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Stability Analysis of Overburden Dump Slope of Coal/ Mineral Mines: A Review

Sumit S. Geete[1]*, Hemant K. Singh[2], T. N. Singh[2] and Prasad P. Dahale[1]

[1]*Shri Ramdeobaba College of Engineering and Management, Nagpur - 440013, Maharashtra, India; sumit.geete@gmail.com*
[2]*Indian Institute of Technology, Bombay - 400076, Maharashtra, India*

Abstract

Open-pit mining generates vast quantities of overburden waste material, which is piled up in the form of overburden dumps. Ensuring the stability of these dump slopes is a primary concern for the open-cast mining industry. Stability analysis is employed as a technique to calculate the factor of safety for these overburden dump slopes. This analysis relies on both the geometric and geotechnical characteristics of the dump. The stability of the slope is influenced by key factors such as bench height, bench width, and the number of benches. Factors such as pore pressure, permeability, degree of saturation, moisture content, and rainfall levels can induce instability in these overburden dump slopes. The shear strength of the material constituting the slope depends on both cohesion and the internal angle of friction. Since overburden dumps are composed of a heterogeneous mix of clay, silt, and rock fragments, employing small-scale direct shear tests or triaxial shear test setups might lead to underestimated or overestimated shear strength values for the dump material. To comprehend the heterogeneity of the overburden dump material, various sieve analysis techniques are utilized. The limit equilibrium method serves as the foundational approach for slope stability analysis. Additionally, probabilistic failure analysis and numerical analysis techniques such as the shear strength reduction method offer robust tools for assessing potential failure scenarios and determining critical factors of safety.

Keywords: *Cohesion, Factor of Safety, Overburden Dump Slope, Stability of Slope*

1.0 Introduction

Coal and minerals form the fundamental requirements for a nation's development. The demand for these resources is progressively increasing, prompting mining operations to delve deeper into the earth. As mining depths escalate, the stripping ratio, which signifies the volume of excavated material (measured in cubic meters) required to produce one metric ton of coal or metal, also rises. This excavated material, known as overburden dump material, is amassed in the form of waste dumps, spoil dumps, or overburden dumps. Generally devoid of utility, this material typically lacks significant mineral content or contains minerals with extremely low concentrations.

When the overburden material is stacked within the mine's confines, it's referred to as an Internal Pit Dump (IPD). Conversely, when this material is deposited outside the mine area, it's termed an external overburden dump. In India, the preference leans toward external dumping over internal pit dumping. The composition of overburden dump slope material is heterogeneous, encompassing fractured rock fragments interspersed with clay or soil particles. Managing the substantial quantity of this material while ensuring stability and cost-effectiveness poses a significant challenge for surface mining industries.

The primary industry objective is to extract maximum coal or minerals at minimal cost and with minimal

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**Author for correspondence*

environmental impact. The environmental aspect relates to stabilizing the overburden dump material while minimizing land use around the mine. Waste dump slopes are usually positioned close to open pit mines to curtail transportation expenses. These overburden dump slopes are artificial constructs, yet historically, insufficient attention has been given to their analysis, design, and implementation, leading to previous accidents stemming from slope failures. Neglecting proper design for these dumps has resulted in uneconomical and unsafe slopes. Consequently, optimizing the stability of overburden dump slopes in an economical manner has become a paramount concern for the mining industry. Ensuring the stability of these slopes is not only crucial for operational personnel but also for the machinery used in mining activities.

If the shear strength of the underlying foundation strata is lower than the shear strength of the waste material in the dump, then the stability of the slope will be predominantly determined by the shear strength of the foundation strata[1]. The stability of the overburden dump slope is directly related to the bearing capacity of the foundation soil[2]. The Factor of Safety (FOS) signifies the stability of the dump slope, and typically, a conservative design aims for a minimum risk with an FOS ranging from 1.1 to 1.15. The Fellenius method is employed to identify the critical failure surface of the waste dump slope. The allowable dumping height is contingent on the waste dump material's index properties and the techniques employed for dumping[3]. Coates introduced charts that correlate dump height with the calculation of the factor of safety, utilizing the slope angle as a key parameter[4]. The failure of internal dumping directly impacts both coal extraction within the mine and the safety of personnel working within its confines[5]. The correlation between dump height and the slope angle is established by considering diverse index properties of both the dump material and the underlying foundation soil[6]. Proposed are connections between the Factor of Safety (FOS) and dump height, as well as between FOS and slope angle[7]. The stability of the dump slope is analyzed with regard to the influence of height increase, along with the introduction of additional bench formations[2].

