Slope Stability Analysis for Optimisation of Overburden Dump Capacity in Opencast Coal Mines

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Abstract. Slope stability study of Over Burden (OB) dump needs to be carried out for maintaining them at the steepest possible angle without any danger from the stability point of view. One of the most important input parameters for stability analysis is the shear strength i.e., cohesion and angle of internal friction of the heterogeneous dump mass. To assess the shear strength behaviour of OB materials, a large direct shear machine (LDSM) is designed and developed at CMPDI Ranchi. To facilitate the testing of materials with bigger particle sizes, LDSM features a shear box of dimension 1000 mm × 1000 mm × 1000 mm. A large specimen with a thickness up to 500 mm and maximum particle size (D_{max}) up to 80 mm can be tested in accordance with ASTM D3080-98 (ASTM D3080 in Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM International, West Conshohocken, PA, 2011). 7 different OB materials from Magadh Coalfields were collected and tested for their shear strength. With obtained shear strength parameters, various profiles of slopes are checked for slope stability using 2D limit equilibrium softwares Slide2 and GALENA to determine an optimised slope profile. The probabilistic modelling is adopted to produce a statistically distributed Factor of Safety (FoS) rather than a deterministic value to avoid the uncertainties associated with the input parameters. This paper aims to predict the higher safer height for OB dumps based on shear strength parameters.

Keywords: Large Direct Shear Box · Over Burden Dumps · Slope Stability · Slide2 · GALENA

1 Introduction

Opencast mining operation involves the excavation of overburden (OB) materials comprise of low-grade and barren materials to access the underlying coal seam. Any instability in the OB dump can affect production and safe mining operations. The stability analysis of dumps in this paper aims to ascertain the maximum possible dump height using the strength properties derived from direct shear testing as input. In India, guidelines for the design of OB dumps are enforced by the Coal Mine Regulations Act (CMR)

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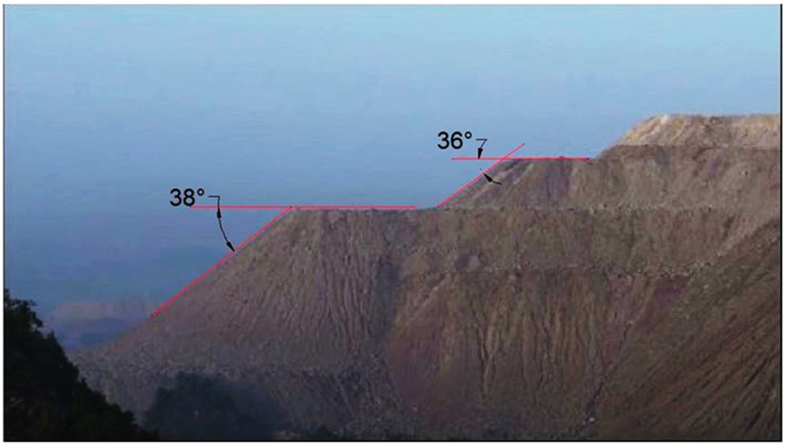

Fig. 1. Individual Bench Angles of External OB Dump at Northern Coalfields Limited

2017 [2] and are verified by the Director-General of Mine Safety (DGMS) [3]. As per the existing guidelines, the slope of an OB dump bench shall be determined by the natural angle of repose of the material being deposited but, in any case, shall not exceed 37.5° from the horizontal. A steeper slope of OB bench can be planned if a scientific study recommends the same. Any OB dump exceeding 30 m in height shall be benched so that no bench exceeds the height of 30 m and the overall slope shall not exceed 1 vertical to 1.5 horizontal. There should be a horizontal berm of 30 m width in between the individual 30 m high dump benches. The height of the external dump i.e. extend outside the mine and above the ground level, shall be a maximum of up to 90 m above ground level, formed in 3 benches. The toe of an OB dump shall not be extended to any point within 100 m of a mine opening, railway or other public works, public road or building, or other permanent structure not belonging to the owner of the mine.

