Shahrood University of Technology

Journal of Mining and Environment (JME)

Journal homepage: www.jme.shahroodut.ac.ir

Iranian Society of Mining Engineering (IRSME)

Engineering Challenges and Remedial Measures in Black Cotton Soil Dump Adjacent to Hamlet: A Case Study from Opencast Mine

Rahul Shende, Omkar Navagire, Himanshu Kumar Jangir, Srinivasan Venkatraman*, Anirban Mandal[1] and Anjan Patel

Visvesvaraya National Institute of Technology, Nagpur 440010, Maharashtra, India

Article Info

Received 28 September 2024

Received in Revised form 14 May 2025

Accepted 26 May 2025

Published online 26 May 2025

DOI: 10.22044/jme.2025.15137.2896

Keywords

Opencast mining

OB dump

Crack orientation and growth

Black cotton soil

Slope stability

Abstract

Due to its intricate challenges, Black cotton (BC) soil is dumped separately in mining areas, and this study focuses on a BC soil dump at an open-cast mine site. This soil, characterized by cohesion of 26-40 kPa and internal friction angle of 13°-17°, exhibits significant expansion and contraction with moisture fluctuations, swelling during wet periods, and shrinking during dry spells, posing considerable challenges in mining areas. The Ministry of Environment, Forest and Climate Change (MoEFCC) has suggested constructing a 15-20m wall to protect the village on the periphery of the BC soil dump of 36m height. This study aimed to identify sustainable and economical alternative feasible remedial solutions. Field testing, including borehole investigation, was conducted to determine the stratigraphy beneath the dump. Numerical analysis using SLOPE/W software was performed for slope optimization and to evaluate remedial measures such as stone pitching and rockfill trench. The study shows that the dump can be stabilized using the design modification and possible cost-effective measures. Based on field observations, dump material testing, and numerical analysis, alternative remedial measures were proposed and implemented. The study also includes a cost-benefit analysis of the recommended remedial measures.

1. Introduction

Open-cast mining (OCM) is a technique for extracting minerals, ores, or coal from the earth's surface. This method involves removing the top layers of soil and rock to expose the mineral deposits underneath. Machines are then used to excavate the minerals in a series of steps, gradually deepening the pit. Overburden (OB) dumps in open-cast mines are designated areas where the overburden, comprising soil, rock, and other unwanted material removed to access the underlying minerals, is deposited [1, 2]. Reasonably, large land areas are damaged during mining, and the natural ecology is replaced by waste dumps, leading to air and water pollution. These OB dumps are carefully planned to ensure stability and minimize environmental impact. OB dumps play a key role in the overall waste management strategy of open-cast mining, ensuring efficient operation and environmental stewardship [3].

Open-cast mines segregate OB dumps based on the materials being removed. This ensures that rocks, cohesive soils, and other materials are disposed of in separate designated areas. Specialized dumping areas are established for rocks, where the heavy and jagged material can be stably stacked, reducing the risk of landslides. Cohesive soils have different compaction and drainage properties and are placed in separate dumps to prevent mixing and potential instability. This careful organization also aids in future land reclamation efforts, making restoring the land to its natural state easier once mining operations are concluded. This OB material does not carry any economic importance, but studies were carried out for the sustainable use of OB material [4, 5]. OB dump can fail due to reasons like weak dumped soil, weak foundation, poor dump geometry, excessive erosion, uncontrolled blasting, and improper maintenance [6–9]. The stability of OB

Corresponding author: srinivasanv@civ.vnit.ac.in (V. Srinivasan)

dumps is crucial because their failure can pose hazards in mining operations[1, 6, 10–14]. In the past, numerous incidents have occurred at open-cast mine sites, resulting in damage to property and loss of life [15]. Several researchers have studied the slope in the OCM in the past to determine its stability and increase it [16] [17][18] [19][20][21] [22][23].

Recent advances in discrete element modeling and the understanding of soil-structure interaction offer valuable insights into geotechnical stability assessments relevant to engineered dumps [24–27]. The latest progress in slope stability and mine waste management has incorporated intelligent and data-driven methods to enhance safety and optimize land use. The fuzzy slope mass rating (FSMR) system, which integrates fuzzy logic into traditional Slope Mass Rating (SMR) classification for more accurate rock slope assessments, was introduced by Daftaribesheli et al [28]. The use of genetic algorithms to iteratively modify and stabilize an open pit wall was demonstrated to achieve a safe geometry with a factor of safety of 1.3 [29]. Further, unmanned aerial vehicles (UAVs) based 3D modeling techniques were effectively applied to identify failure zones in internal mine dumps, offering rapid and precise analysis under static and seismic conditions [30]. Complementing these efforts, Slide3D and Monte Carlo simulations are coupled to expand waste dump capacity while maintaining stability, suggesting that benching strategies that safely accommodate additional volumes were studied [31]. A two-dimensional (2D) analytical framework for slope stability assessment is widely accepted as it offers a practical balance between computational efficiency and conservative estimation of failure conditions. Previous studies have demonstrated that 2D approaches, though conservative compared to 3D analyses, provide sufficiently accurate insights for design-stage evaluations and regulatory compliance, especially in overburden dump configurations [32–34].

Stability of OB dumps in OCM operations is a critical area of research and practice due to the safety risks and environmental concerns associated with these structures. Various techniques for stabilizing these dumps have been explored in recent literature. Incorporating fly ash can enhance parameters such as compaction characteristics and shear strength of the OB material [3, 35]. The geometry of dumps, including the height and angle of the slopes, is also crucial in determining stability, as steeper slopes increase the risk of landslides. Moreover, the configuration of dump benches plays a significant role in stabilizing OB dumps. Amarsaikhan et al. highlighted that optimizing dump bench configurations can effectively increase the load-bearing capacity of the dumps while reducing the likelihood of slope failure due to excess weight [36]. Integrating safety factors through rigorous stability analysis is critical for ensuring that overburden dumps do not become a hazard to the surrounding environment or mining operations [37]. Continuous monitoring of slope deformations and soil movements is necessary to provide real-time data, enabling timely interventions to stabilize the dumps [38]. Monitoring allows for identifying susceptible zones within the dump, which is crucial for predicting failures and maintaining safety [39]. Reclamation efforts also play an essential role in stabilizing OB dumps post-mining. Techniques such as planting vegetation and applying soil amendments can help restore the ecological balance that was disrupted during mining operations [40]. Successful stabilization contributes not only to the physical safety of the site but also aids in mitigating long-term impacts.

In the central Indian region, the top surface of the land is often characterized by Black cotton (BC) soil. BC soil possesses a dark color and is known for its high clay content and moisture-retention capabilities [41]. Its tendency to expand and contract dramatically with fluctuations in moisture causes it to swell during wet periods and shrink during dry spells. This BC soil's swelling behavior is attributed to montmorillonite's unique crystal structure, which allows it to absorb water molecules between its layers [42]. When water enters the soil, it is attracted by the negatively charged surfaces of montmorillonite, causing the clay particles to expand as they hydrate [43]. This expansion increases soil volume due to the swelling characteristic of BC soil. Conversely, when the soil dries out, the water is released from the clay mineral structure, and the soil contracts, which can lead to substantial shrinkage and cracking [44]. This dynamic interplay between moisture and montmorillonite structure is responsible for the soil's swelling and shrinking behavior in BC soil, making it challenging [45]. These cyclic changes can lead to ground movement, causing cracks in the foundation with BC soil. Further, BC soil dumps settle unevenly, resulting in severe failures and slope stability issues. The presence of clay minerals results in a rapid decrease in cohesion during rainfall, as a loss of surface frictional contact between the grains due to the high absorption of water. Clay minerals give more plasticity to the soil, which is one of the most important causes of slope failure [12].

In mining areas, the BC soil is dumped separately as it will cause problems like slope failure, weak zones, poor drainage, compaction issues, swelling and shrinkage, uneven settling, etc., if dumped with the other OB material [46]. Dumping BC soil in open-cast mines poses several challenges that demand careful consideration. The BC soil is used as a topping on the OB dumps after mine closure, as it supports the plantation abundantly. Disposal of BC soil in open-cast mines is crucial due to its significant environmental, operational, and community impacts. The research offers a study of the BC soil dump through field observations, material testing, and a numerical modelling approach to stabilize the dump using different cost-effective, sustainable, and feasible remedial measures. This study is a field-based study, and the suggested measures were implemented at the site. The cost-benefit analysis showed that around 95% of the amount had been saved. The problem associated with the BC soil dump has not been thoroughly studied, and this study provides valuable information regarding it. The study offers insights into the nature of BC soil dumps, challenges, and solutions for better understanding. Additionally, the research informs geotechnical engineering on soil stability and behavior, aiding in safer mine BC soil dump construction.

1.1. Study Area

The Amalgamated Yekona-I and II block is in the Warora Tahsil of Chandrapur district of Maharashtra State. The mine area is delimited by latitudes N 20° 13' 42" to 20° 16' 10" N and longitudes E 78° 55' 00" to 78° 58’ 30" and is covered by Survey of India Topo Sheet No.55L/15 & 55L/16 (Figure 1). The mine is operated by the opencast working method using surface miner technology and conventional drilling and blasting methods with a shovel-dumper combination for ore and waste excavation. The slope-forming materials in the mine mainly consist of soil and sandstone as overburden, followed by a composite coal seam of 15–17 m thickness. The sandstone rock mass is part of the Kamptee and Barakar formations. The Kamptee sandstone serves as an unconfined aquifer and is a significant source of groundwater. The topsoil consists of black cotton soil and silty/clayey sand and is classified mainly as clay of high plasticity. The Wardha River forms a major drainage system of the area and flows from NW to SE along the central part of Wardha Valley Coalfields.

