Evaluation of Dump Slope Stability Using Slide, Geoslope, and Phase 2 Software

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Abstract— Global energy demand continues to grow rapidly. The increasing energy demand needs to be met by fossil fuels, especially in countries like India. In these countries, coal is the major energy producer and mechanized surface mining is the only way to support coal production. In the near future, shallow depth coal reserves will be depleted, and deeper coal deposits will be exploited by surface mining, resulting in handling an immense amount of overburden. In open cast mines, dumping overburden as internal dumps involves many risks and hazards such as slope failure, handling dust sediments in surroundings, and soil erosion in wet weather. As a result of the lack of a dump area, mining companies tend to elevate dump heights, thereby increasing the likelihood of sliding. The stability of these dumps slopes has been a significant concern over the years. The slope stability analysis of a mine dump is presented in this paper by calculating the factor of safety using three different software programs: Slide, Geo-slope, and Phase2 software, and the results obtained are compared.

Keywords: Factor of safety, Finite element method, Geoslope software, Limit equilibrium method, Phase2 software, Slide software.

I. INTRODUCTION

Overall coal production in India during the year 2020-21 was 716.08 Mt [14]. India is the fifth-largest energy producer globally around 223 GW of power generated every year, out of these thermal power plants hold the majority contribution. Mining of coal through opencast or surface mining method is preferred because of its benefits over the underground mining method. Opencast mines contribute about 92% of over-all coal production in India. The slope stability plays a vital role in the finances of the mine, evaluation of slope stability is an essential process in any opencast mine these days. As per the Centre for Research on Epidemiology Disaster (CRED), landslides are to blame for at least 17% of all fatalities resulting from natural hazards globally [3].

Slope failure cases such as the Rajmahal Coal Mine in Jharkhand in 2016 [16], Basundhara MCL, India in 2013 [13], Kulda, MCL India in 2013 [9], Sasti Mine in 2009, Jayant coal mine in 2008 [1] Kawadi Opencast mine in 2000, and other dump slope failures have caused calamitous losses in terms of life, assets, and industrial equipment. Overburden dumps in open cast mines are prone to slide and stability of the dump slope cannot be expected as much as the surrounding country rock because they are disturbed and cast away from their origin.

The practice of dumping overburden on a site away from the mining area has several difficulties that include high conveyance and handling cost. Therefore, it will surge the price of coal production along with the cost of reclamation. Mostly casting the overburden into the de-coaled area, behind the advancement of mining using dragline, bucket wheel excavator and mobile transport conveyor or conveyor belt is found to be a most efficient way of handling it but, failure or disturbance caused by such dumps directly affect the mining operation and poses a greater threat for men and material. The instability of the slope causes slope failure due to changes in stress conditions, rainfall and an increase in the groundwater table [18]. Dump slope failures are avoidable with proper dump designs, numerical modelling technique helps engineers in predicting outcomes of different designs and is handy in the evaluation of existing dumps. An assessment of slope stability using various finite slope stability methods was carried out by Nalgiri [18] using Six finite slope stability methods, namely Spencer method, Morgenstern price method, Bishop method, Janbu method, Sarma method and ordinary slices method. Based on a case study of failed dump slopes in the Indian coalfields, Kainthola [1] used the shear strength reduction technique to evaluate the condition of failure to achieve a target factor of safety using a two-dimensional finite element code and suggested a sustainable, stable angle and height for smooth and safe disposal of the dump. In 2012, Haiwang Ye and Wen Li [7] analyzed the stability of the Malugou dump that has been constantly affected by blasting in a mine nearby with geo-studio software and determined that blasting does not affect the stability of the dump. In 2016, Schmidt [2] performed slope stability analysis based on the generalized Hoek-Brown failure criterion using Phase 2 software on two case studies: The Barite mine and a coal mine in western Turkey.

This paper elaborates the results of the dump slope stability analysis of a Mine by calculating the Factor of safety using three different software that is Slide software powered by Rockscience (Limit Equilibrium method), Geoslope software powered by Geostudio (Limit Equilibrium method) and Phase2 software (Finite Element method). The factor of safety obtained from this software were weighted to conclude with an accurate result.