The dump formation in Indian opencast coal mines primarily involves end dumping. This practice of end dumping makes individual benches attain a slope equivalent to the material's angle of repose, which may vary between 37°–40° [4]. Coal projects of Northern Coalfields Limited and Central Coalfield Limited show the same trend from where the sample collection was carried out and the dumps have reported different values of the bench angles (Fig. 1) ranging from 35° to 45°.

2 Scheme of Stability Analysis

From the geotechnical characterization of OB materials, it was observed that particle sizes ranging from 25 mm–80 mm are present in abundance. These contribute approximately 50% of the mass of OB dump materials (Fig. 2). Standard laboratory direct shear test (DST) with specimen size of 60 mm × 60 mm × 25 mm permits the maximum particle size (D_{max}) <4.75 mm. Hence, to accommodate the higher particle size i.e. D_{max} < 80 mm, shear strength parameters were obtained using LDSM with specimen size of 1000 mm × 1000 mm × 500 mm (LDST) and D_{max} <80 mm [4]. Shear strength

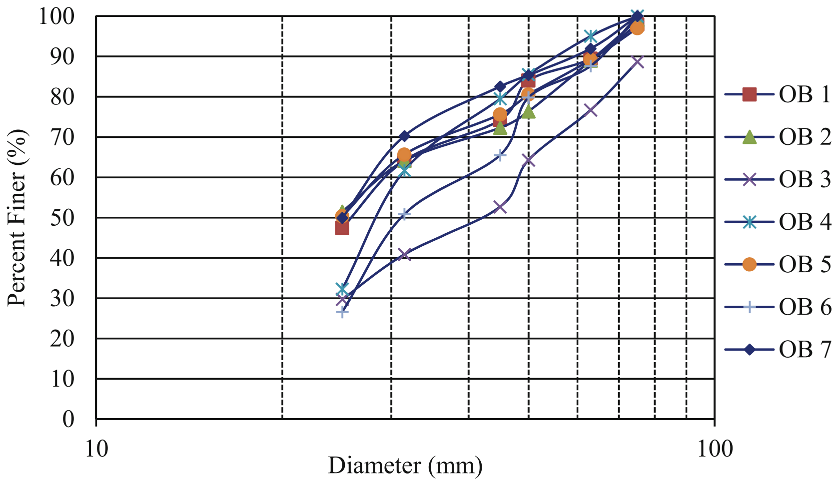

Fig. 2. Grain Size Distribution of OB materials for Particle Size >25 mm

Table 1. Cases Considered for Stability Analysis

Dump	Height (M)	Bench angle	Strength Properties
	90, 120, 150	37.5°, 39°, 40°	DST and LDST

parameters of 7 OB materials determined from DST and LDST are analysed to understand the effect on slope stability of the OB dumps for various profiles [5]. To ascertain the possibility of the enhancement of dump capacity and assessment of dump stability under high stress conditions, the stability analysis of the OB dumps is carried out for the cases shown in Table 1.

2.1 Slope Stability Analysis Using Slide2 and GALENA

Stability analysis is carried out by a 2D limit equilibrium based software Slide2 from Rocscience group [6] and GALENA [7]. First, using Slide2, the analysis is carried out for deriving the factor of safety using Bishop simplified and Janbu simplified method, and probability analysis is carried out using Latin-Hypercube sampling method. Then, these results are affirmed with the results obtained using GALENA. As the observations of past failures suggest that the predominant failure pattern is circular in OB dumps, hence failure surface is assumed circular. While Slide2's comprehensive analysis takes care for local and global failures, individual failure surfaces need to be defined for each, global and local failures, in GALENA. Slide2 helps in avoiding the uncertainties in the manual failure surface selection through grid search. The concept of restraints is used to focus the investigations on meaningful failure surfaces during analysis in GALENA. In practice, failures nearly always pass through, or near, the toe of the slope. Hence

Table 2. Shear Strength Parameters used in the Analysis

	C_{mean} (kN/m^2)	ϕ_{mean} (°)	SD_c (kN/m^2)	SD_ϕ (°)
DST	6.32	35.58	2.03	1.74
LDST	6.91	42.23	5.23	1.96

X-LEFT, X-RIGHT and RADIUS system in GALENA is used to define and explore the area of interest.

