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Stability analysis of a mine waste dump over an existing dump

Dump slope stability is an important activity in the life of an opencast mine. This is because of the safety to mine, machine and personnel as well as economic impact on production. In this paper, stability of heightening of an existing dump is analyzed using analytical method. The waste dump material properties are determined in the laboratory like the cohesion, angle of internal friction, permeability, bulk density, grain density, particle size distribution and in-situ moisture content. The stability of the dump slope is simulated for two extreme conditions of very dry and a wet environmental conditions. Analysis shows that the effects of water on dump stability is more prominent than its bulk density. In these situations, it is pertinent to use the slope stability measures or change the dump profile for better dump stability. In this paper, methodology is developed to ascertain the stability of the existing dump as well as stability analysis by heightening over the older dumps.

Keywords: *Waste dump, slope stability, analytical solution*

Introduction

Increasing the height of mine waste dump is an important engineering aspect of an opencast mine because of its economic impact on production operations and safety to mine, machine and personnel. This is further important because of the space crunch and the competition among the rivals for best utilization of land space and natural resources. Steep slopes are favourable for economic reasons; while low slopes angles are favoured for stability reasons. Any compromise between these two options sometimes results in dump slope failures.

Stability of waste dump is mainly related to the design of slopes as well as the waste dump material properties. The factor of safety is thus dependent on the type and nature of the waste dump material as well as water content. To determine the material properties ten sets of sample have been collected from various location of the existing waste dump to determine the in situ moisture content, permeability, grain size distribution, shear strength, cohesion and angle of internal friction.

Numerical investigations have been carried out using the limit equilibrium methods like Bishop's simplified and Spencer-Wright models are used to ascertain the optimum waste dump slope angle. To simulate the condition of water content two extreme conditions have been assumed like dry and wet condition. The dry condition exists in summer (temperature more than 50^0C) whereas the wet conditions in monsoon season where average rainfall over twelve years is about 1425 mm per year. Because of wet conditions the safety factor of the waste dump slope decreases substantially. It has been found that overall slope angle of about 28^0 is good enough for the satiability of the waste dump slope in monsoon season without any ground stability measures.

Case study

In this paper, waste dump at Sukinda mines (chromite), Kalipani, India is discussed. The mine is located in Sukinda valley, in the state of Odisha, contains 97% of India's chromite ore deposit. The entire lease area represents a highly weathered product of ultramafic mass which is overlain by 10 to 15 m thick ferruginious laterite, top part of which is further decomposed to soil for about 10 to 15 cm. The northern and southern part of the lease area is covered by a 5 to 10 m thick detrital aggregate consisting of boulders, pebbles, cobbles, sand, clay etc., whereas the central part is covered by ferruginious laterite overlain by thin layer of soil (Chakraborty and Chakraborty, 1984). The average annual rainfall over last twelve years (1999 to 2011) indicates an average precipitation of 1421 mm. This signifies that the study area is located in heavy rainfall area.

The paper discussed the work conducted for the existing and proposed waste dump sites (Fig.1). The plan of the existing waste dumps shown in Fig.2 consist of three stages, each having height of 20 m. The existing waste dump is proposed to increase the height of the waste dump by 15-20 m above top bench making the overall height of the waste dump to 75-80 m. The plan of the proposed waste dump is shown in Fig.3. Critical section of the waste dump is manually assessed for its instability based on their overall slope angle

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and overall slope height and three major section (as shown in Fig.3) of the existing dump is selected for stability analysis. Waste dump material is sampled from ten different locations numbered as S-1 to S-10 from the top of existing benches (as shown in Figs.2 and 3). Each samples are collected by digging below the top surface and collected about 50 kg of waste material for laboratory investigation for their geotechnical properties.

(a) (b)

Fig.1 In-situ waste dump site as seen from (a) ground level, and (b) ramp

Laboratory investigation

In this study, an extensive laboratory testing programme has been undertaken to determine geotechnical parameters of waste dump materials. As discussed earlier, sample from existing waste dump at collected from ten different locations to find the particle size distribution, permeability, specific gravity, and direct shear tests. Collected waste dump samples are shown in Fig.4. All these tests are being conducted as per ASTM and IS standards. Results of these tests are discussed here.

