



## DESIGN AND SAFETY ASSESSMENT APPROACH FOR MINE WASTE DUMPS

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### Abstract

The stability of overburden (OB) and waste dump slopes remains one of the most crucial geotechnical issues in surface mining operations, especially in Indian opencast coal and metal mines. This comprehensive literature review evaluates the multidimensional factors influencing dump slope stability and synthesises findings focusing on the Indian context. Material characteristics – such as grain size distribution, cohesion, internal friction angle, density, and moisture retention – play a fundamental role in determining the shear strength of dump materials. Geometric factors, including overall slope angle, bench configuration, and dump height, further influence the internal stress regime and potential slip surfaces. Hydrological factors are especially critical in Indian conditions, where intense monsoon rainfall elevates pore water pressures and reduces effective stress, thereby triggering slope failures. Additional aspects such as seismic loading, vegetation cover, and construction methodology, including dumping rate and compaction practices, also contribute significantly to stability outcomes. Numerical modelling techniques using

FLAC and FLAC/Slope have become essential tools for predicting dump performance under varied load, moisture, and geometric conditions. Parametric analyses and calibrated models based on field data provide a more realistic estimation of the factor of safety and failure mechanisms. Figures and tabulated summaries presented in this study enhance understanding of critical factors and demonstrate practical approaches for ensuring long-term stability and sustainable waste dump management in Indian surface mining operations.

### Introduction

In many mining projects, more environmental damage results from waste rock disposal than any other component of the operations. It is also usually the most visible component. The area occupied by waste rock storages commonly represents a large part of the project 'footprint', often much more extensive than the mine itself. In an open pit mine, the overall stripping ratio is determined by the dimensions and geometry of the ore body, the value of the ore and the shape of the pit, which itself may be determined by slope stability

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considerations. The phrase "mine waste dump" refers to waste/overburden material that has been mined/excavated and moved primarily by truck and by other means of transport/transportation systems, either to the mined-out area or outside the final/ultimate pit boundary, and is then discharged/deposited to form large dumps. These loose waste/overburden materials produced during mining operations are known as internal overburden dump when backfilled into the mined-out regions and as external waste dumps when placed outside the pit area. Under specific mining and geological circumstances (horizontal or flatly lying deposits up to 100), internal dumps are usually generated using transportless mining techniques. Stripping costs for internal dumping on equipment and dump re-handling are significantly higher than those for external dumps. The successful completion of the mining operation as well as the subsequent restoration and reclamation of the mined-out area and waste dumps are directly and significantly impacted by the handling of such overburden/waste materials produced during open-pit mining. Loose open-pit waste dump planning, design, construction, and layout, as well as the process of disposing of them, are crucial and integral parts of surface mine (open pit/opencast/quarry, etc.) planning and the unit operations, and these are as important as that of the open-pit mine proper, as they have a significant impact on the cost of production and safety (Mukhopadhyay, 1988).

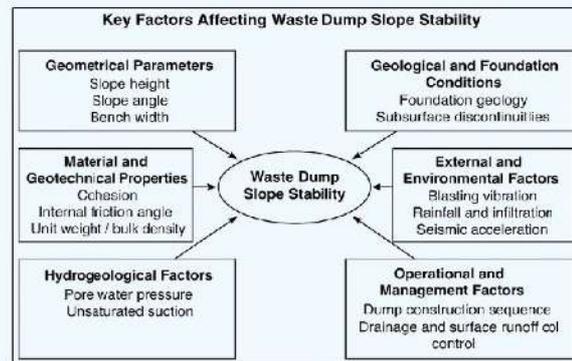


Figure 1: Showing the interaction of key factors in a stability framework

The following objectives apply in planning the storage and disposal of waste rock to minimise environmental damage (Kesler & Simon, 2015):

- ◆ The area occupied by the waste rock storage (i.e., its 'footprint') should be minimised in so far as this is consistent with other objectives;
- ◆ The new landform created by the waste rock storage should be consistent with its future land use(s), in terms of slopes, accessibility, surface roughness;
- ◆ The new landform should be stable;
- ◆ The new landform should not be any more erodable than comparable natural landforms in the vicinity;
- ◆ If the waste rock includes materials that have the potential to generate acid drainage, the storage should be designed to prevent or control this occurrence (e.g., avoidance of run-off from upstream catchment areas);
- ◆ The surface of the waste rock storage should be amenable to rehabilitation, consistent with its future land use(s); and
- ◆ If possible, the new landform should be congruent with its surrounds, meaning that it should not be visually intrusive.

This review synthesises research findings and field observations from 1995 to 2025,



encompassing both coal and metal mining environments. It evaluates key slope failure mechanisms, such as rotational slips, translational slides, and progressive failures, and identifies the dominant influencing factors. By integrating insights from empirical studies, case-based

analyses, and numerical simulations, the review aims to assist geotechnical engineers and researchers in formulating robust, data-driven design and monitoring strategies for safer and more sustainable waste dump management in Indian opencast mines.