2.2 Considerations for the Analysis

The horizontal seismic coefficient is incorporated in the analysis for pseudo static conditions. Seismic forces are considered as per Indian standard criteria for Earthquake Resistant Design of Structures IS 1893 (Part 1):1984 (reprint 2002) [8]. Seismic force/coefficient α_h is calculated as per the above IS Code by two methods named Seismic Coefficient Method and Response Spectrum Method, and a higher value is taken for slope stability calculation.

Shear strength properties of 7 samples of Magadh OCP derived from DST and LDST are taken for this analysis [5]. The dump is the composition of all the collected materials; hence, statistical analysis is carried out for deriving mean and standard deviation for strength properties. The shear strength properties, i.e., cohesion (c) and friction (ϕ) used in the stability analysis are shown in Table 2. In the case of cohesion of the material, standard deviation (SD) is high because the composition of soil in OB dumps is ranging from clay to sand and higher. It's impact on the analysis is less because the slope stability of material with higher particle size depends more on the clast formation and inter particle locking [9] which is a function of internal friction.

Unit weight is considered uniform throughout the dump, and it is taken as 18 kN/m^3. Uniform strata condition for the foundation is assumed for the analysis. To account for the effect of water, the phreatic surface is considered at the base of the dump. Material properties of the dump are assigned for inclusion within the simulations, based on a normal distribution derived from a mean and standard deviation.

3 Results and Discussion

Factors of Safety (FoS) are derived for dump sections with varying dump heights of 90 m, 120 m, and 150 m and varying dump face slope angles of 37.5°, 39°, and 40°. Furthermore, FoS calculation is carried out for both local and global scenarios for each case. Typical results from the stability analysis viz Model with the height of 120 m, analysed using strength parameters from LDST for local and global failure analysis are presented here in Figs. 3 to 5.

A total of 9 Slide2 Models (SM) and 9 GLENA Models (GM) of dumps sections are prepared for the analysis. Each model is prepared for a certain bench angle and overall height. Shear strength properties from both DST and LDST (see Table 2) are considered in each model. Afterwards, each model is analyzed based on failure surface assumption for local and global failure and then, FoS for critical failure circle and probability of failure (PoF) for the critical failure surface is carried out. A summary of results for critical FoS required, mean FoS from model analysis and its standard deviation (SD) is presented in Table 3 to 8.

Comparison plots for FoS from GALENA are prepared for FoS for DST and LDST of OB Dumps for Local and Global Failure in Figs. 6 and 7.

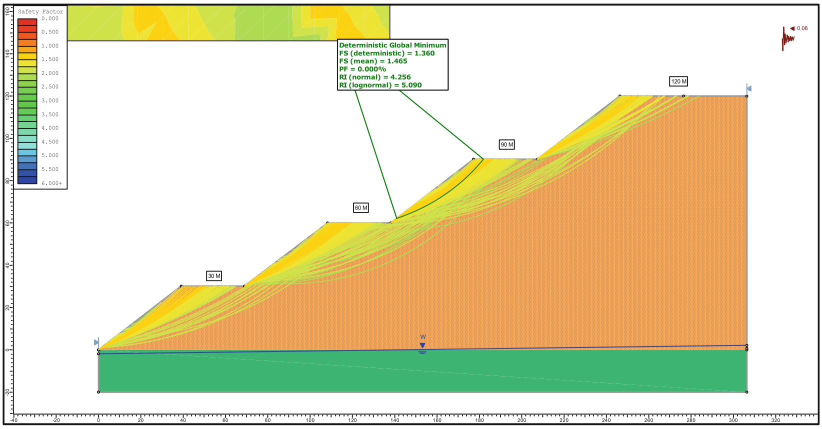

Fig. 3. SM2: Slide2 Analysis Results for Dump Height 120 m and Bench Angle 37.5° with LDST Parameters