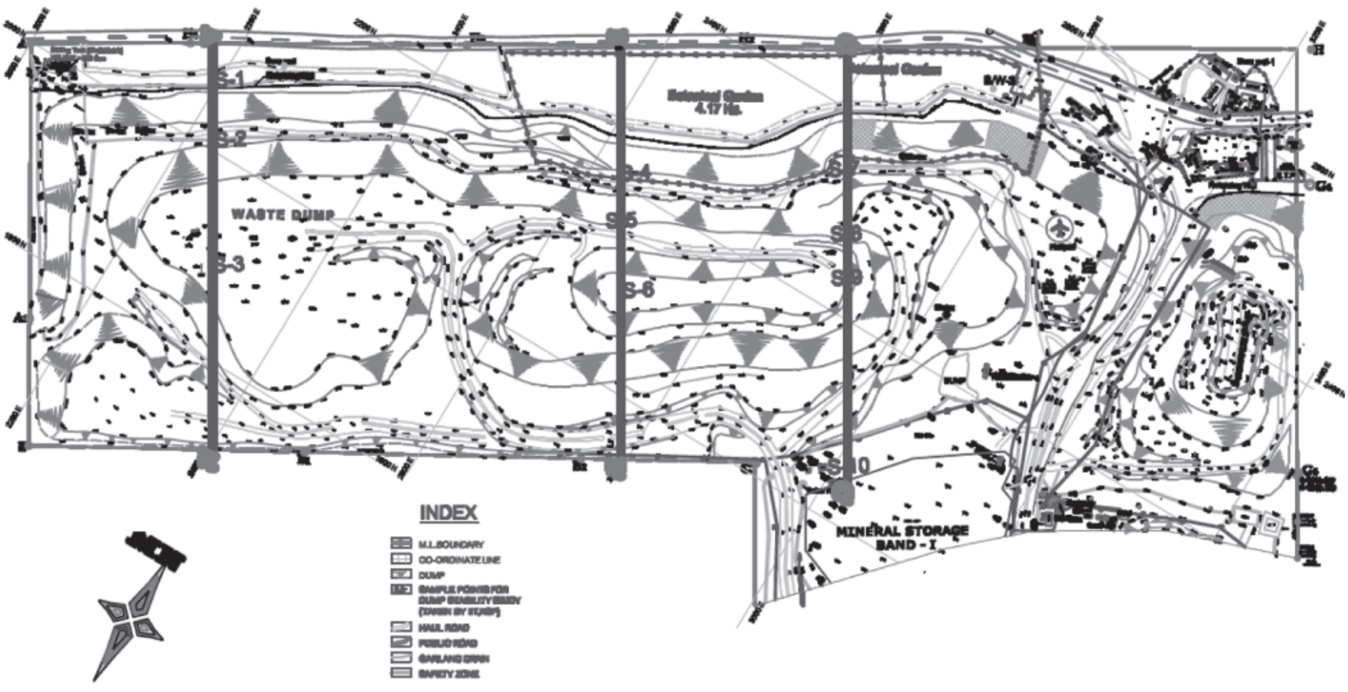


Fig.2 Existing plan of the dump showing the line of three vertical sections and points of sampling

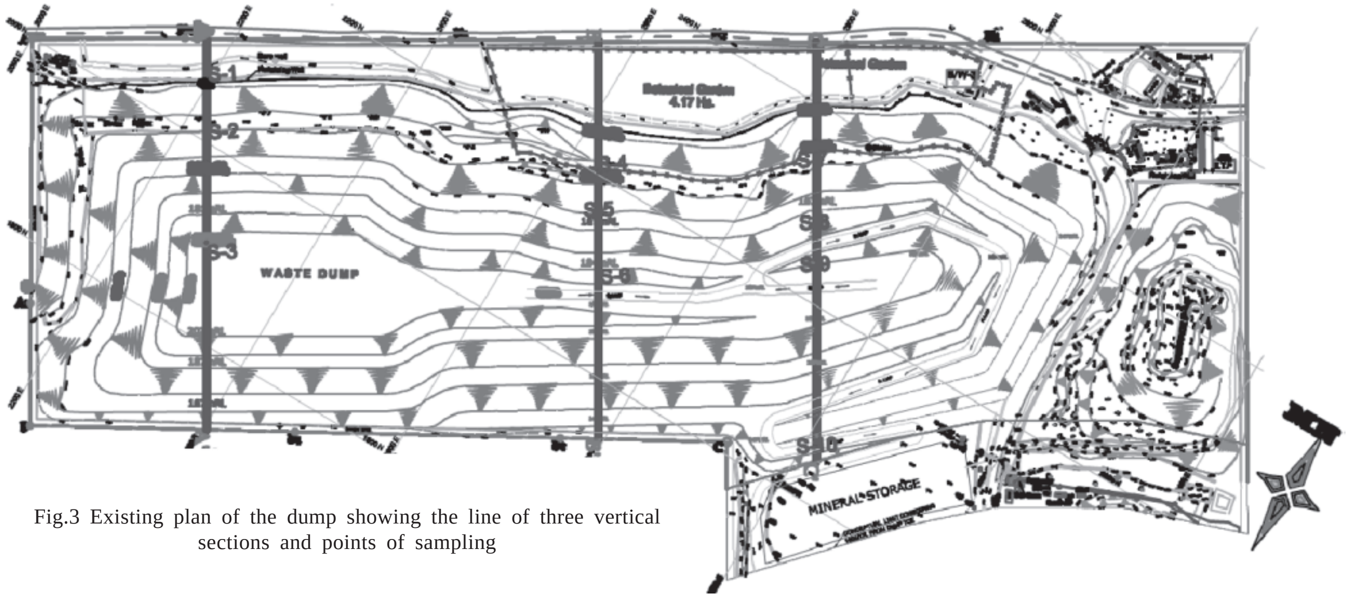


Fig.3 Existing plan of the dump showing the line of three vertical sections and points of sampling