**Table 1: Extended Summary of Indian Waste Dump Slope Stability Case Studies**

Sl. No.	Mine / Site	Location	Study Approach / Tools Used	Key Findings	Recommended Mitigation Measures
1	<b>Srirampur OCP-II</b>	SCCL, Telangana	Limit equilibrium & FLAC/Slope modelling	Factor of Safety (FoS) dropped below 1.2 at 45° slope; influenced by moisture increase.	Reduce overall slope to 37°, improve surface drainage, add retaining toe bunds.
2	<b>Sonepur Bazari OCP</b>	ECL, West Bengal	3D numerical analysis & field monitoring	High spoil height (120 m) and poor compaction caused tension cracks.	Layer-wise dumping, compaction by dozers, and installation of piezometers.
3	<b>Gevra OCP</b>	SECL, Chhattisgarh	Slope mass rating & geotechnical testing	Weathered shale led to progressive failures near dump toes.	Maintain minimum FoS > 1.3; vegetation for surface erosion control.
4	<b>Lakhanpur OCP</b>	MCL, Odisha	FLAC2D modelling & inclinometer data	Failure surfaces developed within loose OB layers during monsoon.	Provide drainage trenches, reinforce slope toes with boulder pitching.
5	<b>Noamundi Iron Mine</b>	Tata Steel, Jharkhand	Limit equilibrium with groundwater coupling	FoS is sensitive to pore pressure buildup during wet season.	Construct subsurface drains, monitor groundwater head continuously.
6	<b>Jayant OCP</b>	NCL, Madhya Pradesh	Drone survey & empirical design	Outer dump stability improved by maintaining bench width ratio 1:1.5.	Regrade outer dump slopes; install rock-armored channels.



Sl. No.	Mine / Site	Location	Study Approach / Tools Used	Key Findings	Recommended Mitigation Measures
7	<b>Kalinga OCP</b>	MCL, Odisha	Shear box testing & slope modelling	Weak clay seams within dump material caused circular slips.	Geotextile layers and proper placement of cohesive materials.
8	<b>Singrauli Coalfield</b>	NCL, M.P.	Rainfall-infiltration coupled simulation	Heavy rainfall episodes increased pore pressure by 30-40%.	Early drainage installation and grass turving to reduce infiltration.
9	<b>Jhingurdah OCP</b>	NCL, M.P.	Field instrumentation & limit equilibrium	Post-blast vibration amplified minor tension cracks.	Limit blast charge per delay; maintain safe distance from dump crest.
10	<b>Talcher OCP</b>	MCL, Odisha	Long-term dump monitoring	Surface runoff channels were obstructed, accelerating erosion at toes.	Regular de-silting of drains and maintaining vegetation covers.
11	<b>Kusmunda OCP</b>	SECL, Chhattisgarh	FLAC3D simulation	Progressive failure during the dump extension phase was observed at height > 90 m.	Dump re-profiling, controlled height sequencing, and installation of drainage benches.
12	<b>Rajmahal OCP</b>	ECL, Jharkhand	Limit equilibrium + field FoS verification	Old internal dump had FoS < 1.1 due to poor compaction.	Regrading, compaction by crawler dozers, and implementation of staged deposition.



Table 2: Comprehensive List of Factors Affecting Waste Dump Slope Stability

Category	Parameter	Description / Influence on Stability
<b>1. Geometrical Parameters</b>	<b>Slope Height (H)</b>	Greater dump height increases driving forces, leading to higher failure potential unless properly benched.
	<b>Slope Angle (<math>\beta</math>)</b>	Steeper slopes reduce the factor of safety; the optimal design angle depends on material shear strength.
	<b>Bench Width and Berm Spacing</b>	Adequate berms reduce runoff, catch rockfalls, and provide drainage; narrow benches promote erosion and instability.
<b>2. Material and Geotechnical Properties</b>	<b>Cohesion (c)</b>	Acts as a binding force between particles; loss of cohesion (e.g., due to saturation) lowers stability.
	<b>Internal Friction Angle (<math>\phi</math>)</b>	Defines shear resistance; higher values improve dump stability.
	<b>Unit Weight / Bulk Density (<math>\gamma</math>)</b>	Heavier material generates greater downslope stress; lighter materials improve stability margins.
<b>3. Hydrogeological Factors</b>	<b>Pore Water Pressure (u)</b>	High pore pressure reduces effective stress, decreasing shear strength and promoting slip.
	<b>Unsaturated Suction (<math>\psi</math>)</b>	Negative pore pressure in unsaturated zones increases apparent cohesion and short-term stability.
<b>4. Geological and Foundation Conditions</b>	<b>Foundation Geology</b>	Weak or weathered bedrock, sheared zones, or clay layers beneath dumps can act as failure planes.
	<b>Subsurface Discontinuities</b>	Bedding planes, joints, and faults can localise shear movement and failure initiation.
<b>5. External and Environmental Factors</b>	<b>Blasting Vibration</b>	Dynamic loading from mine blasts induces transient pore pressure rise and progressive slope weakening.
	<b>Rainfall and Infiltration</b>	Intense rainfall saturates dump materials, raises pore pressure, and accelerates erosion.
	<b>Seismic Acceleration</b>	Earthquakes impart inertial forces and cyclic loading, triggering deep-seated failures.
<b>6. Operational and Management Factors</b>	<b>Dump Construction Sequence</b>	Bottom-up vs. top-down deposition affects compaction, drainage, and stability evolution.
	<b>Drainage and Surface Runoff Control</b>	Proper drainage channels and toe drains prevent water accumulation, reducing failure risk.