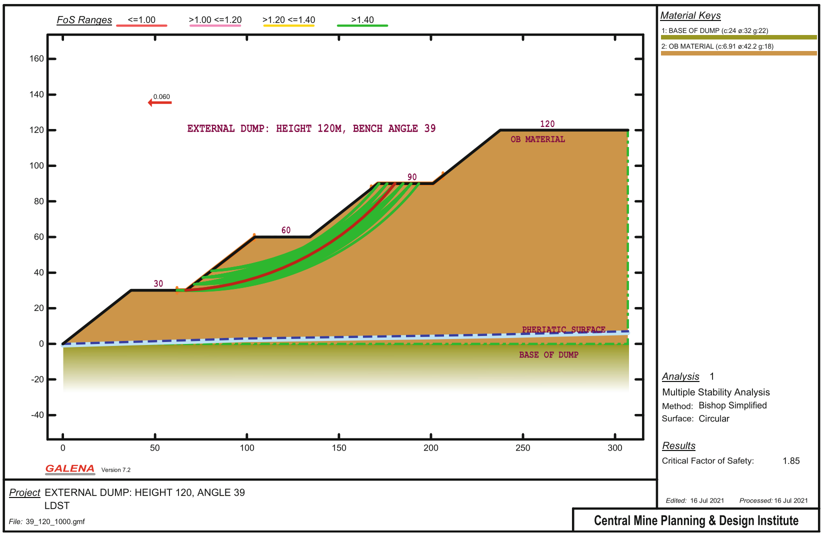

Fig. 4. GM5: GALENA Analysis Result for Critical FoS for Local Failure for Dump height 120 m and bench angle 39° with LDST Parameters

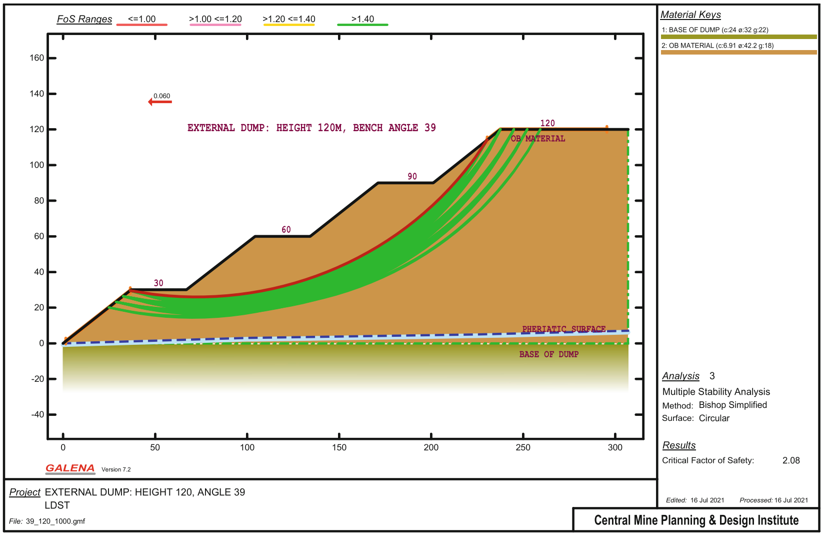

Fig. 5. GM5: GALENA Analysis Result for Critical FoS for Global Failure for Dump height 120 m and Bench Angle 39° with LDST Parameters

Table 3. OB Dump with 37.5° bench angle

Model	**Height (m)**	**FoS (DST)**				**FoS (LDST)**			
		Bishop	Janbu	Mean	PoF	Bishop	Janbu	Mean	PoF
SM1	90	1.08	1.05	1.08	13.8	1.34	1.30	1.47	0
SM2	120	1.09	1.06	1.09	11.7	1.36	1.32	1.46	0
SM3	150	1.20	1.18	1.07	13	1.507	1.47	1.43	0