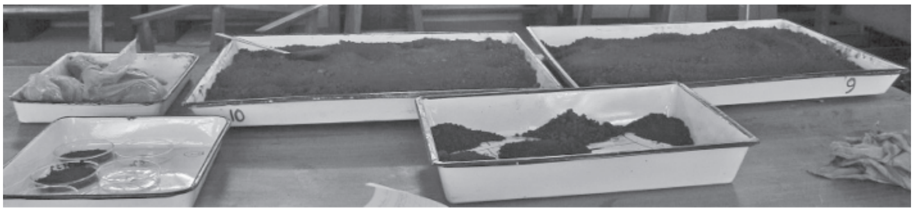


Fig.4 Waste dump material are ready for laboratory test

In situ moisture content varies from 2.5% to 27.64%.The maximum and minimum grain and bulk unit weight of samples has found to be 23.53~34.02 kN/m^3 and 12.73~15.96 kN/m^3 respectively. Based on the grain and bulk unit weight, the porosity of the waste dump material varies from 0.4 to 0.61. The parameter C_c is considered as the coefficient of curvature and C_u coefficient of gradation. If the value of C_u is in the range of 2.17 to 37.78 and C_c in between 0.03 to 3.88, it is considered well graded material. The coefficient of permeability varies as 2.04~1.73×10^{-3} cm/s. Low value suggests that the waste dump material having high water retention capacity. The series of shear strength test on the waste dump shows that, the shear resistance increases with shear displacement until a failure shear stress is reached. After that, the shear resistance decreases for any further increase in the shear displacement. The peak value of the shear strength of the sample is called the peak shear strength and it is different for different sample tested. There is a marked reduction in the shear strength of waste dump material with the increase in the moisture percentage.The friction angle almost same whereas the cohesion reduces with the moisture content. These material properties indicate that the slopes stability is purely based on the cohesive characteristics of the waste dump material. The cohesion and angle of internal friction are determined by assuming that waste materials fail based on the Mohr-Coulomb failure criteria. Table 1 lists the cohesion and angle of internal friction of materials with respect to its moisture content.

Table 1: Shear strength properties and bulk modulus of samples with ascending as received moisture content

	Sample number	Moisture (%)	Cohesion (kPa)	Angle of internal friction (φ)	Bulk unit weight (kN/m^3)
1.	S-8	2.50	8.428	43.47	13.84
2.	S-10	5.40	11.36	39.32	11.41
3.	S-2	5.64	12.04	42.71	14.64
4.	S-6	6.61	7.191	41.15	15.87
5.	S-7	8.11	8.107	43.23	15.70
6.	S-1	8.79	0.00	48.59	11.29
7.	S-5	9.39	3.573	47.75	15.59
8.	S-3	10.16	1.557	44.68	15.66
9.	S-9	11.63	3.939	46.61	16.33
10.	S-4	27.64	0.00	48.09	15.12

Theory – analytical method

The Bishop’s and Spenser-Wright method an extension of the method of slices are used for calculating safety factors of slopes. In Method of Slicing, the entire volume of material bounded by the slope, circular sliding path having a centre (X,Y) from the toe and tension crack is divided into number of vertical slices as shown in Fig.5. Consider a typical slice shown in Fig.5 has height h, inclination of the base α and height of water h_w. The forces acting on each slice are

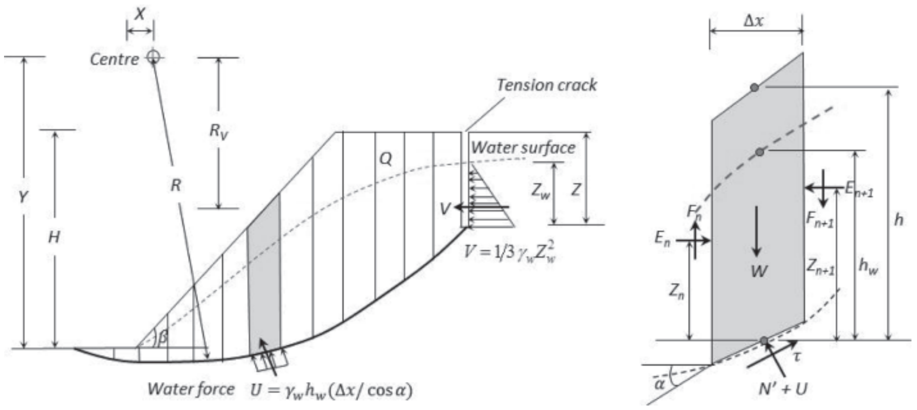


Fig.5 Forces acting on a typical slice (Deb and Verma, 2016)

Results and discussion

WASTE DUMP SLOPE

As waste dump is a three dimensional structure, and its stability analysis is simplified by selecting two dimensional vertical plane along which the potential of failure is more. For this three potential sections have been selected based on field observation and designated as sections A-A’, B-B’ and C-C’. The stability analysis of waste dump has been carried out for existing and proposed profile along sections A-A’, B-B’ and C-C’ as shown in Fig.6. It has been shown that the dump height has already reached a height of 60m at some area over the existing reduced level (RL). The proposed profile is planned to increase the dump height by another 15 m. The stability of both the existing and proposed dump profiles are discussed in this section.

