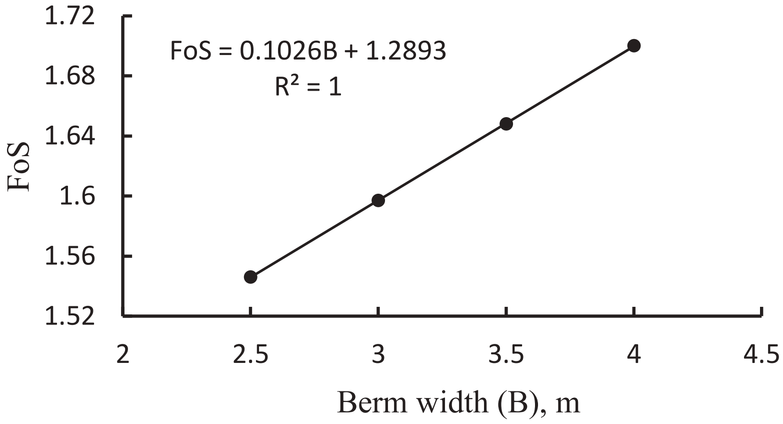


Fig.9 - Factor of safety (FoS) improves with increase in berm width

5.3 Water Present in the Dump Material

One of the important factors for dump slope stability is the effect of water. Waste dump is mainly blasted or screened rock fragments, which is generally highly porous due to the end-dumping techniques. This results in easy percolation of water through the dump to its lower layers. It often results in the accumulation of water in absence of a proper drainage system. This percolated water can be disastrous and may lead to massive failures of dump slope as such failure was seen in 2008 in the western section of Jayant opencast mine (Sharma and Roy, 2015). The effect of presence of water in dumps may influence in following three ways; (i) it creates a hydrostatic pressure due to self-weight increasing the effective stress on the overall slope, (ii) it creates pore pressure and may lead to slope failure, (iii) oversaturation of water reduces the internal properties of the dump material (c and ϕ).

6. SLOPE STABILITY ANALYSIS

In the case of face reject material of fragment size 50-250 mm, cohesion and angle of internal friction have been taken as 50 kPa & 30^o respectively as provided by the project authority. Dump slope of this material has been designed and analyzed for saturated static and seismic conditions and found safe with a factor of safety of 1.5 for static condition and 1.3 for dynamic condition. There are 8 benches each of 8 m height with 3 m wide berms in the dump. Angle of bench slope has been designed as 38° with an overall slope angle of 32°. The material of uppermost layer of the dump would be less consolidated as compare to the material at lower levels and the rain water may percolate below to some depth only. For analysis purposes, rain water percolation has been taken as 4 m. To simulate this water effect, a water table at 4 m depth has been taken in analysis. Figure 10 indicates the model with saturation in static condition. Dump slope covers nearly 103 m horizontal offset with 3 m berm width. Figure 10 illustrates the model analysis in static condition, whereas Figure 12 depicts the seismic analysis for values of horizontal and vertical ground acceleration components as 0.08 and 0.04 respectively.

Similarly, slope stability analysis has been carried out for screen reject material. The fresh screen reject material at the topmost layer is cohesionless whereas pre-existing material below the fresh material has got consolidated due to self-weight exhibiting cohesive strength of 25 kPa. The bench slope has been analysed in saturated static and seismic conditions and found to be stable at an angle of 43°. Figure 13 shows that this slope design covers 76 m at the ground base and dump material categorised as old consolidated material, new consolidated material and fresh unconsolidated material. There are 7 benches each of 8 m height except the top two benches of 4 m each. Each bench is at a slope angle of 43°. The dump slope is analysed to be safe with FoS of 1.5 in saturated condition.