II. FACTORS AFFECTING DUMP SLOPE STABILITY

Several factors deal with the effect of dump slope stability, a clear understanding of which leads to a stable design of the slope. Moreover, these dump materials are disturbed rock and soil that requires utmost care. When it comes to the design of a dump or the geometry of the dump slope perhaps it is the most essential factor of all. The parameters such as dump height, slope angle, and haul road width/berm width significantly influence the slope stability specifically. It is necessary to keep the dump slope gentle so that it will be stable. The second most important parameter is the geotechnical properties of dump material. Properties such as shear strength, density, grain size distribution, degradation behaviour, compression index, saturation, etc. are some of the critical characteristics of the dump material known to design safe dumping. In Fig. 1 various effects of hydrodynamics on a dump slope are displayed

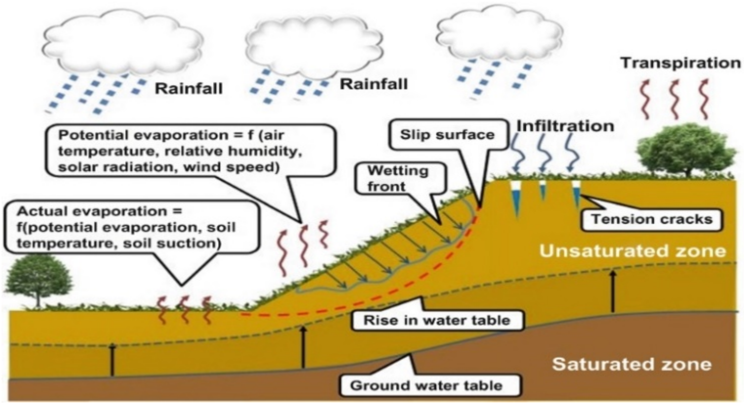

Fig 1. Water cycle in a dump slope and water movement [6]

Geotechnical properties of the foundation of the dump slope are important as other factors and the method of dumping. The steepness of the slope and some other factors depend on dumping methods like layered dumping approaches and the end dumping method that has different scopes for water drainage channels and slope stability. The lithology of the location or hydrological conditions is often disregarded for the steadiness of the slope. The dump material is mostly broken rocks that are usually extremely porous which would lead to seepage of liquids through the lower layers and pitfalls.

An acquaintance of the mode of failure of a dump slope would help to give apt treatment against them. The forms of failure are based on the kinetics of materials and some contribution of external sources such as loading and blasting vibrations. The surface of the Edge slide is the usual type of failure in dumps, it occurs as a result of the occurrence of a material layer parallel to the bottom of the pit that eventually collapses. The end and push method of dumping suffer this mode of failure mostly. Shallow flow slides are even shallower than edge failure cases, these dump failures are caused by partially saturated dump material. Rotational or circular failure usually occurs when the foundation is not sound enough to bear the load of overlying dump materials. It could also occur in rainy seasons while the groundwater pressure pushes the ground upward. The base failure and liquefaction are related to the stability of the base or foundation of the dump. So, in consideration of all the above factors, modelling offers better solutions for evaluating the stability of the slopes. The necessary input parameters required for the different modelling techniques differ in the method of modelling.

III. SAMPLE COLLECTION AND LABORATORY TESTING

To evaluate the stability of the dump the key parameters are the physical, mechanical, geological and hydrological properties of the OB dump material [5,17]. Three locations of the dump yard of the mine are selected for sampling, Sample 1 is collected from deck-3, Sample-2 is collected from deck-2 and sample 3 is collected from deck-1 of the dump, some of those samples are displayed in Fig. 2.

Fig. 2. Collected samples from the dumpsite

The significant Parameters considered in this research as it affects the stability of dump slope are grain size, moisture content, dry density, cohesion and angle of internal friction. The samples collected from the dumpsite are subjected to different laboratory tests to find the parameter mentioned above. Sieve analysis, compaction test, direct shear test, unconfined compression test and Triaxial test were conducted on the samples. In Table I the results obtained from the laboratory tests on three samples of decks -1,2 & 3 are displayed and further taken into the Numerical modelling analysis

Table 1. Results Obtained From Laboratory Tests

Sample No.	Maximum dry density (g/cm^3)	Optimum Moisture content (%)	Unconfined compression test (Kg/cm^2)
1	1.87	14.87	6.20
2	1.81	28.93	6.01
3	2.1	24.48	6.19

Table 1. (**Continued**.,)

Sample No.	Cohesion (Kg/cm2)	Cohesion (KPa)	Internal angle of friction
1	0.856	84	24
2	0.836	82	24
3	0.816	80	21

IV. EVALUATION OF DUMP STABILITY BY LIMIT EQUILIBRIUM METHOD AND NUMERICAL MODELLING

In the next step, analysing the stability with the Limit Equilibrium method & Numerical modelling, the required information is obtained from the laboratory results. Slide and Geo slope software adopting Limit equilibrium method and Phase2 software adopting Finite element method numerical modelling are chosen for model preparation. Results from each software are briefed in the following.