For a particular section, two dump slopes exist. One dips along left side and another along right side of the sections. The slope which is dipping left will be called “Left Side Slope” whereas the other will be called “Right Side Slope”.

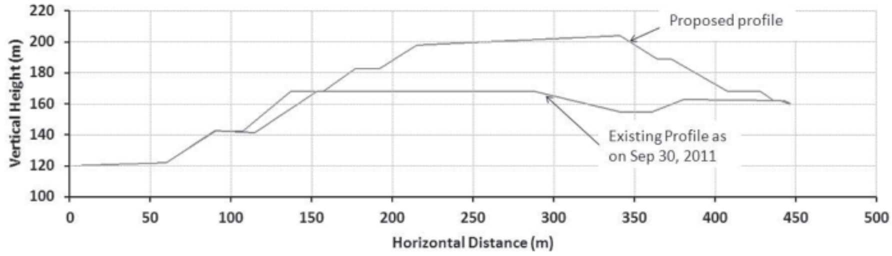
(1) Weight of the slice, W acting downward,

(2) The effective normal force (N') and pore water force (U), where in the absence of interslice forces, $W\cos\alpha - N' - U = 0$.

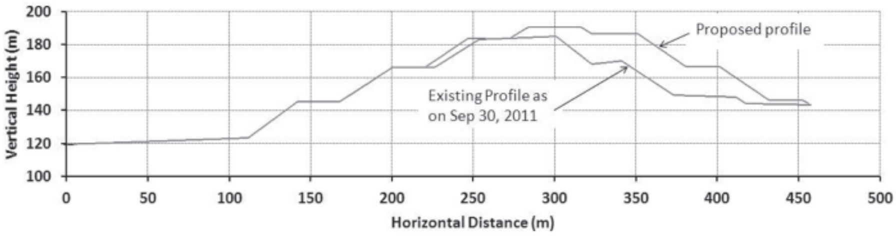
(3) Shear force or resistive force T acts along the base

(4) Interslice forces E_n and F_n act on the left vertical surface and E_{n+1} and F_{n+1} act on the right vertical surface. The location of the forces is Z_n and Z_{n+1} respectively.

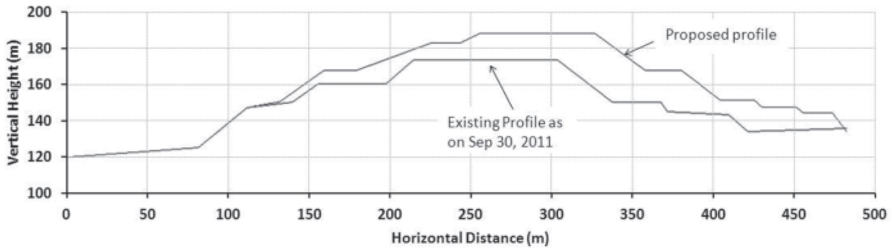
The details about the Bishop’s method and Spenser-Wright method can be referred to from standard text.



(A) Existingand proposed waste dump profile along A-A’ section



(B) Existingand proposed waste dump profile along B-B’ section



(C) Existingand proposed waste dump profile along C-C’ section

Fig.6 Geometrical model of existing and proposed waste dump profile

ASSUMED WATER CONDITION

All the models are analysed for two water conditions as mentioned above. Stability of the slope has been analyzed for two seasons of watery conditions viz., (i) monsoon or wet water condition and (ii) post-monsoon or dry water condition. They are defined below:

(1) Monsoon season (wet condition): Generally, shear characteristics of these materials suggests that cohesion reduces as the moisture content increases in the samples. Also, pore water pressure will be high in the saturated soil strata. For all the sections, the parameter *ru* is taken to be 0.35. In this case, the ratio of γ_w/γ_r varies between 0.360 and 0.521, which means that ratio of h_w/h_r lies between 0.671 and 0.971. Note that a ratio of h_w/h_r = 1.0 represents 100% water saturation of the slope. The assumption made in this study is highly conservative in nature and may occur only if it rains heavy for consecutive several days.