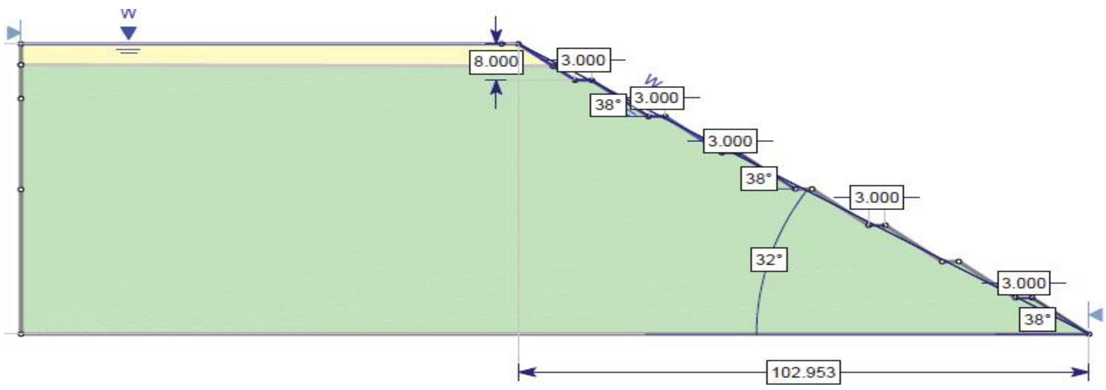


Fig. 10 - Slope of face reject dump

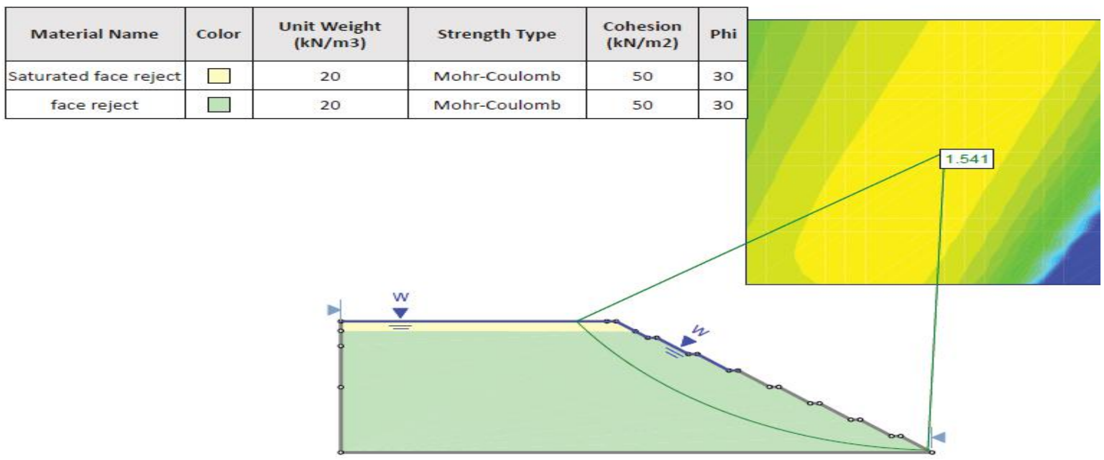


Fig. 11 - Static analysis of face reject dump

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi
Saturated face reject		20	Mohr-Coulomb	50	30
face reject		20	Mohr-Coulomb	50	30