2.0 Index Properties of Dump Slope

Due to its heterogeneous nature, investigating the index properties of Overburden Dump (OBD) material poses challenges. Larger particles are typically excluded during grain size analysis of the OBD material. A total of 11 mine site dump material samples (8 samples per mine) were gathered and subjected to testing for various geotechnical properties[6]. Density and porosity play a significant role in influencing the mechanical behavior of rock-fill materials. The uneven distribution of compaction in space results in variations in the structural characteristics of the rock fill material. In this study, a series of large triaxial tests (300mm in diameter and 700mm in length) were conducted to investigate how density and porosity impact the mechanical properties of the rock fill material. This investigation involved plotting stress-strain curves, volumetric strain, and axial strain. To address the limitations of the Duncan-Chang model, two modified constitutive models were introduced: 1) an exponential nonlinear elastic model and 2) a modified Nanshui double yield model[8]. The dilatancy of the rock fill material is influenced by factors such as the initial particle distribution diameter, current void ratio, effective mean normal stress and deviatoric stress. A constitutive model is put forth to account for the impact of dilatancy, considering variations in density, gradation, and confining pressure[9]. The peak friction angle is contingent upon soil index properties, relative density, unit weight, and void ratio. To establish a correlation with the peak friction angle, undrained direct shear tests were conducted on soil samples featuring varying proportions of Coarse to Fine (C/F). Lateral confinement impacts lateral strain, axial strain, porosity, and lateral pressure coefficient. As lateral confinement intensifies, porosity experiences a reduction[5]. The heterogeneity of OBD material can result in inaccuracies in estimating geotechnical properties. Cohesion and friction angle were graphed using combinations of sand-clay, sandstone-shale, sandstone-clay and shale-clay in different ratios. Cohesion increased as clay content increased, while internal friction declined with greater clay content[10]. X-Ray Diffraction (XRD) analysis conducted on OBD material from a mine in South-eastern Nigeria revealed the presence of swelling mineral (Illite), which is likely a significant contributing factor to the instability of the dump slope[11]. Dump slope rating system is proposed for stability analysis of the dump slope. this rating consists of six parameters namely, overall dump height, overall dump slope, number of benches, hydrological conditions, cohesion of dump material and internal angle of friction of dump material[12]. The geotechnical characteristics of overburden dump material are enhanced through the incorporation of fly ash in specified proportions[13]. The inclusion of sizable boulders in the overburden dump material leads to an increase in permeability and the hydraulic coefficient. Rainfall intensity notably affects slope angles exceeding 30 degrees. During a one-hour duration of rainfall, the coefficient of saturation fluctuates between 0.30 and 0.60[14]. The grain size distribution of the fragmented rock samples is determined using the image analysis method. The outcomes obtained from image analysis, conducted using WipFrag 2.7 by Wip Ware, are juxtaposed with the Kuz-Ram empirical equation[15].