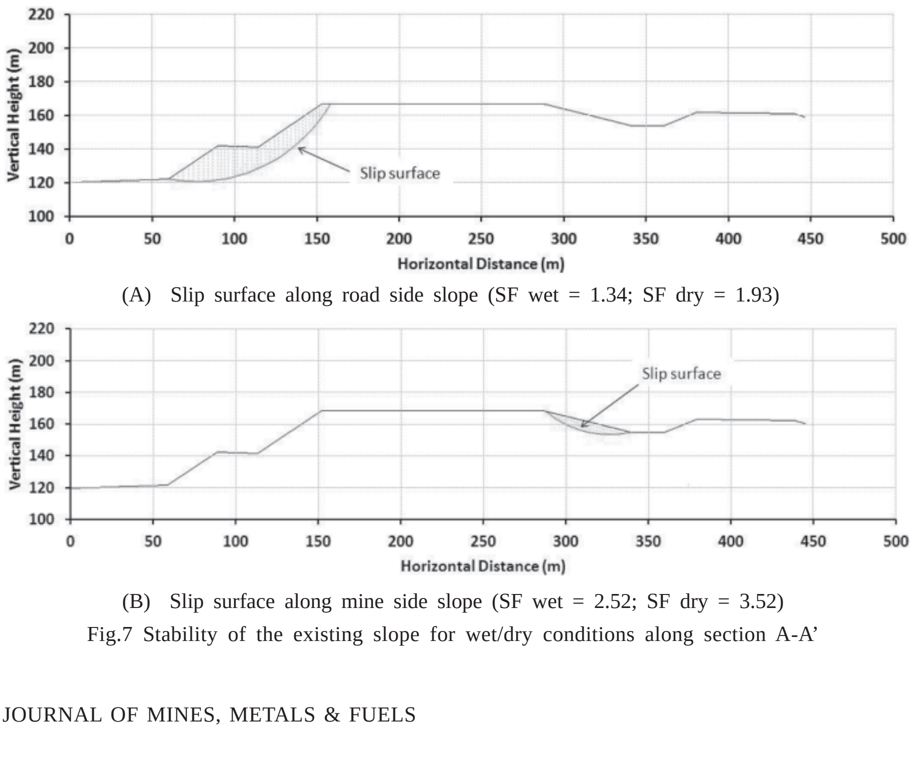
(2) Post-monsoon season (dry condition): Cohesion and friction angles obtained for air dry samples are generally applied for analytical models. In this case, a ruvalue of 0.1 has been considered signifying post rain fall seasons. This assumption provides a ratio of h_w/h_r between 0.191 and 0.277.

Material properties

Since the size distribution of samples (S-1 to S-10) collected from the waste dump may not represent the in situ sizes of particle, cohesion and angle of internal friction of dump material have been reduced by 20% as given in Table 1. Table 2 shows the reduced material properties over the laboratory test data to be used in the analytical models.

Table 2: Waste dump material property used for numerical analysis

Sample no.	Bulk unit weight (kN/m^3)	Cohesion (kPa)	Angle of internal friction (φ)
S-1	11.29	0.00	43.73
S-2	14.64	10.84	38.44
S-3	15.66	1.40	35.75
S-4	15.12	0.00	40.21
S-5	15.59	2.86	38.20
S-6	15.87	5.75	32.92
S-7	15.70	6.49	34.58
S-8	13.84	6.74	34.78
S-9	16.33	3.15	37.29
S-10	11.41	9.09	31.45



(A) Slip surface along road side slope (SF wet = 1.34; SF dry = 1.93)

(B) Slip surface along mine side slope (SF wet = 2.52; SF dry = 3.52)

Fig.7 Stability of the existing slope for wet/dry conditions along section A-A'

Analytical models

For a particular section, two dump slopes exist. One dips towards the existing mine/boundary of neighbouring mine and another dip towards the highway. The slope which is dipping towards the mine will be called "Mine Side Slope" whereas the other will be called "Road Side Slope". All the models are analysed for two water conditions as mentioned above. The safety factors of the slopes are estimated for these conditions.

Existing profile

Using analytical modelling approach, critical slip surfaces of the existing and proposed slope have been determined for the given dump profile for two different water conditions. A critical slip surface signifies a circular surface having the minimum safety factor for the given geometry, material properties and loading conditions. In the following, stability of the existing slope is elaborated.

Section A-A'

Figs.7(A) and 7(B) show the critical slip surfaces for mine side and road side slopes respectively.The critical slip surface for road side slope is obtained with safety factor of 1.34 and 1.93 for wet and dry conditions respectively (Fig.11(A)). Similarly, for mine side slope as shown in Fig.7(B), safety factors of 2.52 and 3.52 have been obtained for wet and dry conditions respectively. These results suggest that for the present geometry condition, both directional slopes are stable.