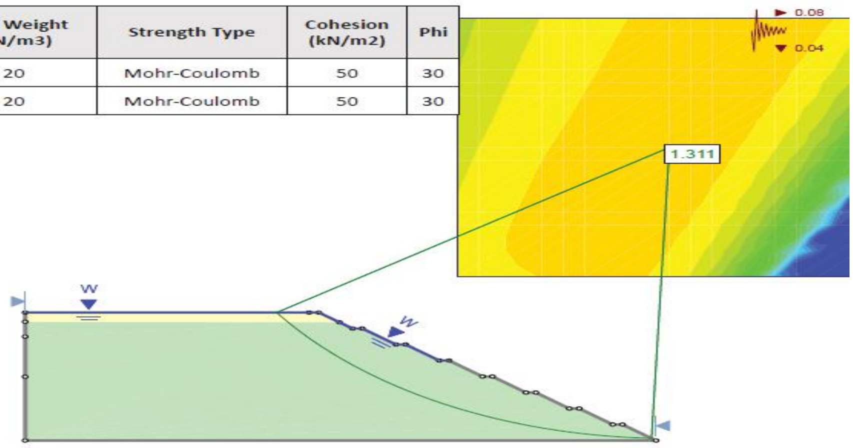


Fig. 12 - Seismic analysis of face reject dump

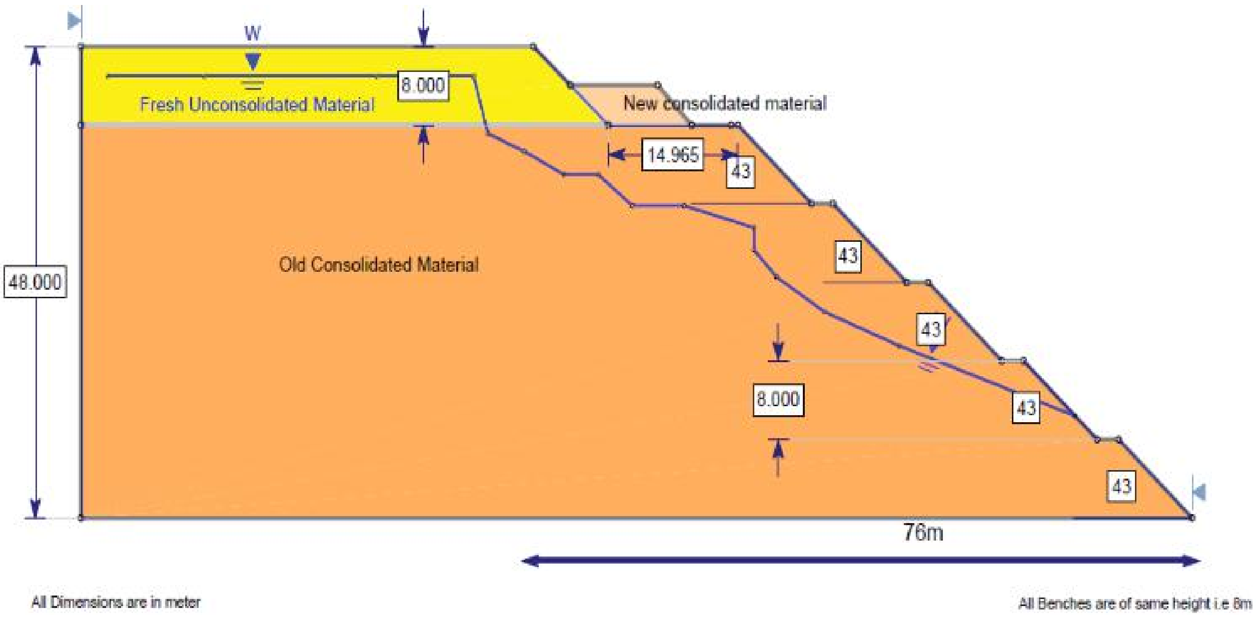


Fig. 13 - Model of screen reject dump

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kN/m2)	Phi
Fresh Material		20	Mohr-Coulomb	0	38
Old Material		20	Mohr-Coulomb	25	38
Material 3		20	Mohr-Coulomb	20	38