The Slide software

The Limit Equilibrium Method (LEM) is used to analyse the stability of slope structures because of its advantages like simplicity, accuracy and speed [11]. It is not suitable for complex slope structures, because of several limitations [4]. Bishop simplified, Janbu simplified, Janbu corrected, Fellenius, Spencer, Morgenstern-Price and Lowekarafiath etc are some various methods of FOS calculation in the Slide software [8]. In this study Bishop simplified and Spencer methods are preferred. The basic requirements for the factor of safety calculation in this software are dry density, cohesion and internal angle of friction. Boundary conditions are defined with calculated coordinates of three decks and foundation (base) with the height and width parameters of the dump. The Mohr-coulomb failure criteria are used for strength calculation. Fig. 3 & 4 represents the result obtained from the analysis of dump slope safety using the Slide software by the Bishop simplified method and Spencer method, the overall minimum safety factor obtained are 1.321 and 1.307 respectively.

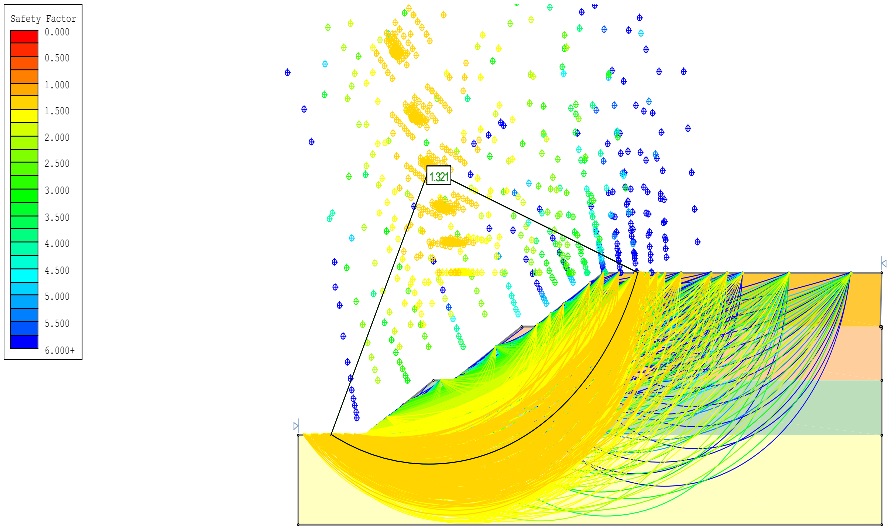

Fig 3. Analysis of dump slope model using the slide software by Bishop simplified method

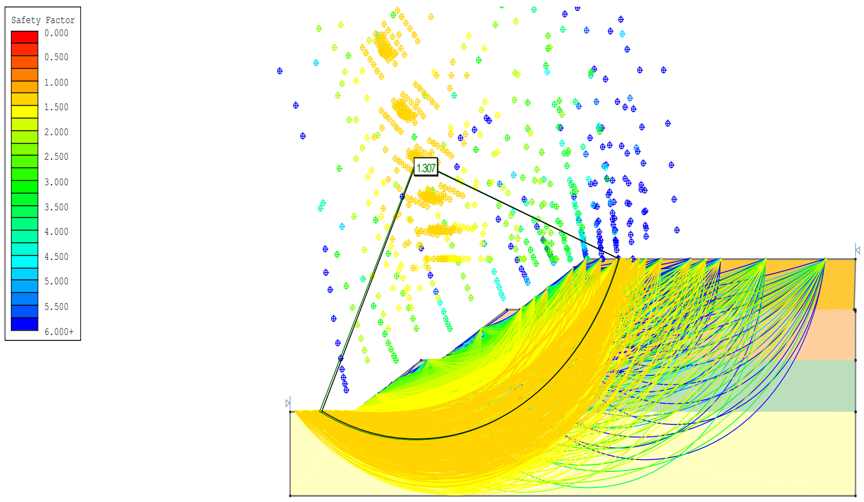

Fig 4. Analysis of dump slope model using the slide software by Spencer method

The Geo-Slope software

It is a novel limit equilibrium software that is useful in complex analysis [18]. The conduction of the experiment is almost similar to the Slide software and Fig. 5 & 6 are representing the results found from the analysis of dump slope safety using Geo-slope software by the Bishop simplified method and Spencer method the overall minimum safety factor obtained are 1.36 and 1.35 respectively.