Section B-B'

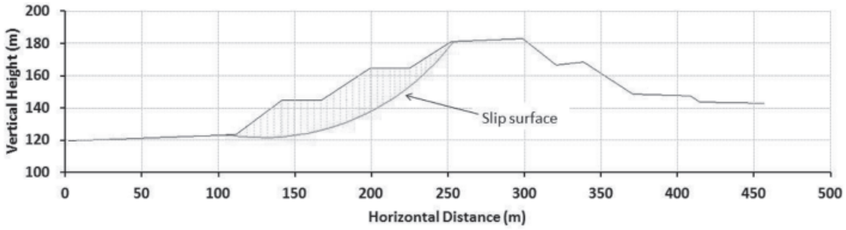
Figs.8(A) and 8(B) shows the slip surfaces for road side and mine side slope along section B-B'. It is noticed that both the slope are very safe in both wet and dry conditions. The wet and dry safety factor of road side slope is greater than 2.0, suggest that the slope is very much stable, whereas it is more than 1.5 for the mine side slope.

Section C-C'

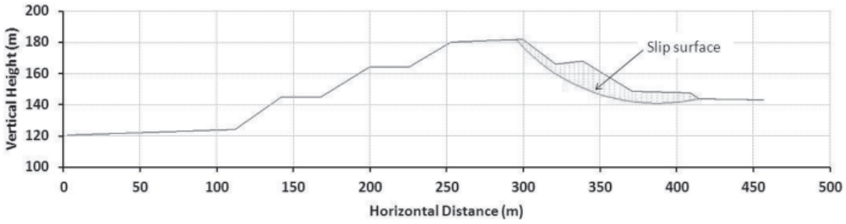
As expected, safety factor of the critical slip surfaces for dry water conditions is more compared to wet water conditions. Figs.9(A) and 9(B) show the safety factor of critical slip surfaces on both the side of the slope along section C-C' is more than 1.2. This suggests that the section of the waste dump is stable even during heavy rain continuously for two to three days.

Proposed profile

The stability of the proposed profile above the existing profile along section A-A', B-B' and C-C' are discussed in this section. The safety

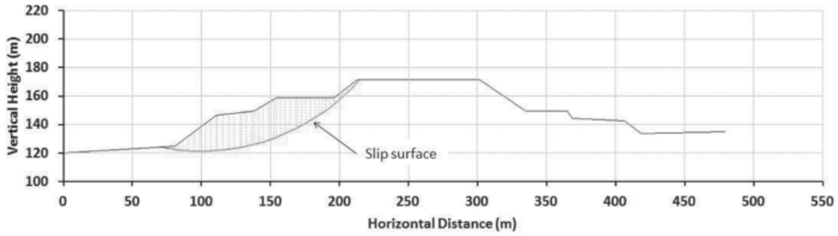


(A) Slip surface along road side slope (SF wet= 2.09; SF dry = 2.13)

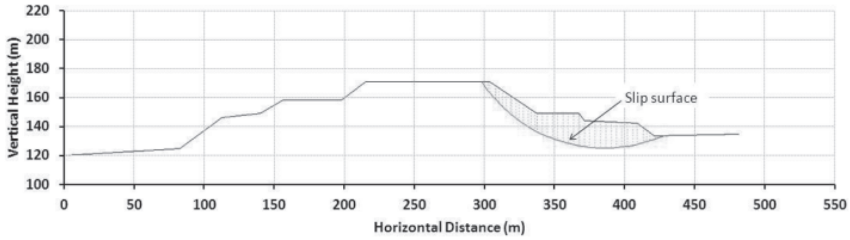


(B) Slip surface along mine side slope (SF wet = 1.62; SF dry =2.32)

Fig.8 Stability of the existing slope for wet/dry conditions along section B-B’

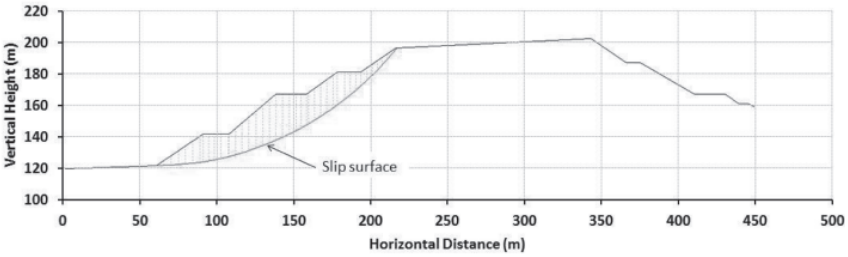


(A) Slip surface along road side slope (SF wet = 1.31; SF dry = 1.53)

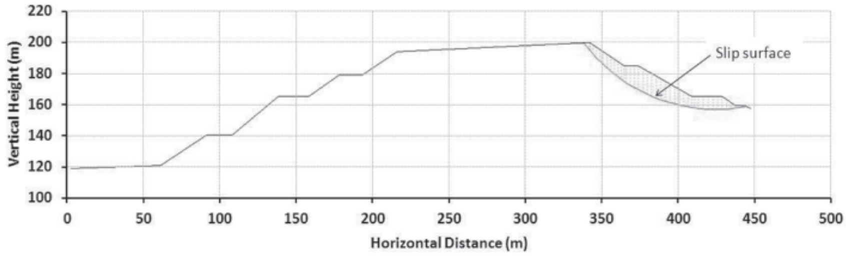


(B) Slip surface along mine side slope (SF wet = 1.94; SF dry = 2.69)