3.0 Shear Strength

Subsequent to deposition, the waste dump material undergoes both physical and chemical weathering, leading to modifications in its properties. This, in turn, brings about alterations in shear strength and permeability characteristics of the dump material[1]. Coates' findings reveal that the effective internal angle of friction and effective cohesion values for coal waste dumps typically fall within the range of 22° to 34° and 0 to 1488 kPa, respectively, based on comprehensive investigations[4]. The shear strength of OBD material diminishes as the moisture content increases. A parametric investigation reveals that the Factor of Safety (FOS) is more responsive to changes in the friction angle than to cohesion alterations. This article offers insights into the potential reasons behind the slope failure at Singareni Colliery in India. The failure of the slope can be attributed either to the collapse of the foundation's black cotton soil or to the failure of the dump slope material itself. When the shear strength of the foundation black cotton soil is exhausted, failure initiates within the foundation and then propagates to the OBD structure[16]. The peak friction angle is contingent upon soil index properties such as soil type, relative density, unit weight and void ratio. The peak friction angle tends to rise with increased angularity of granular soil, augmented surface roughness, and higher relative density. In the case of fine-grained soil, the peak friction angle hinges on the plasticity index, drawing from diverse relationships proposed in various research papers. Relationships correlating grain sizes with peak friction angles are established for varying soil types. Furthermore, empirical relationships have been established to link the effective peak friction angle with different weight ratios of Coarse to Fine (C/F) mix proportions[17]. For determining the shear stress of dump material, a shear box apparatus with dimensions of 1 x 1 m is employed, capable of accommodating dump particles up to 200mm in size. The apparatus supports maximum vertical and horizontal loads of 2000 kN each. The loading is conducted at a rate ranging from 0.5 to 45 mm/min. The Factor of Safety (FOS) for the Overburden Dump (OBD) is computed using both the limit equilibrium method and numerical techniques. These results are subsequently compared with reliability calculations[18]. The shear strength characteristics of the overburden dump material are examined using consolidated drained triaxial shear tests (with a diameter of 300mm and height of 750mm). A physical model of the dump under investigation is constructed. From the perspective of failure wedges, a stability analysis introduces a two-wedge model. In this model, the upper wedge functions as the active component, while the lower wedge is passive. The Factor of Safety (FOS) value derived from the two-wedge model aligns closely with the FOS calculated through limit equilibrium and numerical analysis. The resistive force is primarily provided by the passive wedge, making the strength of the foundation soil a critical factor in controlling the stability of the dump slope[19].

In saturated conditions, the factor of safety for a waste dump slope is lower compared to unsaturated conditions. To ensure the stability of the waste dump slope in the most unfavorable circumstances, a minimum factor of safety of 1.40 is taken into account[20]. Limited literature exists concerning the stability of external overburden dumps. The outcomes related to the stability of external overburden dump slopes exhibit variations across different analysis methods. The real-world behavior of external overburden dump slopes often diverges from the models generated by various numerical analysis methods[8]. The stability analysis of the slope in the Jayant open-cast mine was conducted using the limit equilibrium method. Based on this analysis, revised recommendations for bench width, bench height and slope angle were proposed, along with suggested preventive measures[21]. The probabilistic approach considers the impact of material property uncertainties and variations through different statistical distribution functions. The percentage of Coefficient of Variation (%COV) is directly related to an increased probability of failure. The Monte Carlo method is employed to perform probabilistic slope stability analysis. The deterministic Factor of Safety (FS_d), probabilistic mean Probability of Failure (PF_{mean}) and the actual probability of failure decrease nonlinearly as water content increases. The factor of safety computed through both deterministic Limit Equilibrium Method (LEM) and probabilistic LEM exhibit a strong resemblance[22]. The Factor of Safety (FOS) for the overburden dump is assessed under both dry and wet conditions[23]. A constitutive model was formulated for mixtures of soil and rockfill[15].

As permeability increases, the stability of the slope decreases[1]. Permeability significantly impacts the stability of a dump slope. When the material of the dump allows for a high infiltration rate, its permeability tends to be elevated. As permeability increases, the rate of surface erosion for the dump slope material diminishes. The presence of vegetation also contributes to a decrease in the rate of surface erosion on the dump slope. The influence of fly ash on dump slope stability is evaluated using numerical analysis techniques. Fly ash is introduced as an intermediate layer within the dump slope profile. Water alters both the internal cohesion and internal angle of friction of the dump material within the slope. The layer of fly ash, with its notably lower permeability compared to the OBD material, reduces the rate of infiltration, thereby lowering the accumulation of water at the base of the OBD slope[24]. Slope stability is contingent on shear strength, as well as the height and rate of dumping. The shear strength of the soil relies on both the internal angle of friction and cohesion. Moisture content within the waste dump material impacts slope stability by influencing pore water pressure and altering shear strength characteristics. Pore water pressure diminishes the effective strength of the waste dump slope material. The water content of the soil is determined by factors such as void ratio, particle size of minerals, and the organic content of waste material. The residual shear strength parameter is assessed through ring shear strength tests. The Factor of Safety (FOS) for the slope stability of the waste dump decreases with an increase in pore pressure within the dump's body. It's essential to have hydrological data available before conducting an investigation into the stability analysis of the dump slope[8].

