Journal of Mines, Metals and Fuels, *73(4): 1009-1023; 2025. DOI: 10.18311/jmmf/2025/48195*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Stability Analysis of Dump on Black Cotton Soil Using Overburden Filled Trench Near the Toe

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Abstract

The mining sector is significant for the country's growth in terms of gross domestic product and opencast mining is playing a vital role in it compared to underground mining production. Opencast mining involves the removal of overburden and this material, which is currently a nonmarketable product, must be removed from the site for smooth mining operations. The restricted availability of space makes it necessary for the overburden to be stored judiciously to ensure the saving of ground and chances of any slide back or dangerous incidents or accidents in the future. The stability and safety of overburden dumps are of significant concern in opencast mining. The presence of a weak floor layer can be one of the several reasons for dump failure. Due to the widespread prevalence of black cotton soil in the central part of India, overburdened materials are forced to dump on this weak layer. This can be one of the reasons for dump instability. The study is conducted by collecting geomechanical properties and dump geometry of the coal mining scenario in the central part of India. The study exhibits a parametric analysis using numerical modeling to understand the effect of black cotton soil floor on dump stability and the efficacy of a trench filled with the same overburden material.

Major Findings: *The numerical modeling analysis in this paper was performed using the RS2 software. Through this modeling, the factor of safety derived under saturated conditions is less than that of the model under dry conditions. The dump's height and stability are increased by the method of digging a trench filled with rocks at the toe. Additionally, the same overburden material is used in place of trenches in this study, eliminating the need for extra hard rock collection and transportation.*

Keywords: Black Cotton Soil, Numerical Modeling, Overburden Dump

1.0 Introduction

During open pit mining operations in India, over 1200 million cubic meters of overburden are removed annually[1]. The judicious storage of the overburden material is mandatory to avoid many unprecedented circumstances that have been witnessed over the past years, Figure 1[2]. In December 2016, 23 people were reportedly buried due to an overburden slide at Lalmatia coal mines (ECL)[3]. Therefore, any failure of the dump slope will result in catastrophic losses in terms of life, property, or machinery. Even though all such accidents are being analyzed, and recommendations are made in each case, similar accidents are not prevented. Low height and flat dumps could be ideal from points of stability, but these would occupy more space and prove to be extremely expensive. Thus, there must be a balance between these two conflicting requirements; maximum slope and minimum possible ground space to be occupied while ensuring that dumps do not slide and cause any untoward incidents/accidents.

Overburden dumps can be either external or internal pit dumps. External overburden is created at a site away from the coal-bearing area whereas internal pit dumps

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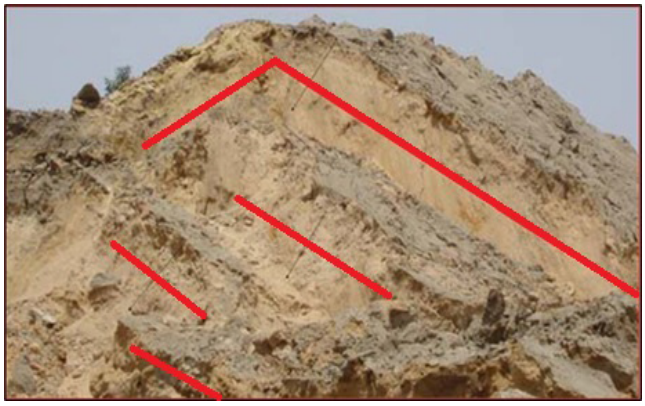


Figure 1. Overburden dump failure[4].

involve in-pit dumping of the overburden material in the voids created during mining or any such activities. The practice of conducting external dumping has some consequential problems such as the requirement of additional land, transportation, and re-handling costs, which will ultimately result in increased coal production costs. Even though in-pit dumping can be performed, the complete elimination of external dumping is not possible. The combination of both would be ideal.