Table 4. OB Dump with 39° bench angle

Model	**Height (m)**	**FoS (DST)**				**FoS (LDST)**			
		Bishop	Janbu	Mean	PoF	Bishop	Janbu	Mean	PoF
SM4	90	1.04	1.03	1.04	25.9	1.30	1.27	1.41	0
SM5	120	1.05	1.03	1.05	26.4	1.3	1.27	1.42	0
SM6	150	1.07	1.05	1.07	20.08	1.32	1.30	1.45	0

The analysis results show that FoS is invariably high for the analyses with the shear strength parameters from the Large direct Shear Test when compared with the analyses with shear strength parameters from the conventional Direct Shear Test. The mean and PoF values derived from the Slide2 indicate that the dump height of 90 m, 120 m, 150 m with individual bench angles 37.5, 39 and 40° result in a safer mean FoS with zero PoF for

Table 5. OB Dump with 40° bench angle

Model	Height (m)	FoS (DST)				FoS (LDST)			
		Bishop	Janbu	Mean	PoF	Bishop	Janbu	Mean	PoF
SM7	90	1.0	0.97	1.00	44	1.36	1.32	1.46	0
SM8	120	1.03	1.01	1.03	32.3	1.27	1.26	1.42	0
SM9	150	1.04	1.025	1.040	27.3	1.30	1.27	1.42	0

Table 6. OB Dump with 37.5° bench angle

Model	Height (m)	Analysis	FoS (DST)			FoS (LDST)		
			critical	mean	SD	critical	mean	SD
GM1	90	Local	1.17	1.16	0.087	1.47	1.49	0.135
		global	1.65	1.65	0.120	2.17	2.12	0.157
GM2	120	Local	1.57	1.56	0.118	1.98	1.99	0.151
		global	1.59	1.58	0.117	2.02	2.03	0.154
GM3	150	Local	1.50	1.51	0.112	1.91	1.93	0.149
		global	1.65	1.66	0.116	2.10	2.12	0.161

Table 7. OB Dump with 39° bench angle

Model	Height (m)	Analysis	FoS (DST)			FoS (LDST)		
			critical	mean	SD	critical	mean	SD
GM4	90	Local	1.05	1.06	0.092	1.32	1.36	0.142
		global	1.59	1.59	0.120	2.02	2.05	0.158
GM5	120	Local	1.45	1.46	0.105	1.85	1.86	0.142
		global	1.63	1.63	0.115	2.08	2.09	0.157
GM6	150	Local	1.45	1.45	0.106	1.84	1.86	0.144
		global	1.74	1.74	0.131	2.22	2.23	0.187

all case with strength parameters derived from LDST. These results are in confirmation with the results obtained from GALENA. Though it is evident from the Table 3–8 that for same section of slope model, Slide2 tends to give conservative result than GALENA. It is due to efficient algorithm of Slide2 which automatically looks for the critical surface. The manual search of potential critical surface in GALENA sometimes may deviates from the actual critical surface.

For all cases, the Large Direct Shear Test (LDST) has reported higher FoS than that of Direct Shear Test (DST) by a factor of at least ~1.5 times (Figs. 6 and 7). Hence, one

Table 8. OB Dump with 40° bench angle

Model	Height (m)	Analysis	FoS (DST)			FoS (LDST)		
			critical	mean	SD	critical	mean	SD
GM7	90	Local	1.04	1.03	0.085	1.31	1.33	0.135
		global	1.61	1.61	0.125	2.05	2.06	0.165
GM8	120	Local	1.37	1.36	0.099	1.73	1.75	0.149
		global	1.61	1.62	0.119	2.06	2.07	0.144
GM9	150	Local	1.45	1.45	0.110	1.85	1.85	0.142
		global	1.73	1.74	0.135	2.22	2.23	0.167