The benefits of internal dumping, or In-Pit Dumping (IPD), in comparison to external dumping were outlined. To optimize land utilization, a proper balance between internal and external dumping should be recommended. Pore pressure has a detrimental effect on slope stability, and both compaction and consolidation processes also impact stability. Erosion is yet another factor that alters the dimensional stability of the overburden dump slope. Erosion washes away the material that binds the gravel in the dump slope material, leading to reduced cohesion. The collection of undisturbed samples from the OBD material proves challenging due to the larger particle size. For dump material, a comprehensive large triaxial test (with a diameter of 300 mm and a length of 620 mm) is conducted. Confining pressures of 9.80, 19.60, and 29.40 kPa are considered, with a loading rate of 3 mm/min. To investigate the behavior of the dump slope, wire sensors and rain gauge stations are installed. Precipitation has an impact on the deformation of the waste dump slope. The Factor of Safety (FOS) is analyzed for both the natural slope and the waste dump slope with a natural foundation soil[25]. To evaluate the impact of water on dump stability, numerical analysis was conducted for both very dry and wet conditions. The angle of internal friction and cohesion values were decreased by 20%, as the tested dump material does not accurately reflect the in-situ material characteristics[26]. The stability of a dump slope is contingent on seepage, primarily pore pressure. Seepage is influenced by factors such as rainfall, dump material porosity, and the presence of discontinuities. The location of the groundwater table, known as the phreatic line, is a critical aspect of dump slope analysis. The area of the dump slope situated below the phreatic line experiences pore pressure, leading to a reduction in the effective strength of the dump material, as outlined by Bishop in 1959. Furthermore, water infiltrating through the overburden dump contributes to the erosion of dump material, which can ultimately lead to slope failure, as indicated by the work[27]. Consequently, the presence of a groundwater table within the overburden dump augments the driving force behind these destabilizing factors. The mobility was notably influenced by the excess pore water pressure generated through static liquefaction[28].

The horizontal peak acceleration component of seismic waves has the potential to render both natural and man-made slopes unstable. During an earthquake's vibrations, the inter-particle bonds within the dump slope are compromised, leading to a reduction in the internal angle of friction and cohesion. This deterioration triggers the instability of the dump slope. The stability of the slope is contingent on the duration during which the seismic wave's disruptive stress surpasses the resisting strength of the dump slope material. Understanding the behavior of seismic waves in heterogeneous and anisotropic dump material is vital. However, integrating this understanding into slope stability calculations remains impractical due to the lack of data. Seismic waves propagate through the body of the dump slope and are subsequently reflected from the slope's face. The interaction between these reflected waves and the incident wave increases the likelihood of a collapse of the slope face[29]. Studying the impact of seismic waves on slope stability by altering both the foundation material of the slope and its geometry is challenging, even for a basic model[29].

Seismic or vibrational forces generate significant inertial forces within the mass of the dump slope. As a result of these vibrational forces, the factor of safety experiences a significant decrease, thereby elevating the risk of dump slope failure[20]. Earthquake loads persist for a very brief duration, causing a rapid reduction in the factor of safety. The cumulative impact on the dump slope involves the accumulation of displacements induced by earthquake forces[11].