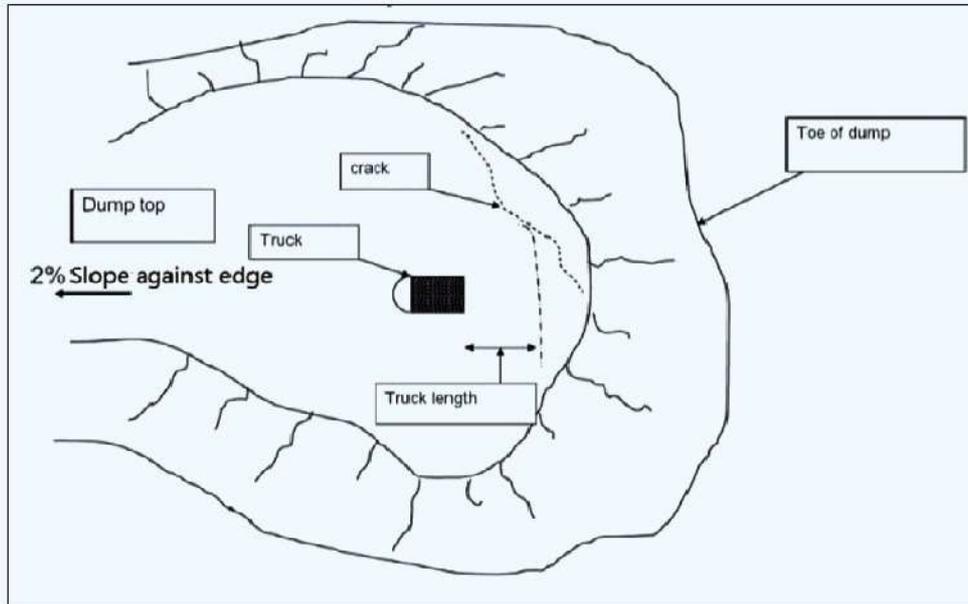
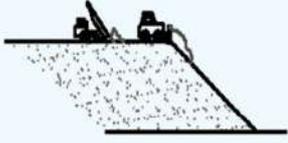
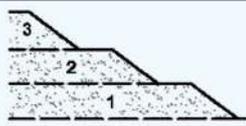
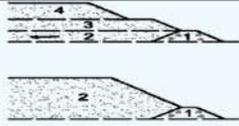
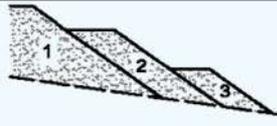


Figure 2: Showing Sketch of Waste Dump

Table 3: Types of Waste Dump, Their Constraints and Geotechnical Criteria for Selection			
	Dump and Doze	End Dumping	
Construction			
Type			
Geometry			
Lift Heights	2.5-40m	2.5-40m	20-100m
Overall Angle	<30° to 31°	<33°	<28°
Base Angle	≤10°	≤10°	<20°
Geotechnical Criteria for Selection	<ol style="list-style-type: none"> <li>1. Low strength rock or soil.</li> <li>2. Poor foundation conditions.</li> <li>3. Sloping base.</li> <li>4. Limit on maximum allowable overall angle.</li> </ol>	<ol style="list-style-type: none"> <li>1. Poor quality waste.</li> <li>2. Good foundations under toe.</li> <li>3. Sloping base.</li> <li>4. Permanent outside dump face.</li> <li>5. Initial dump in creek or water.</li> <li>6. Unstable natural slopes within the dump area.</li> <li>7. Containment of weak material between toe and dump base.</li> </ol>	<ol style="list-style-type: none"> <li>1. Materials of variable geotechnical quality.</li> <li>2. Curved or irregular foundation.</li> <li>3. Need for toe support.</li> </ol>



## Stages in Waste Dumps: Geotechnical Concerns

### 1. Excavation Method

Excavation Equipment	Key Effects	Geotechnical Implications
<b>Bulldozer (Ripping)</b>	Increased material breakdown under repeated trafficking	<ul style="list-style-type: none"> <li>• Reduced strength</li> <li>• Lower permeability</li> <li>• Higher susceptibility to rainfall-induced degradation</li> </ul>
<b>Shovel-Excavator-Dragline (Digging)</b>	<ul style="list-style-type: none"> <li>• Well-graded waste, soil to coarse rock</li> <li>• Larger block size</li> </ul>	<ul style="list-style-type: none"> <li>• Increased shear strength</li> <li>• Improved long-term durability with coarser particles</li> </ul>
<b>BWE / Continuous Miner (Cutting, digging, chipping)</b>	<ul style="list-style-type: none"> <li>• More uniform particle size</li> <li>• Finer overall gradation</li> </ul>	Increased permeability