The slope stability problems in this coalfield are predominantly restricted to soil and very weak sandstone benches. Slope failures occur mainly during the rainy season, from 15th June to 30th September. The study area falls under a subtropical climate zone, experiencing hot summers and mild winters. The average annual rainfall in this coalfield is 1,250 mm. The rainfall measured in the area in July is 605mm, 217mm, and 316mm in the last three years. In some cases, external loading on slopes of OB dumps also contributes to slope instability.

The mine consists of external and internal OB dumps, with one BC soil dump and other hard, rocky OB dumps. Both these dumps require separate analytical treatment to determine slope stability parameters. The hard OB dump's height can be up to 90m, keeping the benches 20m in height and 25m in width, and a bench slope angle of 35°. The Black Cotton soil was dumped separately with the recommended height up to 45m, keeping the benches 10m in height and 15m in width, with a bench slope of 30°. The BC soil dump is an engineered dump constructed in layers/lifts and compacted by a smooth roller and bulldozer at the site. The BC soil dump on the site is currently 36 m high, and the dumping on this site has been discontinued. BC soil mainly contains clay minerals, such as montmorillonite, responsible for swelling and shrinkage.

1.2. Problem Definition

The region's topsoil is predominantly composed of Black Cotton soil, known for its problematic nature. BC soil is high in Montmorillonite minerals, which cause the soil to shrink or swell due to weather changes. This phenomenon pronounces the urgency of promptly addressing the soil stability concerns. As a result, the dump of BC soil is kept separately. The BC soil dump is approximately 100-120 m away from the village of Yekona, as shown in Figure 1. The village of Yekona is in very close proximity to the BC soil dump, which makes the situation potentially hazardous for the villagers in the event of any unforeseen catastrophe. As per a letter from the Ministry of Environment, Forest and Climate Change (MoEFCC), it has been suggested that to protect Yekona village, a toe wall of at least 15-20m in height should be constructed along the OB dump in response to the situation. The current BC soil dump height is 36 m, and building a toe wall that's 15-20 m high may not be practical or cost-effective. However, it's essential to ensure the stability of the BC soil dump in the long term by implementing protective measures based on investigation. To this end, the study was conducted to assess the feasibility of a toe wall or suggest alternative measures to stabilise the BC soil dump and safeguard the village of Yekona. The study was carried out with the inclusion of field observation, data analysis, field investigation, laboratory experimentation, numerical analysis, etc.

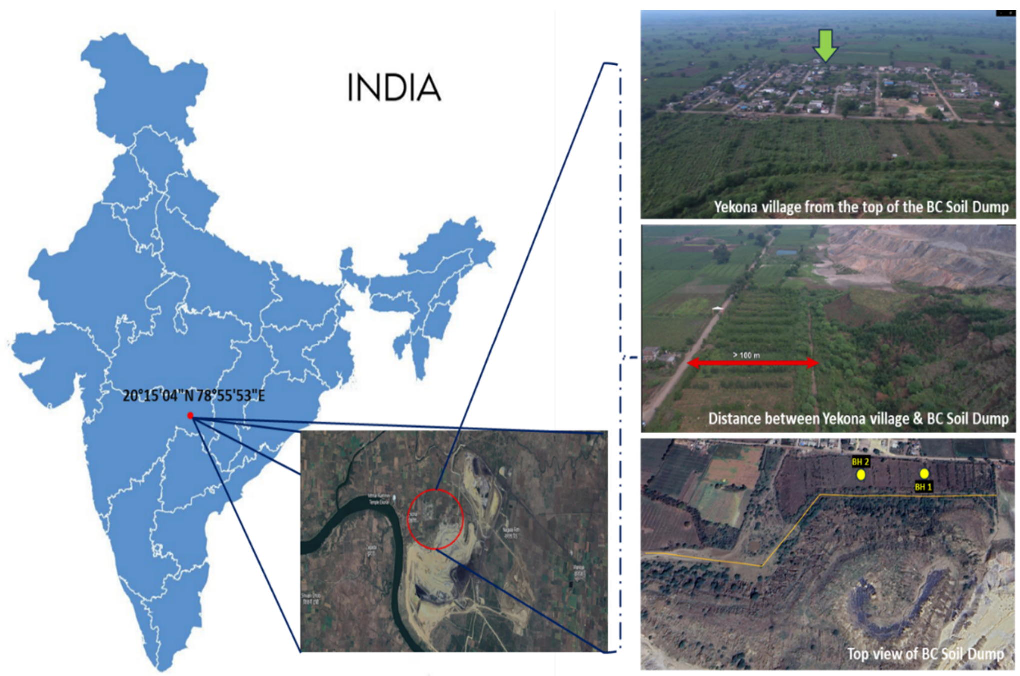


Figure 1. Study location with on-site images

The case study focuses on the site under consideration to conduct a feasibility assessment of the requirement for a toe wall and provide an economical and sustainable solution for protecting the BC soil. This case study includes Field visits and collection of data (contour plan, cross sections, rainfall data, etc.), Geotechnical investigation of BC dump and exploration of ground profile through the borehole, Numerical analysis of existing dump profiles and possible enhancement in factor of safety through possible remedial measures and viability of feasible remedial measures and their suitability to site-specific conditions. Moreover, a cost-benefit analysis was also carried out in the study. The methodology followed in the study is shown in Figure 2.

The present case study is unique as it addresses real-world engineering challenges associated with the BC soil dump located close to human settlements, a situation where both geotechnical instability and community safety are critical concerns. While many studies discuss BC soil behavior in controlled conditions, this case specifically deals with a large-scale, field-level failure risk in an open-cast mine environment. The integrated approach adopted for detailed field investigations combined with numerical modeling, development of cost-effective practical remedial measures, and direct consideration of socio-environmental impacts alongside technical solutions is an innovative aspect of the study.

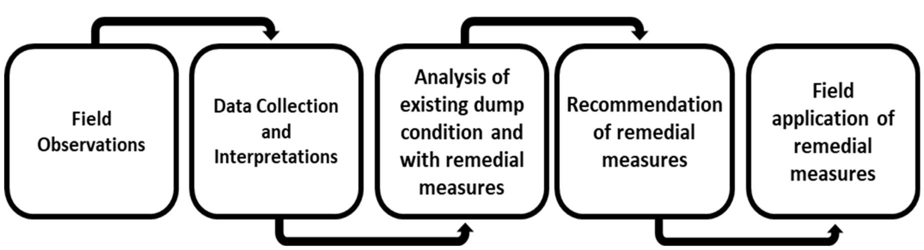


Figure 2. The methodology followed in the present study

2. Methodology

2.1. Field Observations

Field observations are essential in many research and professional areas, especially for studies that focus on specific sites. They are important because they allow for collecting genuine, contextually rich data, crucial for accurate analyses and decisions. Table 1 provides insights into the field observation with possible consequences/inferences.

Table 1. Field observations with consequences/inferences

	Field observations	Consequences/ Inferences
1	The BC dump slope face had experienced soil erosion, with varying degrees of erosion, ranging from partial to complete, leading to a drastic misalignment of the slopes. The erosion caused in the BC dump is severe, and no visible benches can be observed on the site.	The loose BC soil surface layer is potentially susceptible to erosion due to the combined action of rainfall, drying shrinkage, temperature variation, humidity, runoff, etc [47].
2	Steep slopes were noticed at several locations in the BC dump, varying from 40°-50°. Also, the slope at some sections is too steep due to soil mass sliding and vertical collapsing.	This steep nature of slopes can be a potential result of the continuous surface erosion of BC soil dump over the monsoonal cycle. Moreover, the sliding is attributed to the loss of shear strength in the soil at the failure surface due to steep slopes, water movement, external loads, etc [48].
3	Wide rain cuts were observed, formed due to heavy surface water runoff flowing from the dump's top to its toe. These rain cuts damage the slope severely and can widen with time.	Apart from surface erosion, these rain cuts provide a passage of water in deeper depths in the dump, creating a wetting front at higher depths during the monsoon season, potentially weakening the slope [49].
4	It was spotted that on the slope's face, plantation was grown in several places with Stylo Hamata grass. Moreover, Plantations have been carried out in the area between Yekona village and the dump's toe.	Plantations on the dump site play an excellent role in stabilizing slopes by reinforcing the soil. Their roots can penetrate into the slope, preventing erosion and enhancing the area's overall environment [50]. This Stylo Hamata grass helps to prevent slope erosion and reinforces the slope face.
5	At the site, garland drains were constructed at the toe of the BC soil dump to manage surface water flow effectively. The siltation pond connected to the garland drain is constructed to settle suspended sediments, such as silt and clay particles, from stormwater. However, it is to be noted that there is a reasonable depth of siltation and a lack of maintenance of the garland drains. Also, the depth and width of the garland drain were not sufficient.	In the rainy season, considerable soil from the slope's face is washed away by rainwater due to erosion. Sedimentation periodically occurs in the drains, which causes misalignment and decreases the drain's depth. Proper maintenance strategies shall be developed pre- and post-monsoon to keep the flow in the garland drain running and prevent water inundation at the toe of the BC soil dump [51].
6	It has been noticed that there is no provision for surface drains on the BC soil dump.	The surface drains reduce water accumulation and erosion. Improper drainage provisions can lead to gradual deterioration and eventually failure of the structure [52].
7	No heaving was observed near the dump's toe. As the dumping has been restricted to a height of 36m, the pressure on the soil beneath the dump is considerably lower.	In this situation, the dump does not apply appreciable pressure, and heaving may not occur in the periphery.
8	The vibration readings were taken through a vibrometer installed at the village of Yekona and near the BC soil dump. The peak particle velocity (PPV) measured during blasting at the village is under the limiting value (i.e., PPV< 5 mm/sec)	The range of vibrometer PPV readings is within desirable limits; hence, the dynamic loads due to blasting shall not substantially affect the BC soil dump.
9	The measures are taken by creating a drain barrier and a temporary boundary arrangement to keep animals and village people away from the BC soil dump and plantations.	Trespassing can harm plantations, indirectly affecting slope protection measures and causing geometry misalignment.