The Discrete Element Method has been effectively utilized to analyze external overburden dump slope behavior. While maintaining parameters such as cohesion, friction angle, slope angle, and dump height constant, the factor of safety diminishes as the angle of the joint increases[30]. The stability of a slope significantly impacts both mining production and site safety. To enhance the waste dump slope design, finite element methods incorporating the shear strength reduction concept are employed. The conclusions drawn from the experiments are as follows:

- As the dump height rises, the slope's stability diminishes.
- When maintaining a consistent dump height and angle, the factor of safety is 8-11 % lower under saturated conditions compared to unsaturated conditions.
- $FOS=1.462667-0.0013x(H-120)$ [31].
- PFC2D functions as a unique method for micro-mechanical modeling of overburden dump material, offering distinctive insight. Parameters like the average stress-strain rate, porosity, and the count of particle contacts within the assembly are quantified using PFC2D. The stress-strain behavior of the overburden dump material is observed and graphed across varying confining pressures. The Distinct Element Method sheds light on the initiation and spread of failure. The application of the Discrete Element Method is effective in analyzing the stability of external overburden dumps during seismic events, specifically in simulating interactions between fragmented rock and soil within the dump. It anticipates sliding tendencies, identifies the failure surface, and pinpoints the initiation of failure. DEM presents an innovative approach that surpasses FEM and FDM in the analysis of overburden dumps[7].

The Finite Element Method offers greater accuracy compared to the Limit Equilibrium Method[27]. When employing the Limit Equilibrium (LE) method, establishing a constitutive model is challenging, and numerous assumptions are made while constructing the free-body diagram of the slice. Conversely, the strength reduction factor method is iterative and does not directly yield the failure envelope. This study introduces a graph theory approach for determining the Factor of Safety (FOS) and the failure surface. The proposed graph theory is based on the notion of connecting the starting and ending points within the profile through intermediate points in the most efficient manner, ensuring the shortest connecting path. The Ballman-Ford algorithm is utilized in this research to identify the shortest path of the critical slip circle. The corresponding shortest path corresponds to the minimum factor of safety. The FOS increases as the searching radius expands. The type of mesh does not affect the FOS. It is recommended to maintain a mesh size of approximately 1/10th of the slope height[32]. A model of the existing dump was constructed using the parallel gradation technique as recommended by Lowe in 1994. This approach was employed to further assess the geotechnical properties. Samples of Overburden Material (OBM) with varying percentages of fly ash were prepared to investigate their geotechnical characteristics. The stability analysis of the slope was conducted using the finite difference method and the FLAC/Slope software version 6.0. For the numerical analysis of the Overburden Dump (OBD) slope, only gravity load was taken into account. The incorporation of fly ash with varying proportions into the OBD material led to alterations in the Maximum Dry Density (MDD), Optimum Moisture Content (OMC), cohesion, angle of internal friction, and California Bearing Ratio (CBR). As the percentage of fly ash increased, the MDD decreased while the OMC increased[33].

An Artificial Neural Network (ANN) was employed to compute the factor of safety for the dump slope in a coal mine[34].

4.0 Modes of Failure

The concave slope exhibits greater stability and lower susceptibility to erosion compared to the flat slope. The Factor of Safety (FOS) varies with the slope's elevation: the lower layer of the slope possesses a lower FOS value, while the upper layer has a relatively higher FOS value. In order to maintain a consistent FOS across the entire slope, the inclination of the lower layer must be steeper than that of the upper layer[35].

- Adding extra Overburden (OB) material to the upper bench results in an increased slope angle steepness[25].
- Significant fluctuations in the dump's mass lead to insufficient strength of the Overburden Dump (OBD)[5].
- The foundation soil of the OBD lacks the capability to endure the stress levels imposed by the material above it[13].
- Various types of failures in mine waste dumps have been identified, encompassing surface slides, shallow flow slides, base failures, block translations, and circular failures within the foundation. Analyzing an overburden dump is complex due to factors like the dump's self-weight, material diversity (ranging from fractured rock to soil), geotechnical characteristics, foundation strength, seepage pressure, and tension cracks. The existing analytical methods can be challenging to employ. Often, dump design relies on historical insights. Effective monitoring of the dump slope involves observing the rate and extent of deformation[17].

The failure of the Overburden Dump (OBD) slope often results from insufficient or lacking geotechnical investigations. Overburden dump slopes are formed using two methods: top-down (end dumping or tip dumping) and bottom-up (paddock dumping). OBD slopes constructed using the bottom-up method tends to be more stable than those from top-down dumping. However, the bottom-up dumping approach is less economical when compared to the top-down construction method[11].