### 2. Transportation

Transport System	Key Effects	Geotechnical Implications
<b>Dragline</b>	<ul style="list-style-type: none"> <li>• Very short haul distance</li> <li>• Minimal rehandling breakdown</li> </ul>	<ul style="list-style-type: none"> <li>• Minimal impact</li> <li>• Slight strength reduction due to any rehandling</li> </ul>
<b>Truck</b>	<ul style="list-style-type: none"> <li>• Smaller particle size due to excavation/crushing</li> <li>• Vibration effects during haulage</li> <li>• Material exposed unless covered</li> </ul>	Potential for liquefaction when transporting fine, cohesive, moisture-rich materials, particularly under rainfall
<b>Conveyor</b>	<ul style="list-style-type: none"> <li>• Consistent particle fragmentation</li> <li>• Mechanical vibration</li> <li>• Open transport unless enclosed</li> </ul>	Minimal effects; material condition largely unchanged

### 3. Dumping

Dumping Method	Key Effects	Geotechnical Implications
<b>Spreader</b>	<ul style="list-style-type: none"> <li>• Geometric constraints cause dumping above/below the equipment</li> <li>• Dynamic loading of dump face</li> <li>• Rapid advance of dump</li> <li>• Poor selectivity</li> <li>• Used in some operations to avoid active dump failure under spreader</li> </ul>	<ul style="list-style-type: none"> <li>• Highly susceptible to local instability</li> <li>• Potential rapid flow slides</li> <li>• Settlement and trafficability issues</li> <li>• Pore-pressure build-up from rapid loading</li> <li>• Difficult to segregate materials, affecting dump quality</li> </ul>
<b>Truck Dumping</b>	<ul style="list-style-type: none"> <li>• Different materials form different repose angles</li> <li>• Crest settlement</li> </ul>	<ul style="list-style-type: none"> <li>• Over-steepened upper slope may fail</li> <li>• Risk of trucks reversing over dump edge</li> </ul>
<b>Dozer (Dumped &amp; Dozed)</b>	Designed to eliminate issues from truck dumping	Minimal impact due to controlled placement
<b>Dragline Dumping</b>	<ul style="list-style-type: none"> <li>• Sequential dumping allows partial selectivity</li> <li>• Extended bench dumping possible</li> <li>• Tight geometric constraints</li> </ul>	<ul style="list-style-type: none"> <li>• Material compaction</li> <li>• Compaction of spoil toe</li> <li>• Poor-quality material placed deeper</li> <li>• High vulnerability to failure</li> </ul>



## Design Considerations For Waste Rock Dump Management

Mine waste management is an integral part of the overall mining operation, and the proper design and planning of waste dumps are essential to ensure both environmental sustainability and the structural stability of mining operations. The following details the key considerations for designing mine waste dumps, focusing on their environmental and geotechnical stability, reclamation potential, and safety measures.

**Site Selection for Waste Dumps:** The first step in the waste dump design process is the careful selection of the dump location. The site selection process must take into account several factors, including hydrology, geology, and environmental impacts.

**Avoidance of Stream Drainages and Groundwater Discharge Areas:** Waste dumps should not be located in stream drainages, groundwater discharge zones, or areas that could potentially disrupt water quality. These locations can lead to contamination of water resources through runoff and leachate, which is especially harmful when toxic materials, such as heavy metals or acid-generating minerals, are involved. Waste dumps located in such sensitive areas increase the risk of acid mine drainage (AMD) and other water quality issues.

**Hydrogeological Considerations:** A study of local groundwater conditions and hydrological factors is essential. Hydrogeological studies help to

understand how water behaves in the area, including groundwater flow and the potential for seepage or contamination. The hydrological assessment should determine whether groundwater could interact with the waste dump and if it would result in contamination or increased pore pressure in the waste materials.

**Drainage Design and Water Flow Management:** Proper drainage is a critical factor in the stability of mine waste dumps. Water infiltration and erosion can contribute to waste dump failures. Effective drainage systems must be incorporated into the design of the dump.

**Diverting Drainage Around or Through the Dump:** Drainage should be directed around the dump or through the head of the valley or sidehill dumps to prevent excessive water from infiltrating the waste dump. Adequate surface water diversion ensures that water does not accumulate in or around the dump, reducing the likelihood of erosion, sedimentation, and structural failure.

**Durable Drain Construction:** Drains should be constructed using durable materials that are resistant to erosion and slaking (disintegration of rocks when exposed to water). Non-slaking rocks or gravel are often the preferred materials, as they are stable over time and able to handle the volume of water that will flow through them.