2.2. Material collection and testing

Geotechnical parameters are important for analyzing and understanding behaviour [53, 54]. Laboratory experiments determined the representative samples' geotechnical parameters. Laboratory testing uses relevant codes to determine particle size distribution, Casagrande limits, optimum moisture content, maximum dry density, permeability, and shear strength parameters. Testing was conducted on collected BC soil dump material, and a borehole investigation was carried out to determine the soil's stratigraphy.

2.2.1. BC soil dump material collection and testing

Due to the homogeneity of the black cotton (BC) soil dump material, representative samples were collected from two locations. The BC soil dump was constructed exclusively from the topsoil of the mining site, following Directorate General of Mines Safety (DGMS) guidelines, without using any external borrow material, resulting in a materially homogeneous structure. The dumping process was engineered with systematic placement in uniform lifts and controlled compaction, minimizing variability in density and strength properties across the dump. Samples were obtained from a 0.5-meter pit at various benches of the BC soil dump in two distinct areas. Disturbed and undisturbed soil samples were gathered from the bench and slope of the BC soil dump. The results are presented in Table 2. The collected soil was classified as CH (Highly compressible clay) as per IS 1498:1970 [55] with a free swelling index ranging from 90-100%. According to the Casagrande limit, the soil exhibited high plasticity, with a plasticity index of approximately 40. Field bulk density, measured using the core cutter method, was 17.61 kN/m³. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined using the Modified Proctor test. Shear strength parameters were assessed using a direct shear test, and permeability (k) was measured via the falling head test on samples prepared at OMC & MDD. It is worth noting that the samples prepared for the latter were saturated, and the former were in the bulk state. The organic content of the soil was found to be negligible. The results indicate that the dump soil is highly plastic with a significant free swell index, suggesting it may become dynamic when water penetrates.

Table 2. BC dump soil sample results

	Sample 1	Sample 2
Soil Classification	CH	CH
Clay-Silt (%)	86.28	93.1
FSI (%)	100	90
LL (%)	72.4	70.6
PL (%)	32.4	31.2
PI (%)	40	39.4
MDD (kN/m^3)	15.48	15.29
OMC (%)	19	22
c (kN/m^2)	27.56	26.87
Φ°	15.1	14.1
k (m/sec)	7.25×10^{-7}	7.81 10^{-7}

2.2.2. Borehole investigation

Understanding stratigraphy is essential in geotechnical engineering as it offers valuable insights into the arrangement, composition, and characteristics of soil and rock layers. This information is critical for creating stable foundations by determining load-bearing capacity and predicting settlement patterns. It also aids in slope stability analysis, determining excavation techniques, and guiding construction planning by identifying mechanical properties and potential failure planes. In this study, the stratigraphy beneath the dump was determined through borehole investigation. Understanding the stratigraphy is essential for predicting possible future failures, such as heaving and base failure.

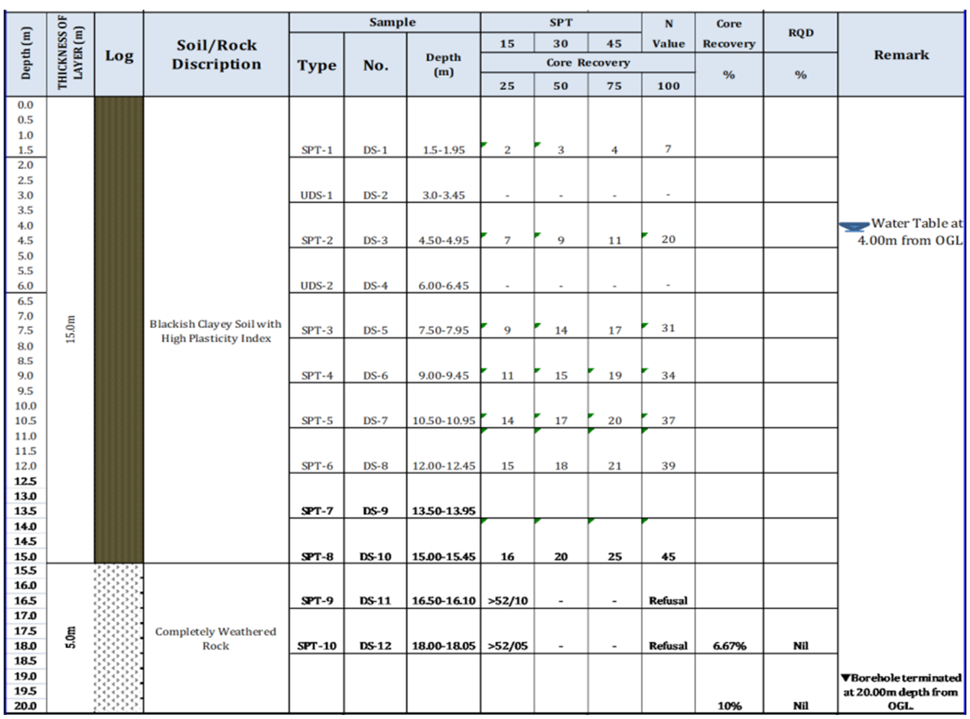


Figure 3. Borehole log for BH1 with SPT value and other characteristics

The borehole investigation locations were decided based on the scientific judgment of the field observation between the BC soil dump and Yekona village. Two points for borehole investigation are marked to determine the stratigraphy, as shown in Figure 1(BH1 and BH2), which is executed at a decided location along the study stretch. The geotechnical investigation includes drilling work, standard penetration test (SPT) at 1.5m intervals, and collection & preservation of disturbed (DS)/ Undisturbed soil (UDS) and rock samples. The groundwater table level (GWT) for BH1 and BH2 is 4m and 5m below the original ground level (OGL). The encountered GWT represents the water level during the investigation and is susceptible to seasonal variation. The fluctuation in GWT may affect the stability as the saturation will tend to expand and contract the BC soil strata beneath the dump. The tests performed on the soil sample collected are the index properties, grain size analysis, bulk and dry density, direct shear test, and consolidation test. Water absorption, specific gravity, and compressive strength are the tests carried out on the collected samples of rocks. Boreholes show that clay soil was observed up to 15m, and completely weathered rock was found between 15 and 20m. During the borehole investigation, undisturbed soil samples were collected at 3m and 6m depth and tested. The results show that at the BH1 and BH2 locations, the CH type of soil was observed, as depicted in Table 3. The grain size distribution of the samples encountered at different depths of the borehole is shown in Figure 4.

Table 3. Undisturbed soil sample results taken from the Borehole investigation

BH No	Depth (m)	Soil Classification	Bulk Density (kN/m^3)	Moisture content (%)	c (kN/m^2)	ϕ (°)
BH1	3.0	CH	15.54	28.90	34.32	16.4
	6.0	CH	15.41	30.10	40.21	13.8
BH2	3.0	CH	15.63	27.10	36.29	12.9
	6.0	CH	15.71	29.10	38.25	13.5

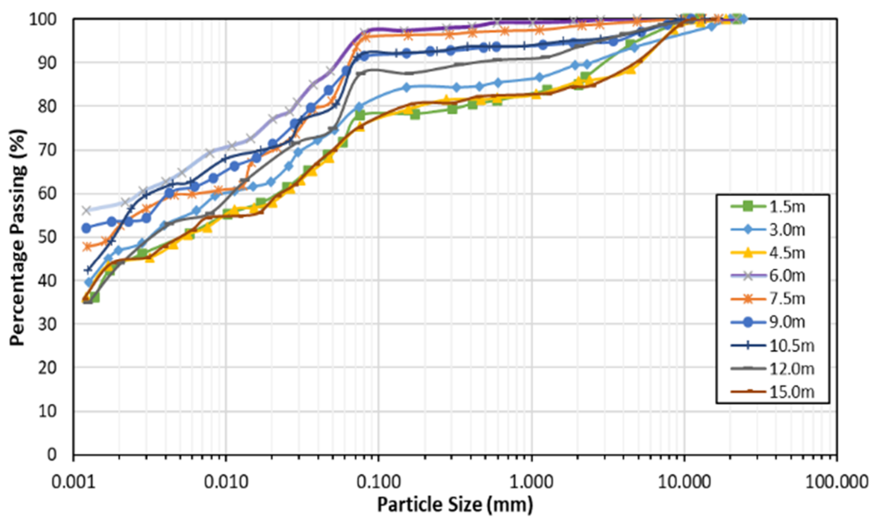


Figure 4. Grain size distribution curve for samples taken from different depths in the BH1 borehole

2.3. Cross-section utilized

Extracting cross-sections from contour maps is a fundamental methodology for elucidating the intricate topography of a given BC Dump site. Ten cross-sections for analysis based on their representativeness of site conditions were extracted from the contour map depicted in Figure 6, and the cutting line over the contour plan is shown in Figure 5. Additionally, the cross-section recommended in the scientific study report of the mine was incorporated into the analysis, and the commonly recommended practice for the BC dump is a 30° bench slope angle with a bench height of 10m and a width of 15m, as shown in Figure 7. Further, the recommended section was modified to incorporate stone pitching at the bottom bench and a rockfill trench at the toe.