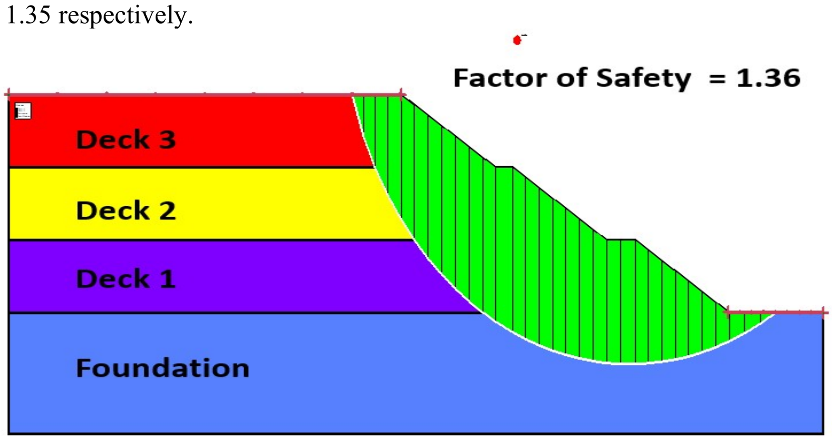

Fig 5. Analysis of dump slope model using the Geo-slope software by Bishop method

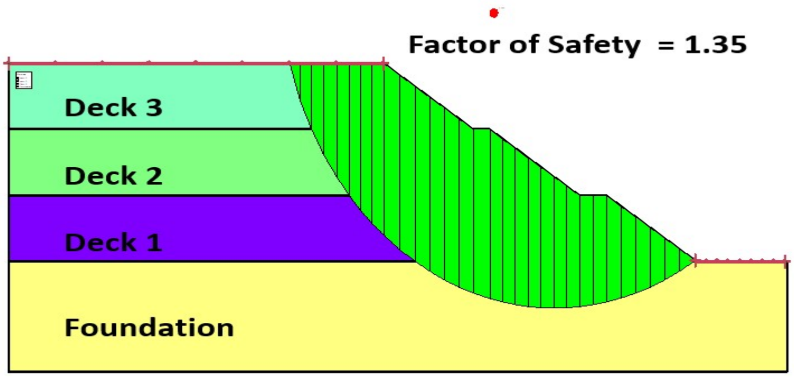

Fig 6. Analysis of dump slope model using the Geo-slope software by Spencer method

The Phase2 software

The Finite Element Method (FEM) of numerical modelling is an effective tool in terms of the computation of slope stabilities. The strength reduction method (SRM) or Factor of the safety of finite element method is adopted because of its ability to find critical slip surfaces automatically [10]. Significant advantages of SRM include its suitability for complex geometries, boundaries, and loading conditions. Additionally, information about stresses, strains, and pore pressure can be obtained easily [15]. In Fig. 7 the result obtained from the analysis of the dump slope model using the Phase 2 software is given and that shows the Factor of safety value of the dump slope is 1.28.

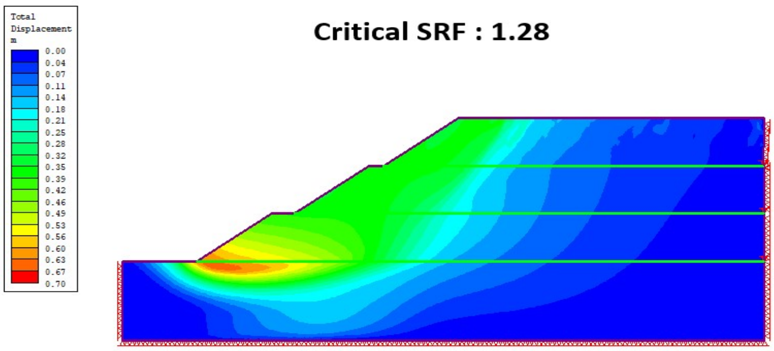

Fig 7. Analysis of dump slope model using the Phase2 software

In Table II the factor of safety values is obtained by using three different software Programmes the Slide, Geo slope, and Phase2 software in the limit equilibrium method and Finite Element Method. Fig. 8 shows the comparison of FOS values of dump slope obtained from the software.