**Stream Flow through Valley Fills:** For cross-valley fills, it is essential to maintain stream flow through the base of the waste dump. This is usually accomplished by



constructing a rubble drain – a rock-filled trench designed to carry water through the dump without compromising the stability of the material. The rubble drain should be designed to handle a design storm flow, ensuring that the water flow capacity is sufficient for extreme weather conditions and heavy rainfall.

**Geotechnical Stability and Dump Design:** The geotechnical stability of waste dumps is a key consideration in preventing slope failures, erosion, and other hazards. Proper design ensures that the waste material is stable and that the dump will not pose a risk to surrounding environments, communities, or infrastructure.

**Grading and Contouring for Mass Stability:** The waste dump should be graded or contoured in such a way as to enhance its mass stability. The slope angle of the dump is determined based on the material properties and the angle of repose, which refers to the steepest angle at which a material can remain stable without sliding. Figure 3, Figure 4 and Figure 5 suggest the profile design of the recommended waste dump and illustrate the schematic plan for a safe working area from the dump toe and the schematic section for a safe working area from the dump toe.

**Base and Toe Materials:** The placement of coarse durable materials at the base and toe of the waste dump can improve internal hydrologic stability and reduce pore pressure within the dump (Figure 6). This helps distribute the weight of the dump more evenly and lowers the risk of failure due to water infiltration.

**Geotechnical Failure Analysis:** A geotechnical failure analysis is critical in identifying potential risks in the waste dump structure. This analysis should be performed during the design phase to assess the potential for slope failure. A foundation analysis is important for large waste dumps to ensure that the dump base is stable and can support the weight of the waste materials. This analysis should consider the material properties of both the waste rock and the underlying soil or bedrock.

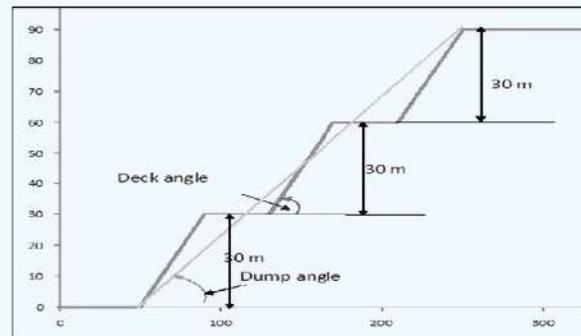


Figure 3: Recommended Design of Waste Dump

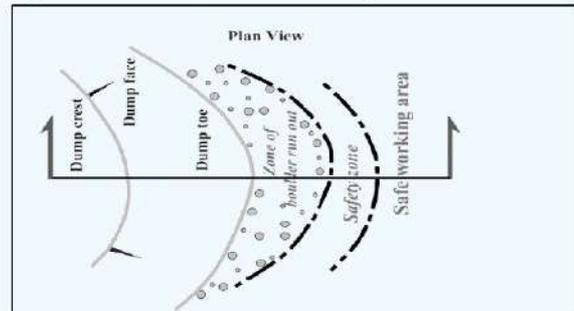


Figure 4: Schematic Plan for Safe Working Area from Dump Toe

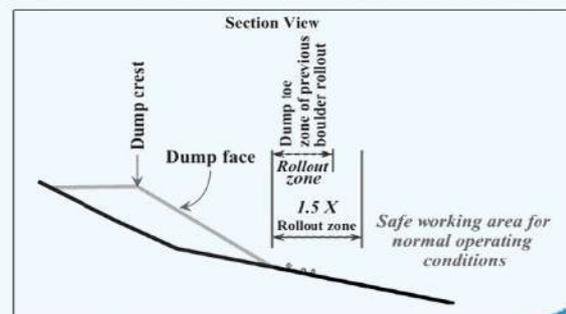


Figure No. 5: Schematic Section for Safe Working Area from Dump Toe

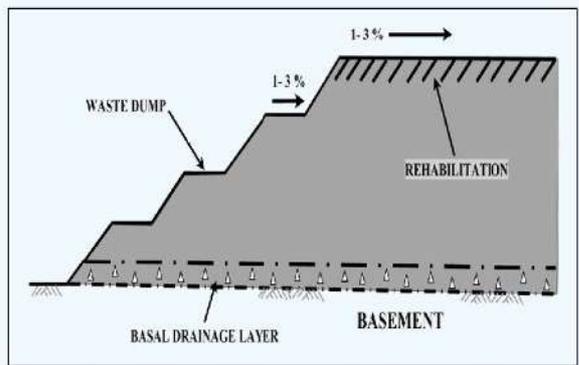


Figure No. 6: Sketch Showing the Control Measures

**Erosion Control and Environmental Protection:** Erosion control is a critical aspect of waste dump design, as uncontrolled erosion can lead to sedimentation in nearby water bodies and damage to the surrounding environment. The design must incorporate features that minimise erosion, reduce surface runoff, and enhance the long-term stability of the waste dump.