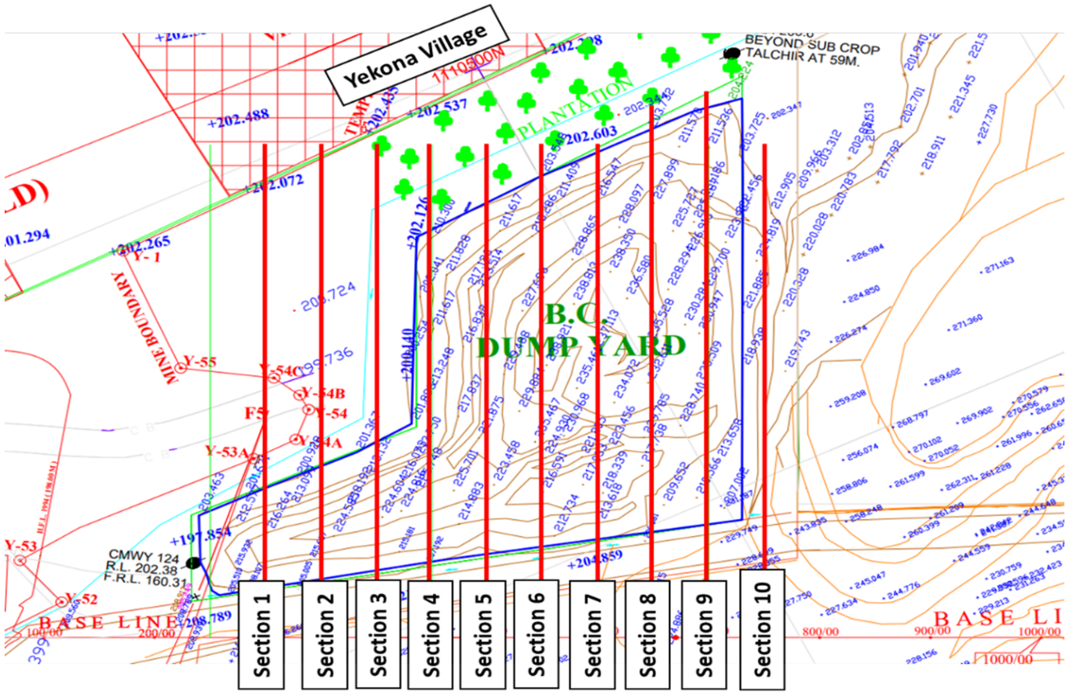


Figure 5. Cutting line over contour map for actual cross-sections

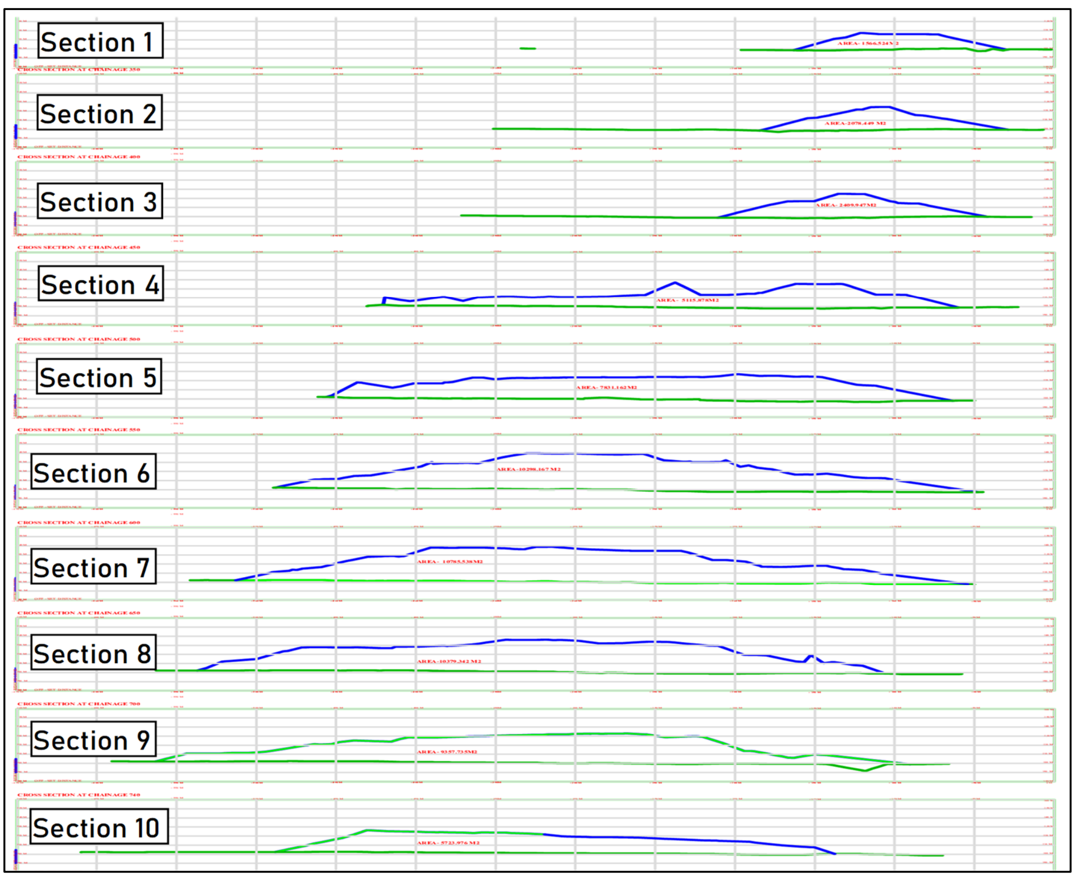


Figure 6. Actual cross-sections at 10 cutting locations at the site

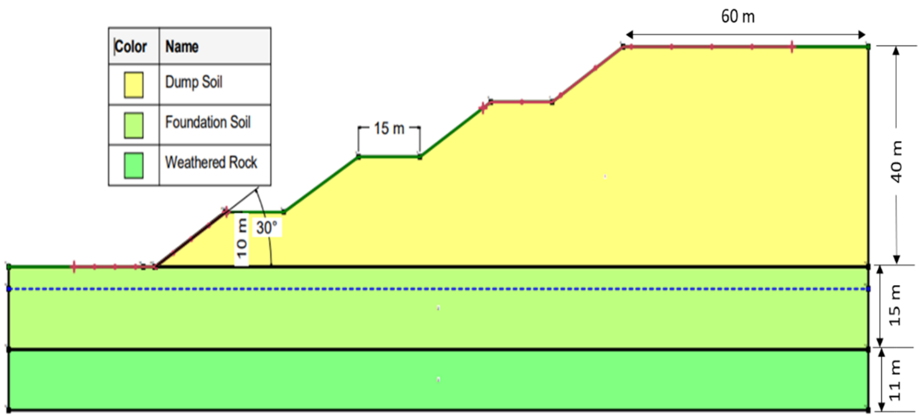


Figure 7. Recommended cross-sections to be followed at the site

2.4. Analysis type and material definition

A two-dimensional Limit Equilibrium Method (LEM) is employed to perform slope stability analysis on the cross sections, evaluating their feasibility using the SLOPE/W software from the Geoslope package. SLOPE/W offers a comprehensive platform for conducting in-depth stability analyses of soil and rock slopes, addressing straightforward and intricate issues. It accounts for various slip surface geometries, pore-water pressure conditions, soil properties, and loading scenarios, ensuring robust and detailed assessments. Developing a numerical model using SLOPE/W involves creating the geometry, assigning materials and boundary conditions, and obtaining results.

Among the several LEM methods, the Simplified Bishop method, a widely adopted technique, is utilized in the present study. This method discretizes the soil mass into slices to compute the Factor of Safety (FoS), satisfying vertical force equilibrium for each slice and overall moment equilibrium about the center of the circular trial surface. It assumes zero interslice shear forces, as horizontal forces at each slice are not considered. The Bishop's Method of slices is a prevalent technique for analyzing slope stability in geotechnical engineering, referring to the capacity of a soil or rock slope to remain in place without failure. In the model, the side boundary conditions were kept as roller support, and the bottom boundary was kept as fixed support.

The Mohr-Coulomb material model is one of the most widely used constitutive models based on the Mohr-Coulomb failure criterion, which states that failure occurs when the shear stress on a plane reaches a critical value determined by the normal stress on that plane. The impenetrable material model represents zones where no shear failure or deformation is allowed. It acts as a rigid, non-failing boundary within the stability analysis, forcing the slip surfaces not to pass through it. The Mohr-Coulomb material model was utilized for BC soil dump, rockfill trench, stone pitching, and foundation soil, while the bedrock was modeled as an impenetrable material model. The properties employed in the analysis are detailed in Table 4. The rockfill trench and stone pitching properties were taken from the literature [56]. The impact of blasting loads was disregarded as the generated Peak Particle Velocity (PPV) values remained within the acceptable codal limits.

Table 4. Properties Used for the Numerical Analysis

Sr.No.	Material	Properties	Values
1.	Dump Soil	Bulk Unit Weight (kN/m^3)	17.61
		Cohesion (kN/m^2)	27.26
		Friction angle (°)	14.90°
2.	Foundation Soil	Unit Weight (kN/m^3)	15.56
		Cohesion (kN/m^2)	37.27
		Friction angle (°)	14.15°
3.	Rockfill Trench/ Stone Pitching	Unit Weight (kN/m^3)	22.00
		Cohesion (kN/m^2)	150.00
		Friction angle (°)	25.00°

3. Numerical analysis results3.1. Slope stability analysis of existing cross-section

The Factor of Safety (FoS) for each of the 10 cross-sections was determined through numerical analysis, with the water table set at 4 meters below ground level. The FoS for each section in each analysis is documented in Table 5. The results for the critical sections with the lowest FoS values, specifically sections 4 and 5. According to the DGMS circular, slopes with a FoS below 1.3 are considered unsafe. The FoS for cross-sections 4 and 5 are 1.14 and 1.27, respectively. These values indicate that the slope of the dump is very steep and prone to failure due to the inclination angle at these sections. It is notable that the cross-sections used in the analysis depicted a flat terrain, which contrasts with the steep slopes observed on-site. This discrepancy is likely due to the timing of the survey, which was conducted before the monsoon season. Post-rainfall erosion has steepened the current state of the dump slope. The slope can be stabilized by implementing remedial measures such as slope flattening.