Material 3 : Fresh material with Little compaction

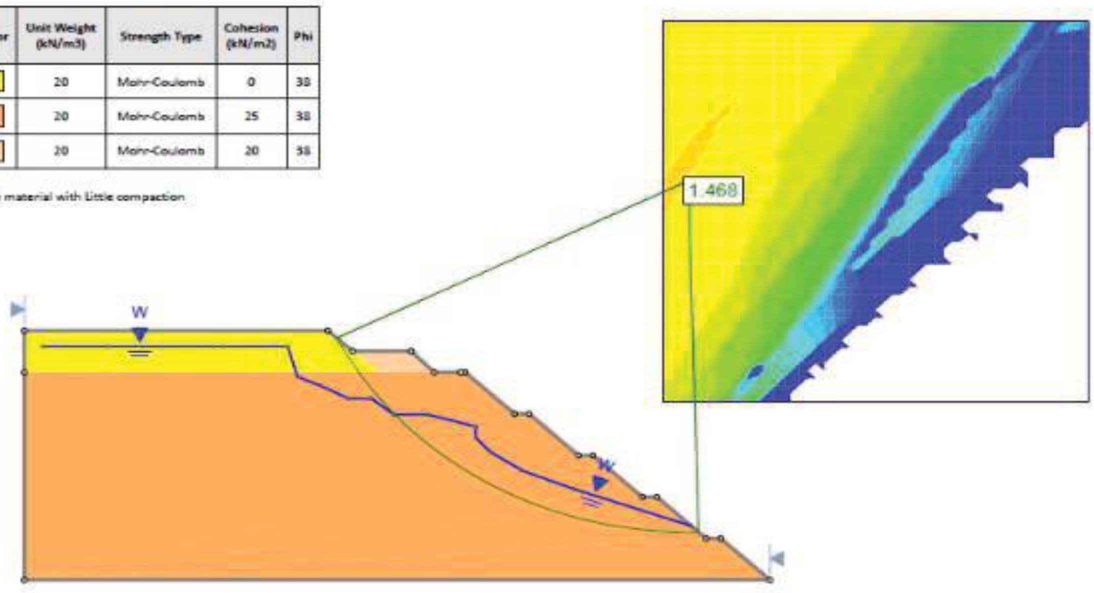


Fig. 14 - Static analysis of screen reject dump considering water saturation

7. PROTECTION OF DUMP SLOPES FROM RAIN WATER

Proper drains at every berm have been designed to minimize the rainwater percolation inside the dump slopes. Design details and pattern of berm drainage have been given for dumps in Figs. 15(a & b) and Fig. 16 respectively. Further, to protect the dump slopes from erosion, either (i) sand-bentonite mix slurry applied over the dump or (ii) geo-synthetics (geogrid or geotextiles) can be laid. Researchers Wu (1984), Chaulya et al. (2000) and Chok et al. (2004) conducted studies and revealed the strengthening effects of plant/grassroots on dump slopes. In this view, seeding has also been recommended to grow grasses with sufficient roots to enable strengthening of the dump slopes for long-term stability. The grass roots would improve FoS by keeping the slope material intact and minimizing erosion along the slope.

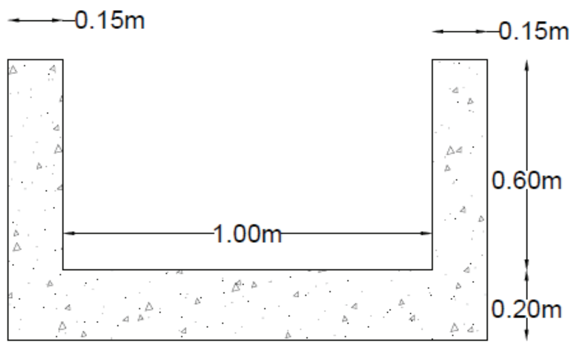


Fig. 15(a) - Drainage along each bench

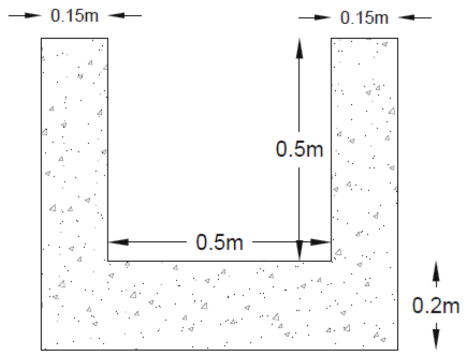
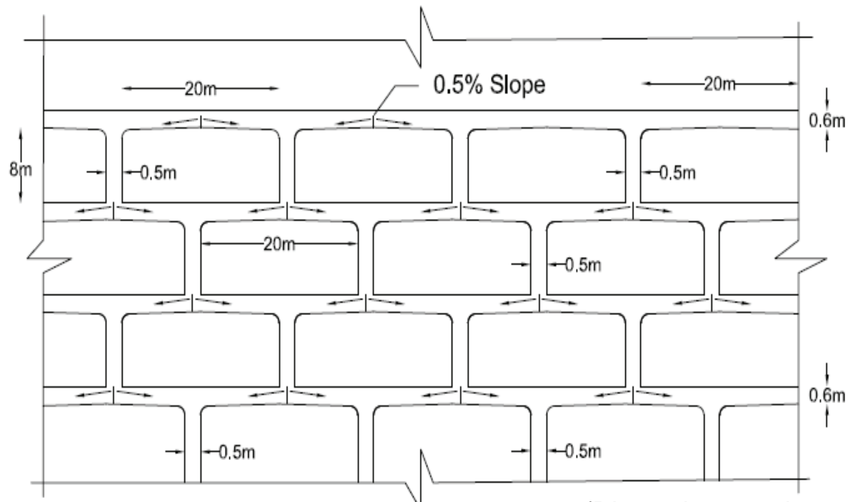