**Controlled Water Flow and Erosion Prevention:** The design should ensure that water flow is controlled to minimise the potential for erosion. This involves both surface and subsurface drainage systems, as well as vegetation to stabilise the surface. By ensuring controlled water flow, the waste dump is less likely to experience significant erosion, which could destabilise the structure and contaminate nearby ecosystems.

**Topsoil and Growth Medium Management:** As part of the reclamation process, topsoil or other suitable growth media should be removed from the proposed dump site and stockpiled for later use in reclamation. These materials will serve as a foundation for planting

vegetation, which helps to stabilise the dump surface and prevent erosion. Finer-textured waste materials that are more adaptable for use as a growing medium should be placed on the exterior of the dump to facilitate plant growth.

**Use of Vegetation in Reclamation:** After the dump has been shaped and graded, available topsoil or other selected subsoils should be spread over the surface of the dump as a growing medium. Vegetation helps in controlling erosion, improving soil structure, and providing habitat for wildlife. Planting native species that are adapted to the local environment is recommended to enhance the ecological restoration of the site. For general guidance in this regard, it may be helpful to keep in mind the predicted relationship between the angle of the dump slope and the effectiveness of revegetation, as shown and illustrated in Figure 7.

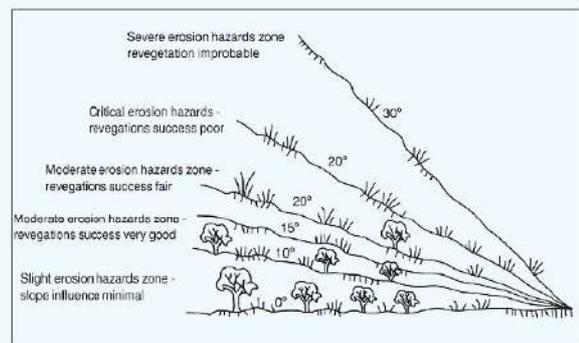


Figure 7: Relationship Between the Angle of Dump Slope and Efficiency of Revegetation  
**Safety Requirements for Waste Dumps**

Safety is a key consideration in the design of waste dumps. The design must take into account potential hazards such as slope failures, settlement, and water-



related risks, which could impact the health and safety of workers, nearby communities, and the environment.

**Safety Calculations for Waste Dumps:** For waste dumps, it is essential to calculate the factor of safety (FoS) related to mass stability, water infiltration, and potential for erosion. These calculations should include the assessment of the FoS, which measures the stability of the waste dump by comparing the forces resisting failure with the forces promoting failure. At the present state of the mass, the latter is balanced by the shear stress acting along the possible failure surface. So, the definition of the factor of safety is:

$$\text{Factor of Safety} = \frac{\text{Maximum resisting force (strength)}}{\text{Driving force (acting stress)}}$$

from that:

- For  $\text{FoS} > 1$ , the strength exceeds the stress, the slope is stable;
- For  $\text{FoS} \leq 1$ , the stress exceeds the strength, the slope is unstable.

**Dump Bench Design:** Waste dump benches should be constructed to allow for the mass settling of the dump. These benches provide areas where the material can settle without increasing the risk of slope failure. Additionally, they can help improve drainage and stabilize the dump structure by distributing the load more evenly. Hawley and Cuning (2017) acknowledged the significance of design confidence when creating Design Acceptance Criteria (DAC) for waste rock dumps (Figure 8). As potential implications grow, acceptance becomes more cautious in accordance with

the criteria stated above. The usage of a matrix where the criteria are directly related with the possible repercussions of failure and the confidence in design was a very helpful method for presenting the proposed criteria in Hawley and Cuning (2017).

		Consequence Category		
		Low	Moderate	High
Design Confidence	Low	FoS 1.3-1.4 PoF 10-15%	FoS 1.4-1.5 PoF 2.5-5%	FoS $\geq 1.5$ PoF $\leq 1\%$
	Moderate	FoS 1.2-1.4 PoF 15-25%	FoS 1.3-1.4 PoF 5-10%	FoS 1.4-1.5 PoF 1-2.5%
	High	FoS 1.1-1.2 PoF 25-40%	FoS 1.2-1.3 PoF 10-15%	FoS 1.3-1.4 PoF 2.5-5%

Figure 8: DAC for Waste Rock Dumps by Hawley and Cuning (2017)

DGMS Guidelines for Waste Dump Management in Indian Metalliferous Opencast Mines - Waste dump management and slope stability assessment are critical components of safe and sustainable opencast mining in India. Metalliferous mines generate large volumes of overburden (OB), interburden, and rejects, which are commonly placed in external or internal dumps. These dumps, if improperly designed or monitored, can fail through mechanisms such as rotational slip, planar failure, flow slides, and foundation failure. In response to a series of slope-failure-related accidents and the increasing scale of mechanised mining, the Directorate General of Mines Safety (DGMS) has issued multiple technical circulars to regulate systematic design,



operation, and monitoring of pit and dump slopes. The literature on mine slope safety in India is therefore strongly anchored around DGMS (Tech) circulars, scientific studies as mandated under the Coal Mines Regulations (CMR) 2017 and Metalliferous Mines Regulations (MMR), national standards, and international best practices. The following sections consolidate and synthesise DGMS guidelines applicable to waste dump management and slope monitoring in metalliferous opencast mines, with emphasis on the most recent circulars: DGMS (Tech) Circulars 02/2001, 02/2010, 02/2020, 03/2020, and Regulation 106 of CMR 2017, all of which serve as reference documents for scientific design and operational safety in both coal and non-coal opencast mines.