Table 5. FoS for 10 sections in the analysis

Cross-Sections	FoS
Section 1	1.58
Section 2	1.48
Section 3	1.53
Section 4	**1.14**
Section 5	**1.27**
Section 6	1.66
Section 7	1.52
Section 8	1.52
Section 9	2.3
Section 10	1.5

3.2. Slope stability on the recommended cross-section by slope flattening

A slope flattening analysis was conducted for the BC soil dump at Yekona mine. The slope flattening was analyzed for bench angles ranging from 25° to 50°, with the FoS calculated for each angle, and the results are presented in Table 6. The height and width of the bench were derived from the recommendations in the scientific report. The findings indicate that a 30° slope angle is adequate for bench flattening, providing a sufficient FoS in line with DGMS guidelines (FoS > 1.3). The results demonstrate that as the slope of the BC soil dump is flattened, the FoS increases.

Table 6. Variation in FoS for slope flattening

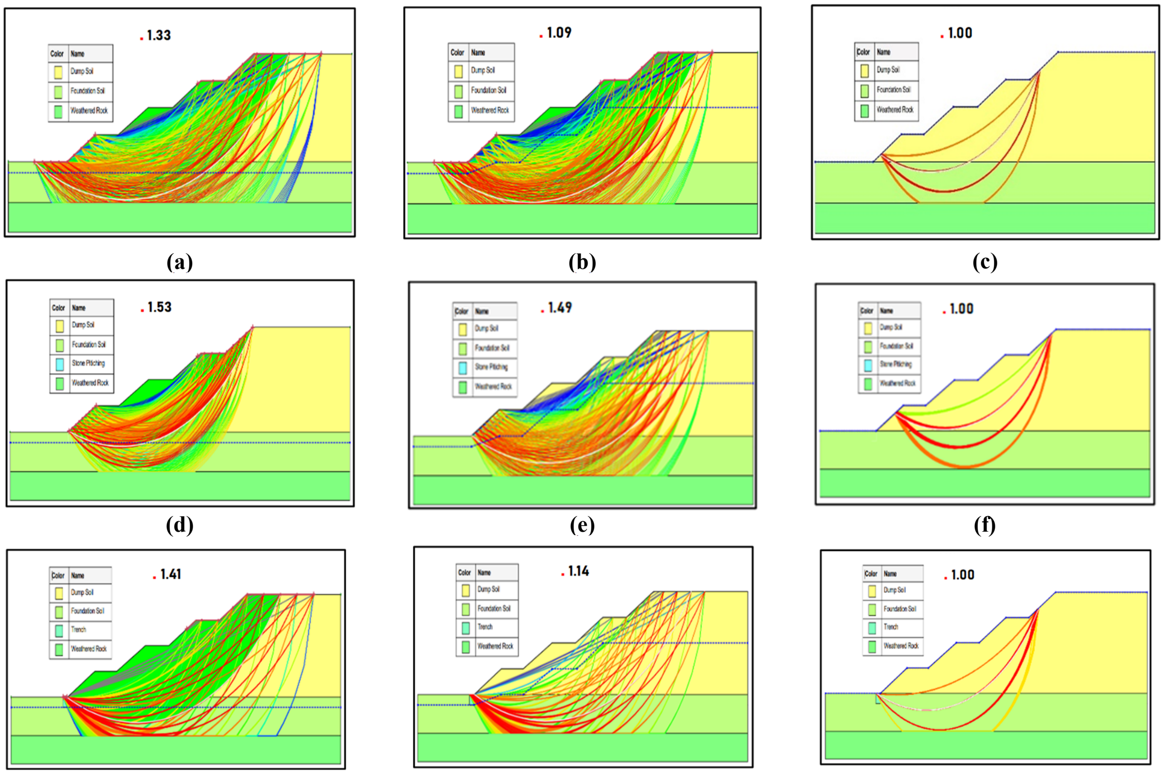
S.No.	Bench angle (°)	FoS
1.	25°	1.42
2.	30°	1.33
3.	35°	1.29
4.	40°	1.26
5.	45°	1.19
6.	50°	1.12

3.3. Slope stability when the dump is partially saturated and fully saturated

This analysis assumes that the water table in the dump rises due to monsoon rainfall. The study incorporates the increase in saturation levels by considering half and full saturation scenarios. Utilizing the recommended cross-section, the water table level was examined under these saturation conditions. Although the half and full saturation conditions are idealized and may not occur in the field, they represent the worst-case scenarios for dump stability. BC soil, with a high Free Swell Index (90-100), is particularly susceptible to shear strength loss upon water contact. This characteristic was factored into the analysis by considering varying saturation levels. The results are illustrated in Figure 8. Figure 8(a) is FoS in a dry state, Figure 8(b) is FoS in half saturation, and Figure 8(c) is FoS in full saturation conditions. The analysis reveals that an increase in the dump's saturation level leads to a decrease in the Factor of Safety (FoS). Despite these adverse conditions, the FoS for the recommended cross-section under half and full saturation is 1.099 and 1.006, respectively, which are considered safe as they exceed the threshold value 1. It can be attributed that a dump bench angle of 30° is effective during saturation conditions.

3.4. Effect of stone pitching

The recommended cross-section was utilized, incorporating 300mm thick stone pitching on the first bench slope. The analysis was conducted with the water table at half and full saturation levels. The failure surface was considered to pass through the stone pitching to evaluate its impact. The results are illustrated in Figure 8(d), (e), and (f) for dry, half saturation, and full saturation states, respectively. The inclusion of stone pitching enhances the FoS of the bottom bench, demonstrating its effectiveness as a remedial measure against face failure and slope erosion. The FoS values with stone pitching, stone pitching with half saturation, and stone pitching with full saturation are 1.420, 1.148, and 1.005, respectively. These findings support the implementation of stone pitching with a 30° bench slope at the bottom bench.



(g) (h) (i)

Figure 8. Analysis results for variation in FoS: (a), (b), and (c) for the effect of saturation; (d), (e), and (f) for effect of stone pitching; (g), (h), and (i) for the effect of rockfill trenching

3.5. Effect of Rockfill Trench

This analysis is carried out by incorporating a rockfill trench with dimensions of 3m in width and 4m in depth at the toe of the cross-section. The analysis was conducted in a dry state and with the water table at both half and full saturation levels, considering the failure surface passing through the rockfill trench at the toe of the dump to evaluate its impact, as illustrated in Figures 8(g), (h), and (i), respectively. The results indicate that the rockfill trench is an effective remedial measure against toe failure of the slope, enhancing retention against failure. The FoS values for the cross-sections with the rockfill trench and with the rockfill trench at half and full saturation are 1.412, 1.141, and 1.006, respectively. This study shows the effectiveness of a rockfill trench at the toe, adhering to proper construction methodology and fulfilling all required site conditions.

4. Remedial measures

From the field observation, geotechnical investigation, and numerical analysis, it is worth mentioning that the EC requirement of constructing a toe wall of 15-20 m height to resist a BC soil dump of about 36 m high may not be an economically viable solution. The numerical analysis results indicate that certain cross-sections require attention to enhance slope stability. However, implementing slope flattening at the site with a bench angle of 30°, a bench height of 10m, and a bench width of 15m can improve the Factor of Safety (FoS). Additionally, incorporating stone pitching at the bottom bench and rockfill trenching at the toe can further enhance the FoS by preventing face failure, toe failure, and slope erosion, ultimately increasing retention against failure. To further strengthen the current BC dump state, the remedial measures discussed below, based on the study, can be implemented.

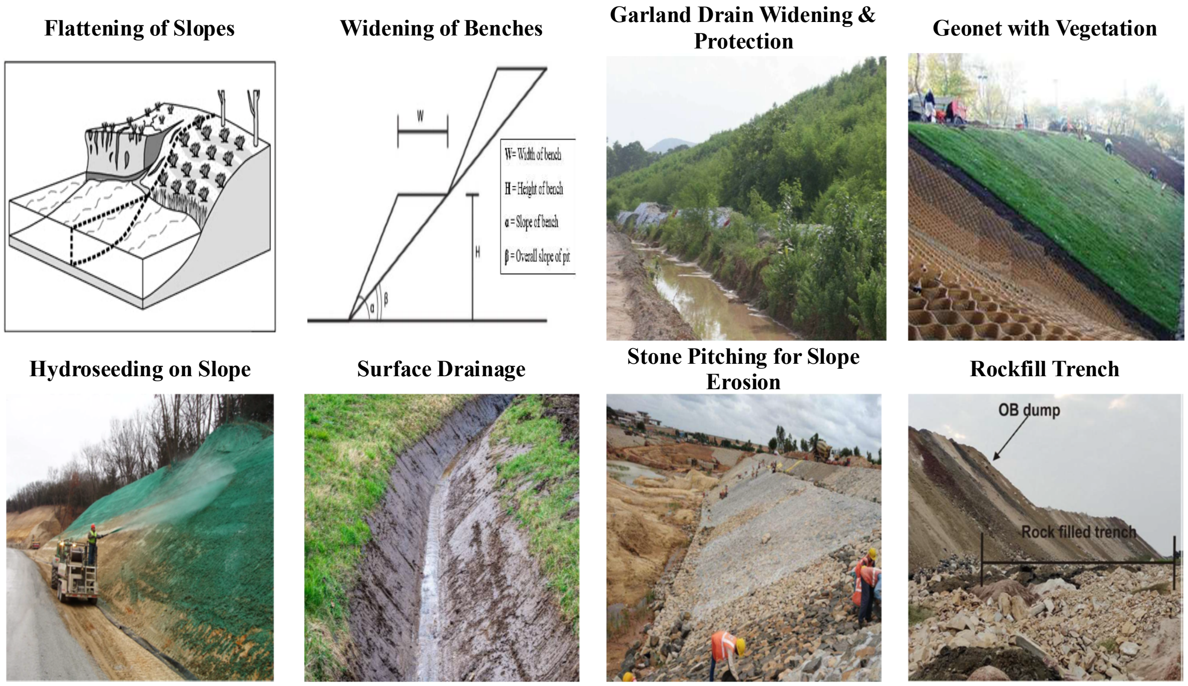


Figure 9. Remedial measures for the BC soil dump

The possible remedial measures are shown in Figure 9. An overview of various remedial measures for BC soil dump slope stabilization is given in this section.