Black cotton soil belongs to the category of inorganic clays of medium to high compressibility. Almost 20% of the total geographical area of our country is occupied by black cotton soil and they are rich in silica, lime, iron, magnesia, and alumina[5], and extend up to an average depth of approximately 3.7 m[6]. Even though there is a widespread occurrence of black cotton soil, their effective utilization in civil and other engineering works

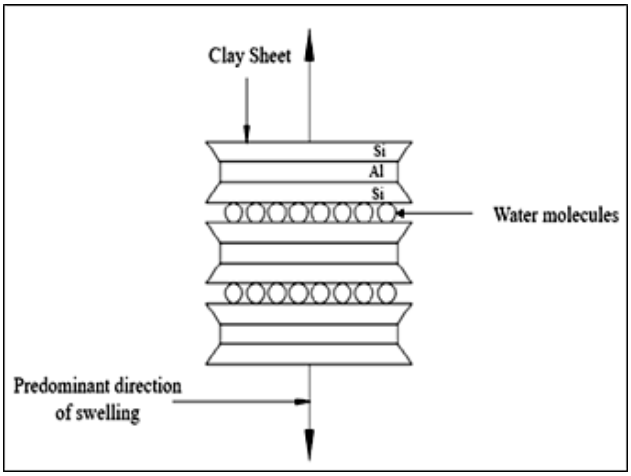


Figure 2. Lattice structure of montmorillonite mineral.

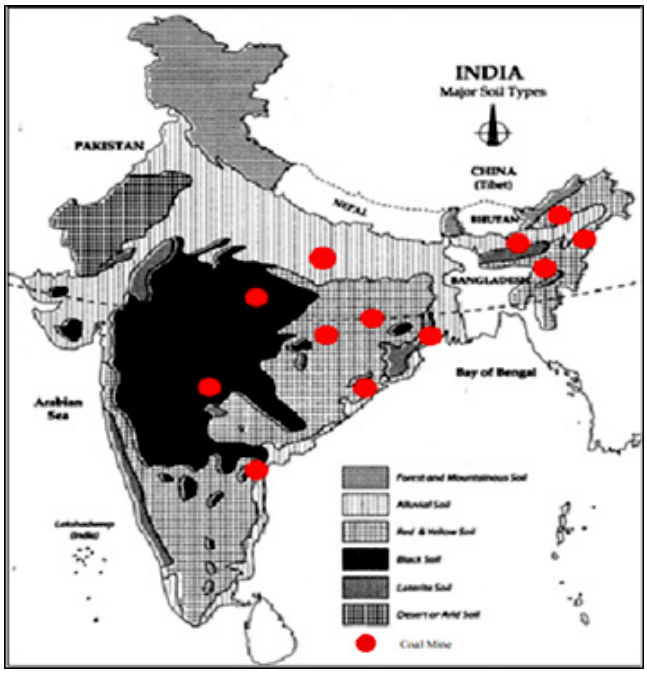


Figure 3. Coal mines in India[8].

is not appreciable. The main reason that it drags back its utilization in engineering works is the geomechanical trouble they pose. Black cotton soil shows a high rate of expansion due to the presence of a large percentage of expansive clay minerals, i.e., Montmorillonite. They have a three-sheeted structure with an expanding type of lattice structure as shown in Figure 2. Water molecules and different types of hydrated cations will get attracted to their surface causing the soil volume to increase. The existence of Montmorillonite and a combination of Montmorillonite and Illite clay mineral is the reason black cotton soil manifests swelling and swelling pressure. With the change in moisture content, they show a high potential for shrinkage or swelling. When it is dry the whole area splits up and large cracks will be formed in the bulk of the soil. When it is in the moist state the soil expands, becomes incredibly soft, and loses capacity. Due to its expansive character, the increase in volume exerts upward pressure. This upward pressure becomes so high that it tends to lift the foundation upward. This reverse pressure induces cracks in the structure found over the soil and for these reasons, black cotton soils are considered problematic.