Fig.9 Stability of the existing slope for wet/dry conditions along section C-C’



(A) Slip surface along road side slope (SF wet = 1.22; SF dry = 1.80)



(B) Slip surface along mine side slope (SF wet = 1.45; SF dry = 2.11)

Fig.10.Stability of the existing slope for wet/dry conditions along section A-A’

factor for the road side slope varies from 1.22 to 1.44 for wet conditions and 1.47 to 2.13 for dry conditions. Whereas for mine side slope it varies from 1.45 to 1.53 for wet condition and 2.11 to 2.20 for dry condition. This suggests that all proposed slopes profiles are stable not only in dry but in wet condition too. However, placement of geotextile is required on the road side slopes.

Section A-A’

Figs.10(A) and 10(B) show the critical slip surface for the slope profile along section A-A’ for dry and wet water conditions. The safety factor of road side slope is 1.22 for wet and 1.80 for dry water conditions; whereas for mine side slope it is 1.45 for wet and 2.11 for dry water condition.

Section B-B’

Fig.11 shows the critical slip surface for the slope made by B-B’ line for dry and wet water conditions. The safety factor of road side slope is 1.44 for wet and 1.47 for dry water conditions. The safety factor of mine side slope is 1.53 for wet and 2.20 for dry water conditions. Along section B-B' the height and angle of slope along mine and road side slope are 44m, 210 and 65m, 220 respectively, with safety factors more than 1.2, suggests a very stable lift of the dump.

Section C-C’

Figs.12(A) and 12(B) show the critical slip surfaces for the slope made by C-C’ line for dry and wet water conditions respectively. The safety factor of road side slope is 1.86 for wet and 2.13 for dry water conditions. The safety factor of mine side slope is 1.56 for wet and 2.20 for dry water conditions. Along section C-C’ the slope is stable along mine as well as road side with safety factor more than 1.50 even in wet conditions.

Comparison of existing and proposed profile

A comparison between the existing and proposed waste dump is shown in Table 3 by the percentage change in safety factor, overall slope angle and height of the critical slip surface.

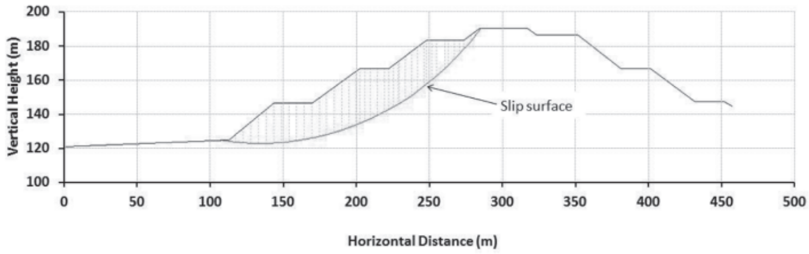
The following major conclusions can be drawn from the above tables:

(1) The existing and proposed dump profiles are safe considering a threshold safety factor 1.2.

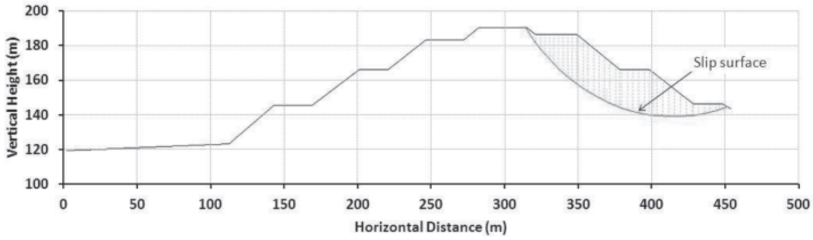
(2) The safety factor of all the proposed slope decreases because of the increase in the waste dump height.

(3) During rainy season (wet conditions), safety factors are lower as compared to dry condition or non-rainy season time.

(4) Although Spencer-Wright method is more accurate than the Bishop's method, the FOS predicted by these methods are almost same.

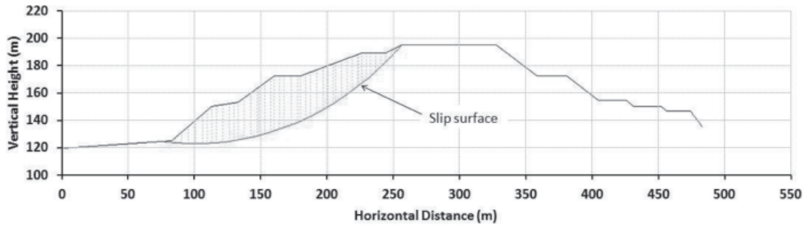


(A) Slip surface along road side slope (SF wet = 1.44; SF dry = 1.47)