- Slope flattening is the most widely used method to enhance the stability of already constructed dumps. The soil's weight is redistributed by reducing the slope's steepness, minimizing the risk of slope failure and mass movements. Maintaining these flattened slopes is essential for mitigating potential hazards and ensuring safety near the dump. The slope of current BC soil benches at steep sections shall be flattened to the recommended limit of 30° or less 30°.
- Bench widening is instrumental in preventing slope failure through several technical mechanisms, including reducing the overall slope angle, enhancing geotechnical stability, and reducing the overburden load on the slope. The bench width of the BC soil dump shall be maintained at 15m or more, and the bench height shall be maintained at 10m or less at all sections.
- Garland drains are used in mining operations to manage run-off water [49]. Proper maintenance and widening of the drains can prevent waterlogging and improve their capacity to manage excess water. The drain needs to be widened due to siltation. The gradient of the drain allows a continuous flow of water without any waterlogging. Stone pitching is recommended to prevent the scouring of the side face and to avert the risk of side slope instability of the garland drain due to running water. There is a strong need for the widening of the garland drain, and the side slope must be protected through stone pitching on the side face of the garland drain. In addition, a proper gradient shall be provided for the easy flow of water.
- Stone pitching is an effective erosion control technique to prevent soil degradation in mining areas [49]. It involves placing rocks along the slope to reduce the impact of water runoff and soil erosion. This method stabilizes the slope and maintains the integrity of the soil dump, safeguarding against hazardous soil movements and environmental damage. However, it is recommended to use stone pitching only at the bottommost bench of the soil dump to prevent erosion and protect the toe. IRC:56 (2011) [57] and IS 8237 (1985)[58] provides guidelines for stone pitching.
- Geonet with vegetation is an effective approach to prevent slope failures of BC soil dumps. The vegetation's roots enhance slope stability by binding the soil particles together, and the geonets provide structural reinforcement. This approach reduces the risk of erosion and landslides while promoting environmental sustainability. Hydroseeding is a cost-effective method for preventing soil erosion by water and wind. It involves applying a mixture of wood fiber/jute fiber, seed, fertilizer, and stabilizing emulsion with a hydroseeder [59]. IRC:56 (2011) [57] provides a guideline for hydroseeding for erosion control. Implementation shall be carried

out among geonets with vegetation and hydroseeding based on the suitability of the site.

- Effective surface drainage planning is crucial for mitigating challenges in BC soil. Proper drainage systems prevent soil erosion, reduce waterlogging, and provide access to runoff. IRC: SP: 42 (2014) [60] provides the guidelines for the provision of surface drainage.
- Trench cutting and filling with hard rocks (rockfill trench) or toe wall at the toe of the slope is an effective method to prevent slope/base failures [56]. The rockfill trench/toe wall provides a stable foundation and retention, inhibiting the failure surfaces. The dimensions of the trench vary depending on the site conditions. This method represents a practical approach for dump stabilization in mining.
- Though the scientific monitoring of slopes suggests instrumentation through inclinometers, extensometers, and tilt sensors in case of volatile slopes, Conventional monitoring of the OB dump shall be carried out by placing the poles/pegs with cement blocks in a grid of 50m × 50m in a staggering pattern. The total station method of surveying can measure the position of the poles/pegs from a reference point. The purpose of this action is to measure abrupt disturbances in the dump during normal working conditions. For the BC dump slope, the top of the poles/pegs will be monitored for displacement once every fortnight during the dry period of October to May. In the rainy season, the monitoring should be done once every seven days, and if there is heavy rainfall, the monitoring should be done twice weekly.

5. Application of remedial measures at the site

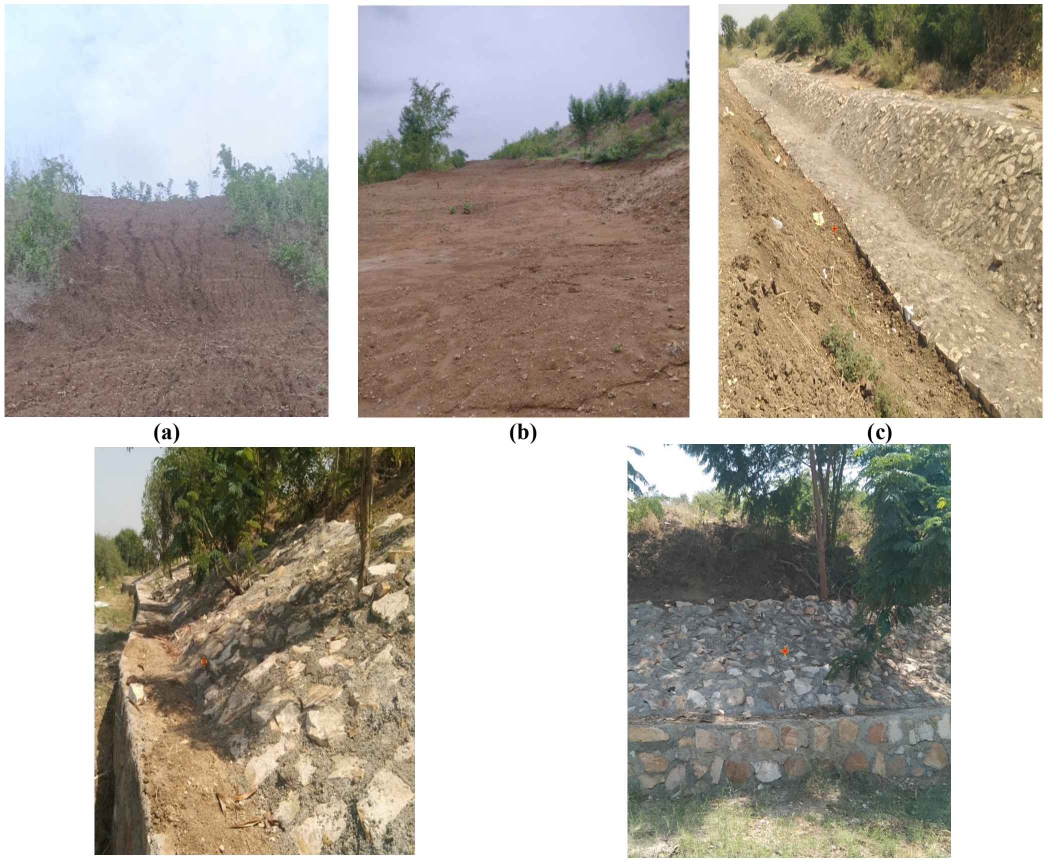
As per the recommended remedial measures, the onsite application of the measures was implemented. The following remedial measures have been implemented at the site:

- The slope of the bench was modified to 30° (Figure 10 (a)).
- The bench's width was increased to more than 15 m, and its height was reduced to less than 10 m where required (Figure 10 (b)).
- The garland drain was widened to 2 m, and stone pitching was carried out on the side of the garland drain (Figure 10 (c)).
- Stone pitching was also carried out at the bottommost bench of the BC soil dump slope (Figure 10 (d)).
- The toe wall was completed (Figure 10 (e)).
- The geonet with vegetation was executed at the site.

6. Cost-benefit analysis

The cost-based analysis was carried out to account for the cost economics. It has been calculated for 300m of dump facing the Yekona village. The feasibility study included a cost-benefit analysis based on the remedial measures proposed by the MoEFCC. Table 7 displays the costs of the applied remedial measures on the site, including the cost of constructing a 15m high wall. It is evident that the cost of remedial measures is less than 5% of the amount required for the construction of a 15m wall. Therefore, it can be concluded that the suggested on-site remedial measures were cost-effective.

Stone pitching, toe wall, garland drain cleaning, and BC dump slope correction toward the Yekona village-side dump are considered a single item in the cost-benefit analysis. This includes activities such as hiring an excavator, cleaning garland drains, sloping work for pitching and toe wall, transporting earth, performing earthwork for the surface of pitching, sand filling, applying PCC, stone pitching, flush pointing, random rubble masonry, using sandbags to maintain slopes, installing UPVC pipes for surface drainage, constructing brickwork for chambers, and applying plaster and shuttering for concrete. Further, implementing geonet over the dump with vegetation was considered another entity in the cost-benefit analysis. The normalized rate of the individual work is shown in Table 7. These normalized rates were site-specific and may vary depending on the site conditions.