DGMS (Tech) (S&T) Circular No. 2 of 2001: Slope Failure Prevention in Opencast Mines - The earliest consolidated regulatory guideline on slope stability is the DGMS (Tech) (S&T) Circular No. 2 of 2001, issued after a series of fatal slope collapses in coal mines. Although primarily aimed at coal operations, the circular formed the foundation for slope design requirements in all opencast mines, including metalliferous operations. The circular highlights that slope failures occur primarily because of inadequate design, unscientific working methods, and lack of monitoring. It stresses that both pit slopes and external waste dump slopes must be designed according to geotechnical principles such as shear strength assessment, bench geometry optimisation,

and hydrogeological control. In the context of metal mines, these principles remain relevant due to the inherently heterogeneous nature of waste rock, which often exhibits variable fragmentation, angularity, and weathering characteristics. The circular establishes two central principles: (1) Scientific slope design must precede development of benches, haul roads, or dumps. (2) Continuous monitoring must be integrated into daily mine operations to identify precursors of slope instability. This document laid the foundation for subsequent DGMS circulars and encouraged Indian mining industries to adopt geotechnical engineering as a mandatory discipline in mine planning.

DGMS (Tech) Circular No. 02 of 2010: Design, Control, and Monitoring of Pit and Dump Slopes - With increasing mechanisation and deeper opencast mines, DGMS issued Circular No. 02 of 2010, which remains the most influential guideline for slope stability in India. It specifically addresses the complex geomechanical environment of deep excavations and large waste dumps. Scientific Slope Design Requirements - The circular mandates that slope design should be supported by: Geomechanical classification of rock masses; Shear strength testing of dump material and foundation strata; Slope stability numerical modelling using analytical or advanced numerical tools; Hydrogeological investigations and pore-water pressure estimation; and Bench design parameters (height, width, face angle, inter-ramp angle) tailored to site



conditions This is particularly relevant for metal mines, where dump materials may include hard rock fragments, clay seams, lateritic soils, and weathered ore, leading to zones of variable shear strength and potential weakness. Waste Dump Hazards and Risks - The circular identifies specific hazards associated with waste dumps: Alteration of stress distributions due to progressive loading; Steep dump slopes without compaction or controlled placement; Excessive height leading to overstressing of foundation material; Poor segregation of weak and strong materials; and Water ingress and build-up of pore pressures. These hazards are commonly observed in Indian metalliferous mines where the annual excavation output may exceed tens of millions of tonnes. Monitoring Protocols - The circular deployment of systematic monitoring, including: Regular surveying of slope profiles; Visual inspection for cracks, tension gaps, subsidence, or oversteepening; Installation of piezometers, inclinometers, settlement markers, and prism monitoring systems; Evaluation of rainfall data and seepage patterns. These circular forms cornerstone for monitoring programs in large metal mines today.

DGMS (Tech) Circular No. 02 of 2020: Systematic Slope Monitoring Guidelines - Recognizing rapid technological advancements, DGMS published Circular No. 02 of 2020, providing updated and highly detailed requirements for slope monitoring in both coal and metalliferous

opencast mines. Deployment of Slope Monitoring Systems - Every mine must implement a slope monitoring system tailored to site-specific geological and operational conditions. The system should define: Instrumentation types: prisms, total stations, radar-based systems (SSR/TLS), LiDAR, piezometers, extensometers; Monitoring frequency: continuous (automated) or periodic; Data acquisition and interpretation methodology; Pattern and layout of monitoring stations; Organizational hierarchy for monitoring responsibilities. Metal mines with high benches, deep pits, and large external dumps increasingly rely on Slope Stability Radar (SSR) and Real-Time Total Station (RTTS) systems as recommended in this circular. Trigger Action Response Plans (TARP) - The circular mandates defining customized trigger levels, commonly: Normal Condition; Warning Level; and Withdrawal Level (Emergency). Each trigger level must be linked with specific operational actions, forming a complete TARP. This structured approach has significantly improved slope risk management in India's large metal mines such as those producing iron ore, manganese, bauxite, and chromite.