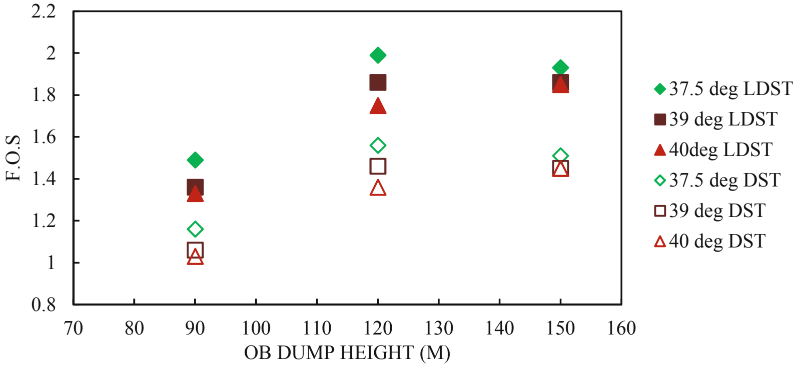

Fig. 6. Variation of FoS w.r.t Dump Height and Slope Angle of OB Dumps for Local Failure on DST and LDST

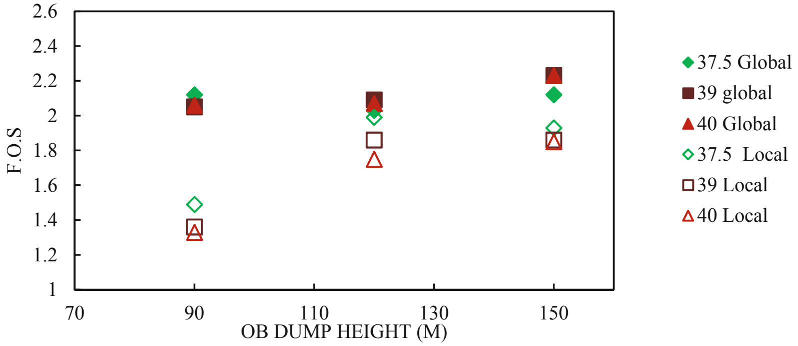

Fig. 7. Variation of FoS w.r.t Dump Height and Slope Angle of OB Dumps for Local and Global Failure on LDST

conclusion is that the shear strength parameters derived from the DST underestimate the stability of the dumps. The shearing mechanism remains the same in varying particle sizes but the zone of influence of shear is higher with a bigger particle size which aids in shear strength parameters [9].

It is observed that local failure reported lesser FoS values when compared to that of global failure (Fig. 7), suggesting that local failure is critical for dumps up to a height of 150 m. Furthermore, in the case of local failures, it is observed that FoS is increasing with the increase of dump height for local failures up to 150 m. This can be attributed to the lower normal stresses generated due to the lower height of the dump.

Dump sections of three different bench slope angles, 37.5°, 39° and 40° were considered to assess the significance of slope angle on FoS. Although dump sections with 37.5° slope angles have shown slight incremental FoS for local failure but no such variance is observed in the global failure scenario. However, it can be ascertained that the dump slope angle has minimal impact on the dump stability up to the max considered slope angle of 40°.

4 Conclusion

Analysis for assessment of dump optimization of OB dumps is carried out by altering the height and bench slope angle. It is inferred that the dump height can be safely extended up to 150 m with adequate FoS. However, OB dump should be limited to 150 m above ground level because, with the increase in the height of the dump, the surface area of the dump at ground level also increases, leading to a need for more land acquisition. Considering this, after reaching the height of 150 m, the OB dump should be advanced in the inward direction towards the mine as internal dump. Also, higher dumps may not be economically and ergonomically viable considering the haulage and fuel costs. Increasing the dump height beyond 150 m above ground level may lead to global failure which will be more dominant than local failure, leading to more damage to men and machinery during failure. Also, the optimum height consideration should be taken into conjecture with bearing capacity and other local attributes before deciding the final height of OB dumps.

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