To ensure the long-term stability of a waste dump slope, planting grass vegetation proves to be an effective measure. This practice helps anchor the dump with its roots and simultaneously reduces the erosion rate[36]. The presence of vegetation on the dump surface functions as reinforcement, enhancing the shear strength of the slope surface due to the interaction with the root zone of the vegetation[36]. To ensure the enduring stability of a waste dump slope, planting grass vegetation is an effective strategy. This practice helps anchor the dump in place through its root system and also reduces the erosion rate[36]. The presence of vegetation on the dump surface serves as a form of reinforcement and augments the shear strength of the slope surface by interacting with the root zone of the vegetation[35]. The stabilization of OBD material through roots involves two main factors: firstly, the friction between soil particles that transfers stresses to the roots, and secondly, the roots acting as fibers to enhance the cohesion of the OBD material. A large shear box apparatus was designed to assess the shear strength of OBD samples with vegetation. The presence of roots elevates the cohesion within the penetrated area, known as the Root zone (R_z)[4]. The factor of safety relies on root penetration, root density, and the thickness of the soil layer covering the dump slope. Additionally, the presence of roots can influence the slip circle associated with the failure of the dump slope[3].

Blending fly ash with OB materials presents a promising opportunity to utilize fly ash and improve the stability of OB dumps. The experimental analysis revealed that the addition of 10% fly ash increased the maximum unconfined compressive strength and cohesion by 21% and 16%, respectively[33].

The presence of vegetation on the OBD slope enhances the cohesion of the upper layer and reduces erosion of the OBD material. Tests were conducted to assess the improvement in shear strength properties of the OBD material using a custom shear strength apparatus with dimensions of 0.15x0.15x0.15 meters[37]. Both the waste dump slope and the natural slope beneath it underwent deformation as a consequence of the additional weight exerted by rainwater infiltration[38].

5.0 Conclusion and Discussion

The connection between the land needed for piling overburden dump material in open-cast mining and the stability of the dump slope is direct. As the dump height and number of benches increase, the land necessary for material stacking decreases. Given the diverse composition of the dump material, its shear strength traits vary within the slope.

To assess the viability and possible improvements to an existing overburden dump slope, stability analysis is pivotal. This involves considering the dump material's inherent characteristics, the geotechnical attributes of the slope, and the hydrostatic properties of the material.

Upon examination, it becomes clear that accurately gauging the shear strength of the dump material is a fundamental aspect of stability analysis. The shear strength of the overburden dump slope is intricately tied to the material's heterogeneity. Current methods for evaluating shear strength often neglect the actual distribution of particle sizes. As a result, the shear strength attributes of the dump material can either be underestimated or overestimated, leading to potentially deceptive stability analysis outcomes.

Factors like pore pressure, permeability, degree of saturation, moisture content, and rainfall intensity significantly influence the destabilization of the overburden dump slope. These parameters collectively contribute to diminishing the shear strength of the dump material. The dump material's tendency to dilate also affects its shear strength traits. The application of bio-stabilization techniques bolsters the shear strength of the outermost layer of the overburden dump slope, enhancing its binding properties.

For the calculation of the safety factor and likely failure scenarios, methods like the limit equilibrium technique, numerical approaches, and probability analysis are employed. The dimensions of benches, in terms of height and width, on the overburden dump slope have a substantial impact on the safety factor.

6.0 Future Scope

- Effect of Dump Material Particle Size on Shear Strength Properties, Including Cohesion and Internal Friction.
- Utilizing Stone Column Methods to Improve Shear Strength Properties of Dump Material.
- Influence of Dilatancy on Shear Strength Traits of Dump Material.