DGMS (Tech) Circular No. 03 of 2020: Scientific Studies under Regulation 106 - Circular 03 of 2020 supplements the regulatory framework by detailing the requirements for scientific studies widely followed by metalliferous mines as best practice. Mandatory Scientific Study Components - Before beginning



mechanized opencast operations, the owner/agent must ensure that: Ultimate pit slopes and dump slopes are scientifically designed; The method of working, including benching, haulage layout, and dumping strategy, is scientifically validated; A comprehensive slope monitoring plan is included; and The study report is kept available at the mine office for DGMS inspection. Minimum Factor of Safety (FoS) - DGMS mandates minimum FoS values: 1.50 for permanent/long-standing slopes; and 1.30 for temporary slopes or intermediate benches. These FoS requirements are crucial for metalliferous mine dumps, which often rely on steep engineered slopes to optimize space. Applicability to Metalliferous Mines - It requires: Scientific design of all opencast workings, including dumps; Compliance with safety precautions listed in sub-regulations; Ensuring that all slope-related recommendations from scientific studies are implemented; and Continuous monitoring and documentation. Metal mines adopt these requirements to align with DGMS expectations and maintain uniform standards for opencast slope stability across mineral sectors.

Relevance to Metalliferous Mines in India - Metalliferous mines present unique geotechnical challenges: Highly variable waste rock gradation; Complex weathering patterns; High dump heights; Seasonal monsoon impacts leading to rapid pore pressure rise; Progressive dump expansion requiring staged design. DGMS circulars

collectively guide metal mines to adopt: Engineered dumping with controlled lifts and compaction; Staged dump development with drainage and stability berms; Advanced slope monitoring including radar, drones, and LiDAR; Predictive modelling using FLAC, Phase2, PLAXIS, and SLOPE/W; and Risk-based slope management aligned with TARP. These guidelines are now consistently referenced in scientific studies submitted to DGMS for mine plan approvals.

Numerical Modelling (Finite Difference Method) - Numerical modelling using the Finite Difference Method (FDM) provides an advanced approach to analysing dump slope behaviour under varying geological and environmental conditions. Software such as FLAC/Slope and FLAC2D allows for simulating stress-strain responses, pore pressure evolution, and progressive failure mechanisms within heterogeneous dump materials. The model typically incorporates realistic boundary conditions, such as fixed bases and free lateral boundaries, to replicate in-situ conditions accurately. Figure 9 illustrates the representative dump slope geometry, including the mesh configuration and boundary zones used for computation. Material properties are defined based on laboratory and field data—cohesion, friction angle, density, and permeability. Simulations enable assessment of Factor of Safety (FoS), potential failure surfaces, and deformation patterns under static and dynamic conditions. Such numerical frameworks are invaluable for evaluating design



alternatives, optimising slope geometry, and validating field observations, ensuring the stability and long-term performance of waste dumps in large opencast mines.

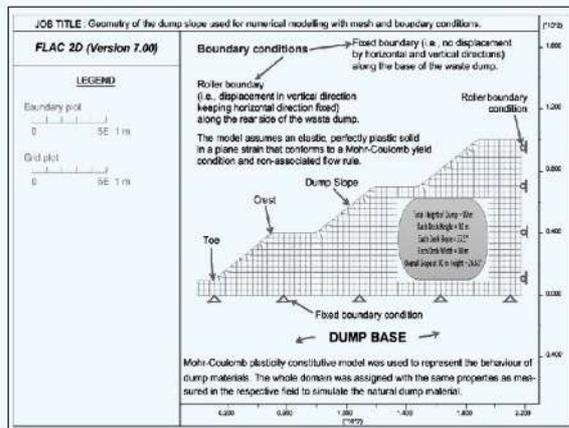


Figure 9: Dump Slope Geometry, Mesh Layout, and Applied Boundary Conditions

## Conclusions

The planning, design, and management of mine waste dumps are complex and require careful attention to various environmental, geotechnical, and safety considerations. By adhering to the guidelines outlined in this paper, mining operators can minimize environmental damage, improve structural stability, and ensure the long-term sustainability of their operations. Proper waste dump management is crucial not only for minimizing environmental impact but also for ensuring the safety of mining personnel and surrounding communities. Incorporating a holistic approach that integrates geotechnical analysis, environmental protection, and reclamation practices will lead to the proper design and management of waste dumps. Design considerations for waste dumps should

consider local groundwater conditions and geo-hydrologic factors. The dump should be placed in a valley, with drainage diverted around or through the head. Durable, non-slaking rock or gravel drains should be used. The dump should be graded or contoured for mass stability. Geotechnical failure analysis and foundation analysis are recommended. Placement of coarse durable materials at the dump's base and toe provides additional stability. Controlled water flow minimizes erosion and enhances structural stability. Cross valley fills should provide stream flow through the dump. Toxic materials should not be placed in valley fills. DGMS regulations and circulars form the backbone of slope stability and waste dump management protocols in Indian metalliferous opencast mines. Circulars from 2001 to 2020 progressively enhance regulatory expectations, shifting from conventional design to scientifically engineered slopes, systematic monitoring, and risk-based response frameworks. Compliance with DGMS guidelines ensures safer mine operations, reduces slope failure risks, and promotes sustainable waste dump design. As metalliferous mines continue to deepen and expand, adherence to these DGMS guidelines - supported by numerical modelling, geotechnical testing, and real-time monitoring technologies - will remain critical for long-term mine stability and operational safety.



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