(a) (b) (c) (d) (e)

Figure 10. Implemented remedial measures at the site

Table 7. Cost-benefit analysis for applied measures at the site with respect to the suggested measures based on the MoEFCC recommendation

Work	Total cost of work	Remarks
Stone pitching, Toe wall, garland drain cleaning, and BC dump slope correction towards the Yekona Village side dump.	Estimated Amount: ₹ 4914905/-	Calculated for a 300m stretch at the toe of the BC soil dump. **Normalized rate per work:** Stone pitching: ₹ 290/m^2 Toe wall: ₹ 2633/m^3 Garland drains cleaning: ₹ 157/m^3 BC soil Slope correction: ₹ 95/m^3
Implementation of geonet over the dump with vegetation	Estimated Amount: ₹ 1470000/-	Area of BC dump for geogrid application 6000 m^2 (300m length and 20m height) **Normalized rate:** Implementation of Geogrid with vegetation: ₹ 245/m^2
Total Amount	Estimated Amount: ₹ 6384905/-	
Costing of the Toe wall of 15m height as per the MoEFCC instructions. The width of the wall is assumed to be 10m, and the depth of the foundation is 10m below GL.	Estimated Amount: ₹ 141201900/- Amount = volume× rate Excavation amount: 30000×90= ₹2700000 Earth handling amount: 30000×60= ₹1800000 Plith preparation volume: 900×40= ₹36000 Random rubble masonry Volume: 44100×3099= ₹136665900	The calculation was carried out from the rate sheet provided in the quotation. Volume = length *breadth*height Excavation volume: 300×10×10= 30000 m^3 Earth handling Volume: 300×10×10 = 30000 m^3 Plith preparation volume: 300×10×0.3= 900 m^3 Random rubble masonry Volume: 300×10×14.7= 44100 m^3

7. Concluding remarks

The BC soil dump is a crucial part of open-cast mining as its handling plays a vital role in the mining operation. Moreover, dumping BC soil with overburden poses stability risks, necessitating separate dumping. The BC soil dump has several issues, such as substantial erosion, rain cuts, soil sliding, etc., that can be prevented by applying remedial measures. The concluding remarks of the present study are as follows: The study showed that the remedial measures like slope flattening, bench widening, garland drain widening and protection, surface drainage, slope protection by stone pitching, vegetation with hydroseeding or geonet, and rockfill trench/toe wall will be feasible solutions at the site to stabilize BC soil dump.

- The on-site implementation of these measures demonstrated long-term effectiveness, significant stability improvements, and reduced erosion and soil movement.
- The cost analysis showed that the cost associated with the recommended measures was less than 5% of the construction cost of a 15m high wall (MoEFCC suggested) for a stretch of 300m of the dump section facing Yekona village. This translates to significant cost savings while ensuring the structural integrity of the dump.

The study is instrumental in ensuring proper containment to mitigate risks and enhance the overall stability of BC soil dumps, safeguarding both the environment and public safety.

Acknowledgments

We take this opportunity to thank the mine officials of Western Coalfields Limited (WCL) of Majri Area for their invaluable support and cooperation throughout this study. We appreciate their willingness to provide essential data and insights, which significantly enriched the quality and depth of our research. Our Special Thanks to Er. Elyas Husen Sheikh, Area General Manager, for giving us this opportunity to carry out the scientific study, and Er. Gautam Roy, Sub-Area Manager, Er. Venkatesh Gorak, Deputy Manager (Civil) & Er. Shobhit Agarwal, Environmental Division, whose guidance and expertise were crucial in navigating complex technical challenges. This project would not have reached its full potential without their generous assistance, which we sincerely appreciate.

Data availability

The data supporting this study's findings are available in the article. The corresponding author can provide additional datasets generated and analyzed during the study.

Conflicts of interest

In this study, the authors aim to share new scientific findings to make informed decisions regarding the stability of BC soil dumps. The manuscript reflects the technical viewpoint on engineering judgment, testing, and analysis. The content is intended solely to convey the technical aspects of the study area and does not imply any legal interpretations or potential litigation.

Funding

This study was not supported by any of the agencies.

Disclosure statement

The authors report there are no competing interests to declare.

Reference

[1]. Gupta, T., Rai, R., Jaiswal, A., & Shrivastva, B. K. (2014). Sensitivity analysis of coal rib stability for internal mine dump in opencast mine by finite element modelling. *Geotechnical and Geological Engineering, 32*, 705–712.

[2]. Rai, R., Kalita, S., Gupta, T., & Shrivastva, B. K. (2012). Sensitivity analysis of internal dragline dump stability: Finite element analysis. *Geotechnical and Geological Engineering, 30*, 1397–1404.

[3]. Rajak, T. K., Yadu, L., & Chouksey, S. K. (2020). Strength characteristics and stability analysis of ground granulated blast furnace slag (GGBFS) stabilized coal mine overburden-pond ash mix. *Geotechnical and Geological Engineering, 38*, 663–682.

[4]. Gouda, J., Srinivasan, V., Reddy, D. S., & Shende, R. (2024). Evaluating overburden materials for haul road construction with and without cellular confinement: A comprehensive study in Indian context. *Mining, Metallurgy & Exploration*.

[5]. Gouda, J., Reddy, D. S., Srinivasan, V., & Dudhabaware, A. (2025). Unlocking the potential of mine overburden materials and coconut coir geotextile: A full-scale study on reinforcing low-volume roads in India. *Road Materials and Pavement Design*.

[6]. Poulsen, B., Khanal, M., Rao, A. M., et al. (2014). Mine overburden dump failure: A case study. *Geotechnical and Geological Engineering, 32*, 297–309.

[7]. Zou, D. H. (2016). Exploring a waste dump site failure – Possible causes and prevention measures.

International Journal of Geohazards and Environment, 2, 25–33.

[8]. Bakhaeva, S. P., Gogolin, V. A., & Ermakova, I. A. (2016). Calculating stability of overburden dumps on weak bases. *Journal of Mining Science, 52*, 454–460.

[9]. Upadhyay, O. P., Sharma, D. K., & Singh, D. P. (1990). Factors affecting stability of waste dumps in mines. *International Journal of Surface Mining, Reclamation and Environment, 4*, 95–99.

[10]. Kainthola, A., Verma, D., Gupte, S. S., & Singh, T. N. (2011). A coal mine dump stability analysis—A case study. *Geomaterials, 1*, 1–13.

[11]. Mohanty, M., Sarkar, R., & Das, S. K. (2022). Probabilistic assessment of effects of heterogeneity on the stability of coal mine overburden dump slopes through discrete element framework. *Bulletin of Engineering Geology and the Environment, 81*.

[12]. Behera, P. K., Sarkar, K., Singh, A. K., et al. (2016). Dump slope stability analysis – A case study. *Journal of the Geological Society of India, 88*, 725–735.

[13]. Sharma, S., & Roy, I. (2015). Slope failure of waste rock dump at Jayant opencast mine, India: A case study. *International Journal of Applied Engineering Research, 10*, 33006–33012.

[14]. Sengupta, S., Sharma, S., & Roy, I. (2016). Stability analysis of overburden internal dump material of Amlohri opencast coal mine, India. *ARPN Journal of Earth Sciences, 5*, 50–57.

[15]. Dash, A. K. (2019). Analysis of accidents due to slope failure in Indian opencast coal mines. *Current Science, 117*, 304–308.

[16]. Ismail, M. A. M., Ng, S. M., & Abustan, I. (2017). Parametric study of horizontal drains for slope stability measure: A case study in Putrajaya, Malaysia. *KSCE Journal of Civil Engineering, 21*, 2162–2167.

[17]. Verma, D., Kainthola, A., Thareja, R., & Singh, T. N. (2013). Stability analysis of an open cut slope in Wardha valley coal field. *Journal of the Geological Society of India, 81*, 804–812.

[18]. Zhang, L., Wang, J., Bai, Z., & Lv, C. (2015). Effects of vegetation on runoff and soil erosion on reclaimed land in an opencast coal-mine dump in a loess area. *Catena, 128*, 44–53.

[19]. Steiakakis, E., Thalassinakis, J., Agioutantis, Z., & Galetakis, M. (2016). Failure process of the external waste dump of a lignite mine using (FEM). In *13th International Symposium on Continuous Surface Mining (ISCSM 2016)* (pp. 587–593).

[20]. Verma, H., Rudra, E. S. C. K., Rai, R., et al. (2023). Design of dump slope on weak foundation. *Journal of the Institution of Engineers (India): Series D, 104*, 107–118.

[21]. Puell Ortiz, J. (2017). Methodology for a dump design optimization in large-scale open pit mines. *Cogent Engineering, 4*(1), 1–11.

[22]. Wang, Y., Nazem, M., & Smith, J. V. (2022). Effect of dimension variables on the behaviour of slopes stabilised by an integrated method combining gabion-faced geogrid-reinforced retaining wall with embedded piles. *International Journal of Geosynthetics and Ground Engineering, 8*, 1–19.

[23]. Shende, R., Srinivasan, V., Ahmed, M. S., & Mandal, A. (2024). Probabilistic retro-analysis of failed OB dump on the weak ground with water table variation and varied preventive measures. *Physics and Chemistry of the Earth, 136*, 103784.

[24]. Sarfarazi, V., Tabaroei, A., Dias, D., et al. (2024). 2D discrete element analysis of the footing above excavated circle in soil. *Scientific Reports, 14*, 1–18.

[25]. Sarfarazi, V., Zhou, L., Haeri, H., et al. (2025). Failure mechanisms of concrete-bolt attachment surface: Impact of cable bolt indent number and shape. *Journal of Mining and Environment, 16*, 223–239.

[26]. Sarfarazi, V., Haeri, H., Marji, M. F., et al. (2023). Investigation of shear properties of open non-persistent latitudinal discontinuities of same level. *Journal of Mining and Environment, 14*, 1361–1371.

[27]. Sarfarazi, V., Haeri, H., Marji, M. F., & Saeedi, G. (2024). On 2D discrete element analyses of transversely isotropic elastic geo-materials; Insight to scale effects and loading rate. *Journal of Mining and Environment, 15*, 1051–1070.

