CHAPTER 9

CONCLUSIONS, LIMITATIONS AND SCOPE FOR FUTURE WORK

9.1. Conclusions

A system for Stability Analysis and HAzard RAting (SAHARA) has been developed for evaluating the long-term stability of dump slopes in opencast coal mines in India. It considers Factor of Safety (FoS), maximum horizontal displacement (XDIS), maximum shear strain increment (SSI), Stability Rating and Probability of Failure (PoF) as the performance measuring parameters. The stability state of the dump slope structure was classified into stable, critically stable, and unstable states.

The significant conclusions of this work are as follows:

- The total dump height, bench height, bench slope angle, bench width, density, cohesion, and friction angle of OB dump material were the prime parameters in the design of the dump slope structure. The study showed that the influence of the bench slope angle and the friction angle were the most significant, while the density and total dump height possessed the least impact on the stability of the dump slope structure.
- FoS combined with maximum horizontal displacement and shear strain increment provided improved design criteria for the assessment of slope stability and its long-term performance. The design limits of these output parameters were in line with existing regulatory provisions and findings of the previous studies.
- The instability initiated from the middle benches in large dump slope structures when varying the considered stability governing parameters. The instability zones moved from the middle benches toward the top benches for increased dump height

and propagated from the middle benches toward the bottom benches while varying the bench height, bench slope angle, and bench width. The instability zones were present in all benches when the shear strength of OB dump material was not sufficient to provide adequate resisting force.

- The stability of dump slopes was classified into three categories: 'Stable', 'Critically Stable', and 'Unstable'. For stable slope structure, the FoS was greater than 1.30 while the maximum XDIS and SSI were less than 10mm and 0.25%. respectively. For critically stable slope structures, FoS varied between 1-1.30 while XDIS was 10-100mm and SSI was 0.25-3%. FoS less than 1, XDIS greater than 100mm, and SSI greater than 3% indicated unstable slope structure.

- The stability classification rating for different parameters is given in Table 9.1.

Table 9.1 Summary of stability classification system

Stability Class	**Geometrical Parameters**								**Geotechnical Parameters**					
	T (m)	R	H (m)	R	A (°)	R	W (m)	R	C (kPa)	R	φ (°)	R	ρ (kg/m^3)	R
Stable	<180	4.4-6	<30	7.6-11	<37.5	21.5-30	>30	6.9-9	≥24.8	6.2-8	>29	22.4-29	<1800	6.5-7
Critically Stable	180 - 420	3.8-4.4	30-58	6.4-7.6	37.5 - 45	18.1-21.5	30 - 14	5.6-6.9	24.8-11.2	5.1-6.2	29-24	18.9-22.4	1800-2300	6.2 - 6.5
Unstable	>420	0-3.8	>58	0-6.4	≥45	0-18.1	<14	0-5.6	<11.2	0-5.1	≤24	0-18.9		

T: total dump height, H: bench height, A: bench slope angle, W: bench width, C: cohesion, φ: friction angle, ρ: density, R: rating

- The Latin Hypercube sampling method with a lognormal distribution function provided a best-fit explanation among various examined probability distribution functions.

- The cumulative value of slope stability rating varied from 75.4 - 100 for stable, 64.1 - 75.4 for critically stable, and 0 – 64.1 for unstable state of dump slopes. The PoF was 0.12% for stable, 0.12 to 41.3% for critically stable, and 41.3-100% for unstable slopes.

- The design limit of 10mm of maximum horizontal displacement (XDIS) and 0.25% of maximum shear strain increment (SSI) can be used to delineate vulnerable zones of failure in critically stable dump slopes for their remediation and avoidance of large-scale failure. It will also help in the design of optimally safe dump slope structures for long-term stability and avoiding the construction of unstable dump slopes.

9.2. Limitations of the Current Work:

- Particle size greater than 20mm could not be considered for evaluation of dump material matrix owing to the limited size of the shear test box.

- The formulation of the numerical model considered a competent floor free from any weak material.

- The design limits for the formulation of hazard quantification have an estimation error of 4.7%. Hence, due care should be taken while drawing inferences at boundary limits of the various designed output parameters.

- The empirical formula for evaluating FoS considers uniform bench geometrical parameters such as bench height, bench width, and bench slope angle. It may not be applicable in conditions otherwise.

- The stability rating should be applied for total dump height exceeding 90 m only.

9.3. Scope for Future Work

This work is based on 87 field cases of dump slopes. The database should be further enriched for its wider applicability. The effect of dump interface, seismicity, and rainfall, could be incorporated in future studies. The extent of PoF may be further reduced by reducing the range of spatial variability of the geotechnical properties of the dump material. Exclusive nonlinear failure criteria could be developed for the improved explanation of failure in OB dump materials.

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