7.0 References

1. Upadhyay OP, Sharma DK, Singh DP. Factors affecting stability of waste dumps in mines. Int J Surf Mining, Reclam Environ. 1990; 4(3):95-9. https://doi.org/10.1080/09208119008944174.
2. Kainthola A, Verma D, Gupte SS, Singh TN. A Coal Mine Dump Stability Analysis. Geomaterials. 2011; 1-13. https://doi.org/10.4236/gm.2011.11001.
3. Zhu H, Zhang LM, Xiao T, Li XY. Computers and Geotechnics Enhancement of slope stability by vegetation considering uncertainties in root distribution. 2017; 85:84-9. https://doi.org/10.1016/j.compgeo.2016.12.027.
4. Rai R, Shrivastva BK. Large In Situ Shear Test Box for Mine Waste Dump. J Inst Eng Ser D. 2012; 93(1):19-22. https://doi.org/10.1007/s40033-012-0008-7
5. Li M, Zhang J, Sun K, Zhang S. Influence of lateral loading on compaction characteristics of crushed waste rock used for backfilling. *Minerals*. 2018; *8*(12):552. https://doi.org/10.3390/min8120552.
6. Koner R. Characterisation of overburden dump materials : a case study from the Wardha valley coal field. Bull Eng Geol Environ. 2015. https://doi.org/10.1007/s10064-015-0830-x.
7. Koner R, Chakravarty D. Stability Study of The Mine Overburden Dumps Slope : A Micromechanical Approach. 2010; 32(1).
8. Liu D, Chen H. Relationship between porosity and the constitutive model parameters of rockfill materials. J Mater Civ Eng. 2019; 31(2):1-14. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002598.