[28]. Daftaribesheli, A., Ataei, M., & Sereshki, F. (2011). Assessment of rock slope stability using the fuzzy slope mass rating (FSMR) system. *Applied Soft Computing Journal, 11*, 4465–4473.

[29]. Goshtasbi, K., Ataei, M., & Kalatehjary, R. (2008). Slope modification of open pit wall using a genetic algorithm – Case study: Southern wall of the 6th Golbini Jajarm bauxite mine. *Journal of the Southern African Institute of Mining and Metallurgy, 108*, 651–656.

[30]. Chand, K., & Koner, R. (2023). Internal mine dump slope stability and failure zone identification using 3D modelling. *Journal of Mining and Environment, 14*, 1105–1119.

[31]. Rezaei, S., Rafiee, R., Ataei, M., & Javadi, M. (2023). Sustainability analysis of waste dump in mine No. 4 of Golgohar, Sirjan, for purpose of increasing waste dump volume. *Journal of Mining and Environment, 14*, 1373–1391.

[32]. Yang, Z., Song, Z., Ding, X., et al. (2025). Investigating slope stability of multiple stopes prone to instability in the Ziluoyi iron ore mining site. *Scientific Reports, 15*, 1900.

[33]. Kumar, S., & Dey, K. (2025). Stability analysis of overburden rocks — A new approach. *Arabian Journal of Geosciences.*

[34]. Enkhbold, B., Ikeda, H., Toriya, H., & Adachi, T. (2025). Internal waste dump stability analysis: Insights from numerical simulations. *Discover Geoscience.*

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

[36]. Amarsaikhan, T., Shimada, H., Wahyudi, S., et al. (2018). Optimization of dump bench configuration to improve waste dump capacity of Narynsukhait open pit coal mine. *International Journal of Geosciences, 9*, 379–396.

[37]. Geete, S. S., Singh, H. K., Singh, T. N., & Dahale, P. P. (2023). Stability analysis of overburden dump slope of coal/mineral mines: A review. *Journal of Mines, Metals and Fuels*, 1215–1223.

[38]. Singh, V. K., Masood, M. M., & Verma, T. (2024). Slope monitoring techniques in opencast mines: A review of recent advances. *Journal of Mines, Metals and Fuels*, 83–92.

[39]. Chand, K., & Koner, R. (2024). Mine active internal dump susceptible zone identification using MMO technique. *Journal of Mines, Metals and Fuels*, 165–177.

[40]. Srivastava, N., Ram, L. C., & Masto, R. E. (2014). Reclamation of overburden and lowland in coal mining area with fly ash and selective plantation: A sustainable ecological approach. *Ecological Engineering, 71*, 479–489.

[41]. Navagire, O. P., Sharma, S. K., & Rambabu, D. (2022). Stabilization of black cotton soil with coal bottom ash. *Materials Today: Proceedings, 52*, 979–985.

[42]. Ikeagwuani, C. C., Obeta, I. N., & Agunwamba, J. C. (2019). Stabilization of black cotton soil subgrade using sawdust ash and lime. *Soils and Foundations, 59*, 162–175.

[43]. Hensen, E. J. M., & Smit, B. (2002). Why clays swell. *Journal of Physical Chemistry B, 106*, 12664–12667.

[44]. Noorany, I., & Scheyhing, C. (2015). Lateral extension of compacted-fill slopes in expansive soils. *Journal of Geotechnical and Geoenvironmental Engineering, 141*, Article 04014106.

[45]. Vonk, C. K., & Valdes, J. R. (2023). Soil swell accommodation by compressible inclusions. *International Journal of Geomechanics, 23*, Article 04023002.

[46]. Soundara, B., & Selvakumar, S. (2020). Experimental investigation on the swelling behavior of expansive soils with EPS geofoam inclusion. *Indian Geotechnical Journal, 50*, 519–530.

[47]. Hartanto, H., Prabhu, R., Widayat, A. S. E., & Asdak, C. (2003). Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management. *Forest Ecology and Management, 180*, 361–374.

[48]. Shi, Z. H., Fang, N. F., Wu, F. Z., et al. (2012). Soil erosion processes and sediment sorting associated with transport mechanisms on steep slopes. *Journal of Hydrology, 454–455*, 123–130.

[49]. Jangir, H. K., Shende, R., Navagire, O., et al. (2025). Feasibility study for providing remedial measures for overburden dump in new Majri UG to OC mine, WCL Majri area, Warora, Chandrapur. *Journal of Sustainable Mining, 24*.

[50]. Zhao, C., Gao, J., Huang, Y., et al. (2016). Effects of vegetation stems on hydraulics of overland flow under varying water discharges. *Land Degradation & Development, 27*, 748–757.

[51]. Samal, S. K., Mishra, S. N., Banchhor, R. K., & Mishra, A. K. (2023). Dump management in South Kaliapani chromite mines. *Journal of Mines, Metals & Fuels, 21*, 48–55.

[52]. Shende, R., Patil, M., Srinivasan, V., et al. (2025). Engineering assessment of reinforced earth wall and vehicular underpass sections in a six-lane highway: Analysis, causes, and remedial measures. *Case Studies in Construction Materials, 22*, e04482.

[53]. Bishwal, R. M., Sen, P., & Jawed, M. (2018). A laboratory study on estimation of shear strength and compaction properties of overburden dump material in Indian coal mines. *Journal of the Geological Society of India, 92*, 363–367.

[54]. Koner, R., & Chakravarty, D. (2016). Characterisation of overburden dump materials: A case study from the Wardha valley coal field. *Bulletin of Engineering Geology and the Environment, 75*, 1311–1323.

[55]. Bureau of Indian Standards. (1970). *Classification and identification of soils for general engineering purposes* (IS:1498–1970). New Delhi, India: BIS.

[56]. Sekhar, S., Singh, U. C., Porathur, J. L., & Budi, G. (2021). Overburden dump stabilization over weak floor using rock-filled trench near the toe—a numerical modeling approach. *Arabian Journal of Geosciences, 14*.

[57]. Indian Roads Congress. (2011). *Recommended practices for treatment of embankment and roadside slopes for erosion control (First Revision)* (IRC:56–2011).

[58]. Bureau of Indian Standards. (1985). *Code of practice for protection of slope for reservoir embankment (First Revision)* (IS:8237–1985).

[59]. Emeka, O., Nahazanan, J., Kalantar, H., Khuzaimah, B., & Sani, Z. O. (2021). Slope reinforcement technology. *Land, 10*, Article 333.

[60]. Indian Roads Congress. (2014). *A manual of guidelines of road drainage* (IRC: SP:42-2014), 1-138.

نشریه مهندسی معدن و محیط زیست
نشانی نشریه: www.jme.shahroodut.ac.ir
انجمن مهندسی معدن ایران
دانشگاه صنعتی شاهرود

چالش‌های مهندسی و اقدامات اصلاحی در محل دفن خاک سیاه پنبه‌کاری مجاور هملت: مطالعه موردی از معدن روباز

راهول شنده، اومکار ناواگیر، هیمانشو کومار جانگیر، سرینیواسان ونکاترامان*، آنیربان ماندال و آنجان پاتل

موسسه ملی فناوری ویسوِسوارایا، ناگپور ۴۴۰۰۱۰، ماهاراشترا، هند

اطلاعات مقاله

تاریخ ارسال: ۲۰۲۴/۰۹/۲۸
تاریخ داوری: ۲۰۲۵/۰۵/۱۴
تاریخ پذیرش: ۲۰۲۵/۰۵/۲۶

DOI: 10.22044/jme.2025.15137.2896

کلمات کلیدی

استخراج روباز
دپوی OB
جهت‌گیری و رشد ترک
خاک سیاه پنبه‌زار
پایداری شیب

چکیده

خاک سیاه پنبه (BC) به دلیل چالش‌های پیچیده‌اش، به طور جداگانه در مناطق معدنی تخلیه می‌شود و این مطالعه بر روی یک تخلیه خاک BC در یک معدن روباز تمرکز دارد. این خاک که با چسبندگی ۲۶-۴۰ کیلوپاسکال و زاویه اصطکاک داخلی ۱۳-۱۷ درجه مشخص می‌شود، با نوسانات رطوبت، انبساط و انقباض قابل توجهی از خود نشان می‌دهد، در دوره‌های مرطوب متورم می‌شود و در دوره‌های خشک جمع می‌شود و چالش‌های قابل توجهی را در مناطق معدنی ایجاد می‌کند. وزارت محیط زیست، جنگل و تغییرات اقلیمی (MoEFCC) پیشنهاد ساخت یک دیوار ۱۵-۲۰ متری برای محافظت از روستا در حاشیه تخلیه خاک BC با ارتفاع ۳۶ متر را داده است. هدف از این مطالعه شناسایی راه‌حل‌های اصلاحی جایگزین پایدار و اقتصادی و امکان‌پذیر بود. آزمایش میدانی، از جمله بررسی گمانه، برای تعیین چینه‌شناسی زیر تخلیه انجام شد. تجزیه و تحلیل عددی با استفاده از نرم‌افزار SLOPE/W برای بهینه‌سازی شیب و ارزیابی اقدامات اصلاحی مانند سنگفرش و سنگریزه انجام شد. این مطالعه نشان می‌دهد که تخلیه را می‌توان با استفاده از اصلاح طراحی و اقدامات مقرون به صرفه تثبیت کرد. بر اساس مشاهدات میدانی، آزمایش مواد زائد و تحلیل عددی، اقدامات اصلاحی جایگزین پیشنهاد و اجرا شد. این مطالعه همچنین شامل تحلیل هزینه-فایده از اقدامات اصلاحی پیشنهادی است.

نویسنده مسئول مکاتبات: srinivasanv@civ.vnit.ac.in (سر. ونکاترامان)