Table 2. Summary of Factor of Safety Values

Methods	Factor of Safety
LEM- Slide software (Bishop's Method)	1.32
LEM- Slide software (Spencer Method)	1.30
LEM- Geoslope Software (Bishop's Method)	1.36
LEM- Geoslope Software (Spencer Method)	1.35
NM- Phase 2 software	1.28

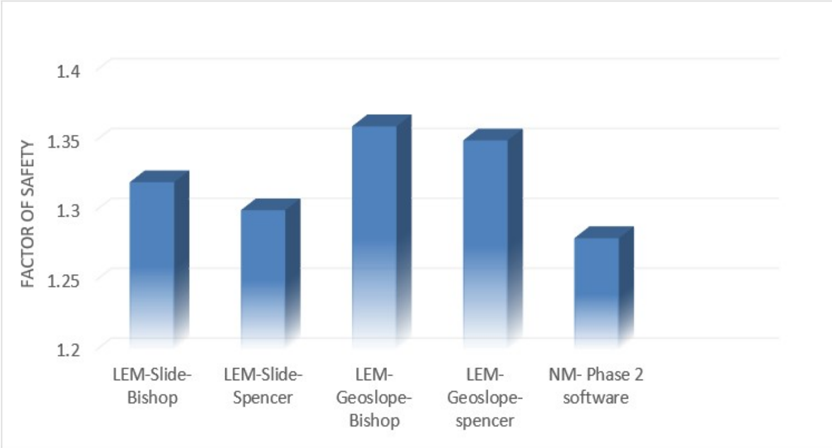

Fig 8. Comparison graph on the obtained factor of safety values of different software

V. INFLUENCE OF PIEZOMETRIC LINE

One of the most significant contributors to the strength reduction of dump slope is pore water pressure [4]. It causes instability by accelerating the driving forces [12,19]. It is observed that the groundwater level of the dump area rises 30 to 35m meters from the foundation in the rainy seasons. So it is decided to check the effect of the piezometric line at varying heights from the base in the foundation. And the results obtained are displayed in the below figures.