Fig. 15(b) - Berm cross-drainage

(Drawing not to the scale)



(Dimensions are in metre)

Fig.16 - Drainage pattern for dump slopes

8. CONCLUSIONS

The field study gives an appropriate value of soil strength parameters and therefore the models are designed with optimum berm width and height for face reject dump at a slope angle of 38^0 and screen reject dump at a slope angle of 43^0 which shows to be stable in static as well as in dynamic conditions. To avoid steep slope angles, berms of sufficient width have been designed in view of long-term stability. The dumps are susceptible to hydro-geological conditions thus due importance is given towards the construction of drainage to avoid percolation of water which could initiate erosion. However, water saturation has already been considered for design while analysing the stability of slopes.

In addition to the above considerations, emphasis is given in the application for vegetation on the slope for their additional stability by seeding and growing grass on the face of the slope.

References

Behera P. K., Sarkar K., Verma A. K., Singh A. K., Singh T. N. (2016). Dump slope stability analysis - A case study. Journal of the Geological Society of India 88(6), 725–735.

Chaulya S. K., Singh R. S., Chakraborty K., Srivastava B. K. (2000). Quantification of stability improvement of a dump through biological reclamation. Geotechnical and Geological Engineering 18(3), 193–207.

Cho Y. C., Song Y. S. (2014). Deformation measurements and a stability analysis of the slope at a coal mine waste dump. Ecological Engineering 68, 189–199.

Chok Y. H., Kaggwa, W. S., Jaksa M. B., Griffiths D. V. (2004). Modelling the Effects of Vegetation on Stability of Slopes. Proc. 9th Australia New Zealand Conference on Geomechanics, Auckland 8-11 Feb, 391-397.

Gupta T., Singh T. N. (2018). Geo-hydrological stability analysis of fly ash stabilized overburden dump slopes in opencast coal mines using finite element analysis. International Journal on Advanced Science, Engineering and Information Technology 8(2), 405–410.

Kainthola A., Verma D., Gupte S. S., Singh T. N. (2011). A Coal Mine Dump Stability Analysis - A Case Study. Geomaterials 01(01), 1–13.

Poulsen B., Khanal M., Rao A. M., Adhikary D., Balusu R. (2014). Mine Overburden Dump Failure: A Case Study. Geotechnical and Geological Engineering 32(2), 297–309.

Sharma S., Roy I. (2015). slope failure of waste rock dump at Jayant opencast mine, India - A case study. Int. J. Appl. Eng. Res., 10(13).

Singh P. K., Kainthola A., Singh Rajesh, Gupte S. S., Maji V., Singh T. N. (2013). Estimation of critical parameters for instability in an in-pit mine-dump. SGAT Bulletin 14(1), 34-44.

SLIDE2 Version 9.0.20 (2021). Stability analysis for soil and rock slopes, Slide, User's Guide, Geo-mechanical software Solution, Roc-science Inc. Canada.

Wu Tien H. (1984). Effect of vegetation on slope stability. Proc. Transportation Research record, 63rd Annual meeting of the Transportation Research Board in Washington District of Columbia, United States 965, 37-46.

Zevgolis I. E. (2018). Geotechnical characterization of mining rock waste dumps in central Evia, Greece. Environmental Earth Sciences 77(16), Art 566, 1–18.