9. Li X, Han L, Guan Y, Mechanics C. State-dependent Dilatancy Theory and Numerical Modelling of Rockfills. J Civ Eng Constr. 2018; 2:100-6. https://doi.org/10.32732/jcec.2018.7.2.100
10. Bishwal RM, Sen P, Jawed M. Characterization of shear strength properties of spoil dump based on their constituent material. Int J Appl Eng Res. 2017; 12(19):8590-4.
11. Zevgolis IE. Geotechnical characterization of mining rock waste dumps in central Evia, Greece. Environ Earth Sci. 2018; 77(16). https://doi.org/10.1007/s12665-018-7743-5.
12. Sharma R, Rai R, Shrivastva BK. Dump slope rating for indian coal mining. Res J Min. 2017; 1(1):12-26.
13. Gupta AK, Paul B. Augmenting the stability of OB dump by using fly ash : A geo technical approach to sustainably manage OB dump at jharia coalfield, India. 2016; 11(1):204-11. https://doi.org/10.12944/CWE.11.1.25.
14. Koner R, Chakravarty D. International Journal of Mining Science and Technology Numerical analysis of rainfall effects in external overburden dump. Int J Min Sci Technol. 2016. https://doi.org/10.1016/j.ijmst.2016.05.048.
15. Brito A, Maranha JR, Caldeira LMMS. A constitutive model for soil-rockfill mixtures. Comput Geotech. 2018; 95:46-56. https://doi.org/10.1016/j.compgeo.2017.09.009.
16. Poulsen B, Khanal M, Rao AM, Adhikary D, Balusu R. Mine Overburden Dump Failure: A Case Study. Geotech Geol Eng. 2014. https://doi.org/10.1007/s10706-013-9714-7.
17. Arvanitidis C, Steiakakis E, Agioutantis Z. Peak Friction Angle of Soils as a Function of Grain Size. Geotech Geol Eng. 2018; 8. https://doi.org/10.1007/s10706-018-0675-8.
18. Estaire J, Santana M. Geotechnical characterization and stability study of coal mine dumps Geotechnical characterization and stability study of coal mine dumps. 6th Int Congr Environ Geotech New Delhi (India). 2010; 445-50.
19. Wang J, Chen C. Stability analysis of slope at a disused waste dump by two-wedge model. Int J Mining, Reclam Environ. 2017; 31(8):575-88. https://doi.org/10.1080/17480930.2016.1270498.
20. Fernando J, Nag D. A study of internal overburden dump design and stability analysis for Hazelwood Power Mine, Latrobe Valley, Victoria, Australia. Appl Comput Oper Res Miner Ind South African Inst Min Metall. 2003; 267-74.
21. Sharma S, Roy I. Slope failure of waste rock dump at Jayant opencast mine, India: A case study. Int J Appl Eng Res. 2015; 10(13):33006-12.
22. Huvaj N, Oguz EA. Probabilistic slope stability analysis : A case study. Sak Univ J Sci. 2018; 22(5):1458-65. https://doi.org/10.16984/saufenbilder.430032.
23. Banerjee L. A finite element approach of stability analysis of over burden dump slope - A case study. 2017; 14-7.
24. Gupta T, Singh TN. Geo-hydrological stability analysis of fly ash stabilised overburden dump geo-hydrological stability analysis of fly ash stabilised overburden dump slopes in opencast coal mines using finite element analysis. 2018. https://doi.org/10.18517/ijaseit.8.2.3449.
25. Cho YC, Song YS. Deformation measurements and a stability analysis of the slope at a coal mine waste dump. Ecol Eng. 2014; 68:189-99. https://doi.org/10.1016/j.ecoleng.2014.03.005.
26. Verma AK, Deb D. Stability analysis of a mine waste dump over an existing dump. J Mines Met Fuels. 2017.
27. Griffiths D. Slope stability analysis by finite elements: A guide to the use of Program slope. 2015; 64:32.
28. Tong Zhan L, Gang Guo X, Qian Sun Q, Min Chen Y, Yu Chen Z. The 2015 Shenzhen catastrophic landslide in a construction waste dump: analyses of undrained strength and slope stability. Acta Geotech. 2021; 16(4):1247-63. https://doi.org/10.1007/s11440-020-01083-8.
29. Hack R, Alkema D, Kruse GAM, Leenders N, Luzi L. Influence of earthquakes on the stability of slopes. 2007; 91:4-15. https://doi.org/10.1016/j.enggeo.2006.12.016.
30. Radhakanta K, Debashish C. Discrete element approach for mine dump stability analysis. Min Sci Technol. 2010; 20(6):809-13. https://doi.org/10.1016/S1674-5264(09)60286-6.
31. Yan J, *et al.* Copyright ASCE 2010 GeoShanghai 2010 International Conference Copyright ASCE 2010 GeoShanghai 2010 International Conference. Paving Mater Pavement Anal. 2010; 97-102. https://doi.org/10.2308/accr-10032.
32. Li E, Zhuang X, Zheng W, Cai Y. Effect of graph generation on slope stability analysis based on graph theory. J Rock Mech Geotech Eng. 2014; 6(4):380-6. https://doi.org/10.1016/j.jrmge.2014.05.003.
33. Rajak TK, Yadu L, Chouksey SK, Dewangan PK. Stability analysis of mine overburden dump stabilized with fly ash. Int J Geotech Eng. 2018; 1-11. https://doi.org/10.1080/19386362.2018.1503780.
34. Rahul, Khandelwal M, Rai R, Shrivastva BK. Evaluation of dump slope stability of a coal mine using artificial

neural network. Geomech Geophys Geo-Energy Geo-Resources. 2015; 1(3-4):69-77. https://doi.org/10.1007/s40948-015-0009-8.

35. Gray D. Influence of Slope Morphology on the Stability of Earthen Slopes. Geo-Congress. 2013; 1902-11. [Online]. https://doi.org/10.1061/9780784412787.191.
36. Chaulya SK, Singh RS, Chakraborty MK, Dhar BB. Numerical modelling of biostabilisation for a coal mine overburden dump slope. Ecol Modell. 1999; 114(2-3):275-86. https://doi.org/10.1016/S0304-3800(98)00157-4.
37. Ranjan V, Sen P, Kumar D, Saraswat A. Enhancement of mechanical stability of waste dump slope through establishing vegetation in a surface iron ore mine. Environ Earth Sci. 2017; 76(1):1-9. https://doi.org/10.1007/s12665-016-6350-6.
38. Cho YC, Song YS. Deformation measurements and a stability analysis of the slope at a coal mine waste dump. Ecol Eng. 2014; 68:189-99. https://doi.org/10.1016/j.ecoleng.2014.03.005.