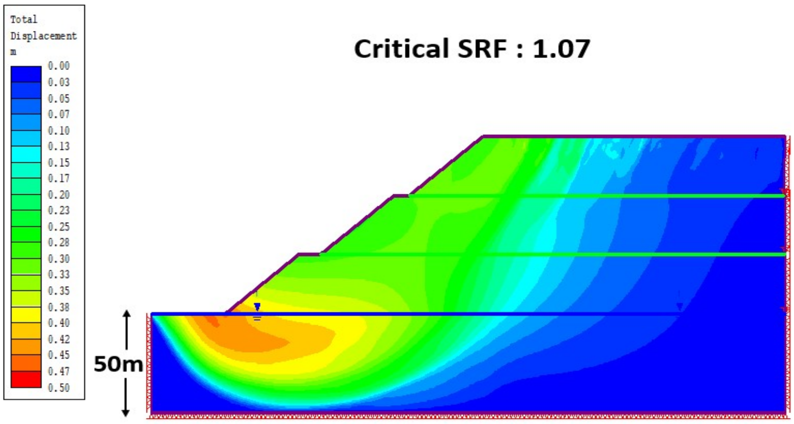

Fig 9. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 50m from the base

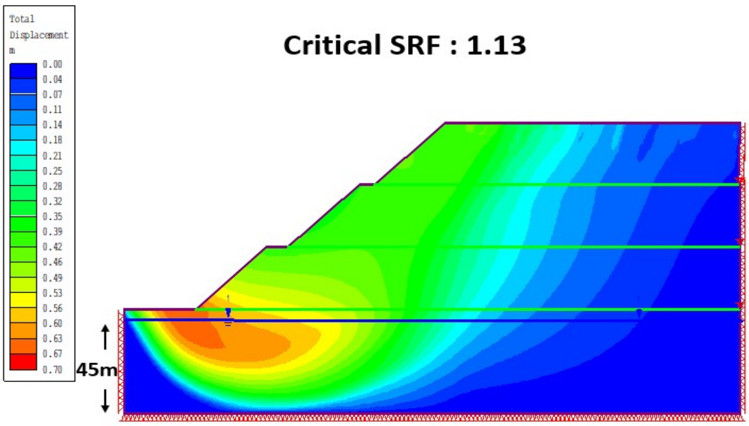

Fig 10. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 45m from the base

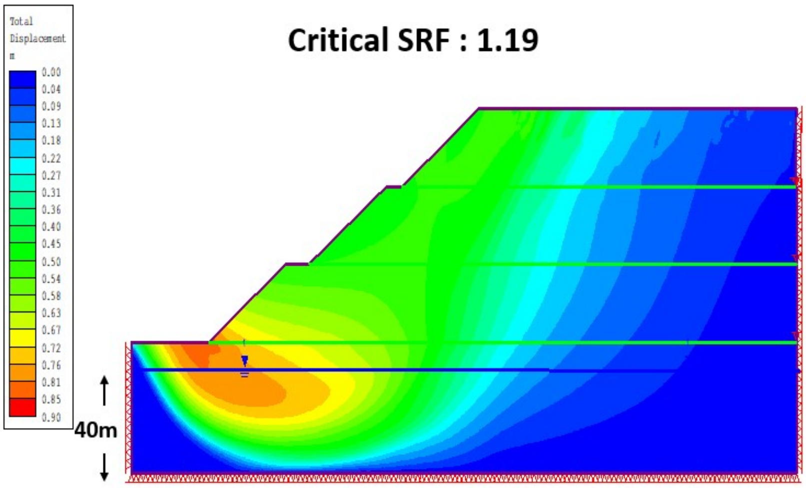

Fig 11. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 40m from the base

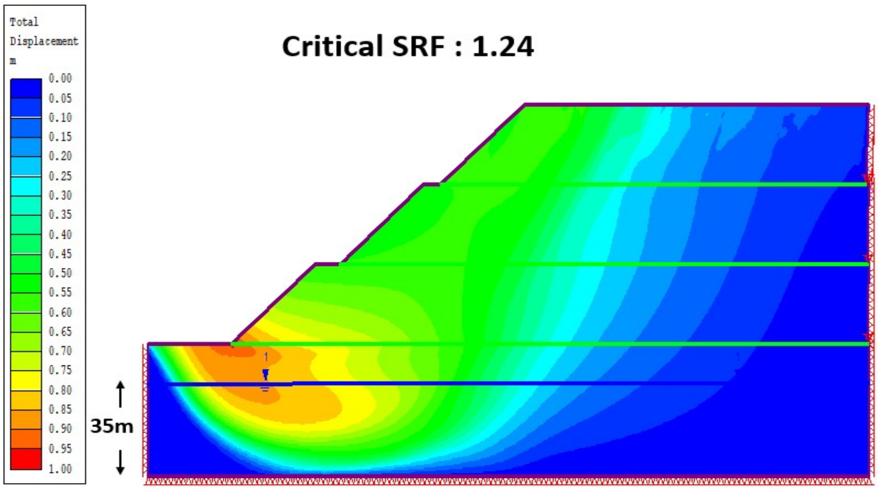

Fig 12. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 35m from the base

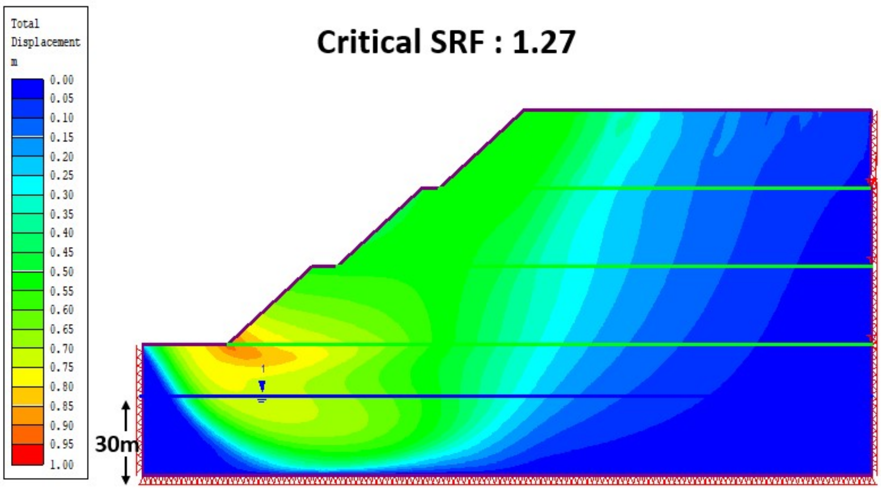

Fig 13. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 30m from the base

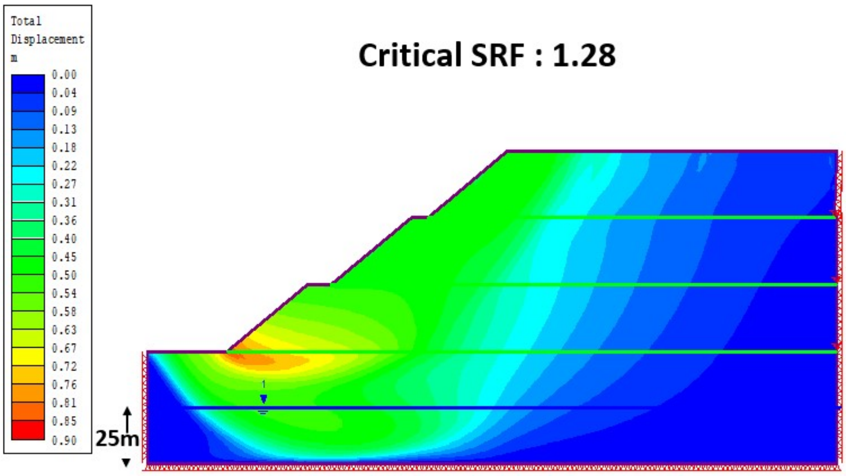

Fig 14. Analysis of dump slope model in Phase2 software with a piezometric line at a height of 25m from the base

The effect on the FOS value of the dump due to the variation in groundwater table ranges from 25m to 50 m i.e. lowest minimum and highest maximum possible values are considered for this evaluation and in Table 3 the results are displayed

Table 3. Summary of Factor of Safety Values Against Different Piezometric Line Heights

SI. No	Piezometric line height in m	FOS
1.	50	1.07
2.	45	1.13
3.	40	1.19
4.	35	1.24
5.	30	1.27
6.	25	1.28

From the above table, it could be seen that the value of the factor of safety is profoundly reduced when the groundwater table is at 50m still the value of FOS is in the safe margin so, it is assumed to be safe and stable. A graphical representation of the variation of FOS values concerning the variation in the piezometric height is shown in Fig. 15.