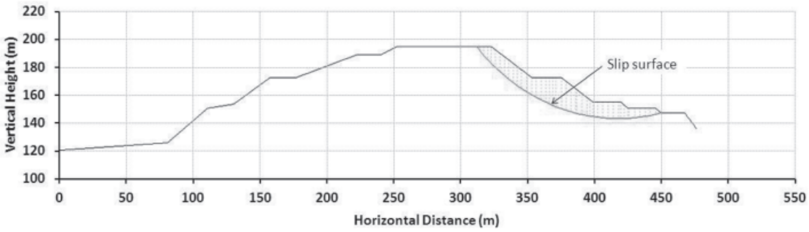


(B) Slip surface along mine side slope (SF wet = 1.53; SF dry = 2.20)

Fig.11 Stability of the existing slope for wet/dry conditions along section B-B'



(A) Slip surface along road side slope (SF wet = 1.86; SF dry = 2.13)



(B) Slip surface along mine side slope (SF wet = 1.56; SF dry = 2.20)

Fig.12. Stability of the existing slope for wet/dry conditions along section C-C'

Conclusions

In this study, an extensive laboratory testing programme has been undertaken to determine geotechnical parameters of waste dump materials. Particle size distribution, permeability, specific gravity, and direct shear tests are conducted on the collected soil/rock samples of the mine. Based on the laboratory tested data, geometry of the slopes and water conditions, limit equilibrium approach has been adopted to estimate the safe waste dump slope at 3 sections. Following conclusions of this study are drawn:

(1) Safety factors for the existing and proposed slopes are above 1.2 for both dry and wet water conditions. This signifies that slopes will be stable for the given material and assumed water conditions.

(2) Permeability analysis shows that waste dump material have water retention capacity.

(3) The factor of safety decreases with the water content into the waste dump. The source of the water can be from rain or groundwater.

(4) The height of the waste dump can be increased to its proposed layout. The maximum and minimum over all slope angles are 28^0 and 19^0 respectively.

(5) Right side slopes are more stable than the road side slopes.

(6) At A-A' section, safety factor of 1.22 has been noticed in the left side slope for 73 m slope height considering wet water condition. Since this value is the least among all other safety factors, it is advisable that while dumping waste rock in the vicinity to A-A' section, it is advisable to reduce the effect of water retention and make necessary arrangement for compaction of loose ground.

TABLE 3: CHANGED IN WASTE DUMP STABILITY FACTORS BECAUSE OF PROPOSED PROFILE (BISHOP'S METHOD)

Section		Road side slope					Mine side slope				
		Height (m)	Slope angle (deg)	Safety factor Dry	Safety factor Wet	Safety factor % change	Height (m)	Slope angle (deg)	Safety factor Dry	Safety factor Wet	Safety factor % change
A-A'	Existing	45	26	1.93	1.34	44.03	14	15	3.52	2.52	39.68
	Proposed	73	26	1.80	1.22	47.54	41	23	2.11	1.45	45.52
B-B'	Existing	59	23	2.13	2.09	1.91	41	19	2.32	1.62	30.17
	Proposed	65	22	1.47	1.44	2.08	44	21	2.20	1.53	30.45
C-C'	Existing	48	20	1.53	1.31	16.79	39	18	2.69	1.94	27.88
	Proposed	62	20	2.13	1.86	14.52	53	19	2.20	1.56	29.09

TABLE 4: CHANGED IN WASTE DUMP STABILITY FACTORS BECAUSE OF PROPOSED PROFILE (SPENCER-WRIGHT METHOD)

Section		Road side slope					Mine side slope				
		Height	Slope angle	Safety factor			Height	Slope angle	Safety factor		
		(m)	(deg)	Dry	Wet	% change	(m)	(deg)	Dry	Wet	% change
A-A'	Existing	45	26	1.73	1.22	41.80	14	15	3.39	2.43	39.51
	Proposed	73	26	1.71	1.17	46.15	41	23	1.88	1.28	46.88
B-B'	Existing	59	23	1.92	1.32	45.45	41	19	2.17	1.54	40.91
	Proposed	65	22	1.93	1.33	45.11	44	21	2.09	1.45	44.14
C-C'	Existing	48	20	2.02	1.45	39.31	39	18	2.51	1.83	37.16
	Proposed	62	20	1.77	1.24	42.74	53	19	2.09	1.49	40.27

(7) For all other proposed sections (except A-A'), factor of safety greater than 1.44 in monsoon season.

(8) Although Spencer-Wright method is more accurate than the Bishop's method, the FOS predicted by these methods are almost same.

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EFFECT OF VARIOUS PARAMETERS ON THE PERFORMANCE OF THE BLASTHOLE DRILLING

(Continued from page 54)

- With the increase of the penetration rate, the required torque to rotate the drill bit and the service life of the tricone bit increases. So, for better performance of the blasthole drilling, the feed force should be 200-250 m/h for the given rock compressive strength.

The mentioned blasthole drill rig gives better performance and the optimum service life of the drill bit when it operates at 165-180 mm drill diameter, 10600-11600 kg feed force, 200-250 m/h penetration rate and 35-75 rpm rotary speed for drilling of 20-60 MPa rock strength.

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