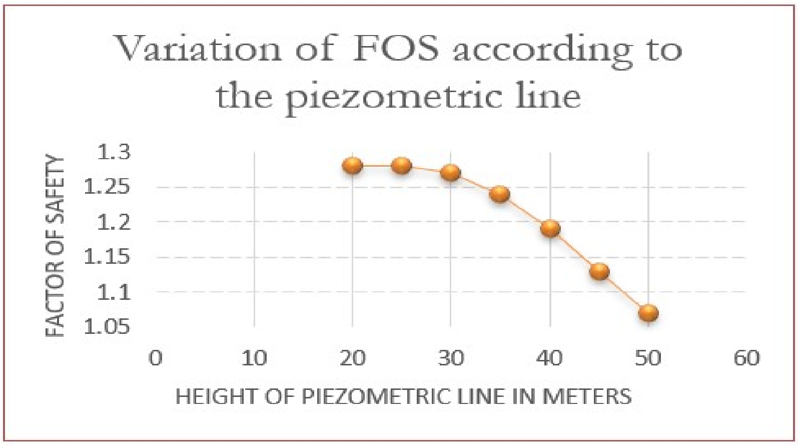

Fig 15. Graphical representation of the variation of FOS according to the piezometric line from the foundation in Phase2 software

VI. CONCLUSION

Overburden materials from opencast mines are dumped with steeper slopes and higher heights that cause the dump to fail eventually. Slope stability analysis of such dump slopes helps engineers evaluate the dump slopes to take necessary action if it is required, and design a safe dump yard. In this paper Slope stability analysis of a dump, the slope is carried out by calculating the factor of safety using three different software programs: Slide, Geo-slope, and Phase2 software. And the range of FOS values obtained as a result of this software varies from 1.28 to 1.36 which ultimately declares that the slope is safe and stable. The effect on the FOS value of the dump due to the variation in the groundwater table is evaluated using Phase2 software and the results vary from 1.07 when the groundwater reaches the maximum possible level and 1.28 at the minimum possible level. It is observed that as the groundwater level increases the FOS reduces but, the value of FOS remains greater than 1.0 so, so it can be concluded that the dump is safe and stable.

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