In the central part of India, the most prevalent soil type is black cotton soil, Figure 3; hence over these areas,

dumps are forced to be made on thick weak layers of black cotton soil[7]. Many reported cases of dump failures have occurred in different parts of India that are directly attributed to weak floors below the dump. Scarcity of land and the impracticality of removing the entire weak floor layer, overburden is dumped over the available land even if the floor is weak. This research aims to provide a study on the applicability of black cotton soil for the design of an overburden dump.

Sekhar has performed a study on the stability of overburden dumps over weak floors by creating a rock-filled trench at or near the overburden dump toe[9]. The rock-filled trenches are made by removing the loose material before starting the dumping operation and are filled with hard rock fragments of sandstone, igneous or metamorphic rocks which are available at that site. The mathematical simulation was then performed with different combinations of dump height, the thickness of expansive soil, trench width, and trench height. The study concluded that this practice of providing rock rock-filled trench will improve the dump stability by restricting the movement of the soft floor and strengthen the overburden dump toe.

In this paper, a study is conducted such that the trenches are replaced by the same overburden material so that additional collection and transportation of separate hard rocks are not required. This will also help in reducing the overburden of material quantity and overall economy.

2.0 Analysis of Overburden Filled Trench

The method involves the construction of a trench near the bottom of the slope and filling the trench with the same overburden material. The location of the trench is to be finalized by placing the trench at different positions on the dump floor using the trial-and-error method. For this study, the trench width is kept equal to the dump height. The analysis is done for dump heights 120 m, 90 m, and 60 m with the following conditions.

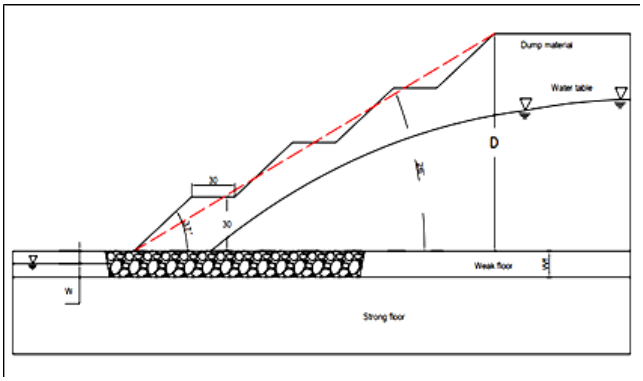


Figure 4. The geometry of the designed dump.

Condition I: Without trench.

Condition II: Dump with trench positioned outside toe.

Condition III: Dump with trench positioned inside toe.

Condition IV: Dump with the middle of the trench positioned at the toe.

Condition V: Dump with 20 m trench lies outside the toe and rests inside.

For each case, analysis is done for both dry and saturated conditions and the trench is laid out in such a way that it intersects with the expected failure zone. In the rainy season, heavy rainfall causes the material to retain water in its pores, which results in pore pressure. The trench is designed to operate as a robust artificial floor, improving toe stability. To simulate a wet environment,

Table 1. Geomechanical properties used for modeling

Material	Density (kg/m^3)	Modulus of Elasticity (MPa)	Cohesion (MPa)	Friction angle (degree)
Overburden dump	1700	100	0.060	25^0
Black cotton soil layer	1700	50	0.040	11^0
Rock fill	1700	100	0.060	25^0
Strong floor layer	2300	1000	0.250	30^0

the water table is provided at a depth of 5 m from the surface[10-15]. The water table inside the dump is assigned in accordance with the surface topography, as it is said that the water table will mimic the topography. The soft floor thickness considered for the analysis is 4.5 m. The geometry of the designed dump and the geomechanical properties of different materials considered are shown in Figure 4 and Table 1, respectively.

2.1 Development of Model and Analysis

The numerical simulation method has been applied to geotechnical engineering, with continuous progress in science and technology. Using computer software, models can be generated, simulated, and finally analyzed to understand the failure mechanism of the real slope with its actual geological environment, lithology, and stratum. Here the analysis is done using the powerful 2-dimensional finite element program RS2 (RS2= Rock and Soil 2-dimensional analysis program, version 11.012). The main feature of RS2 is finite element slope stability analysis using the shear strength reduction method. In the finite element method, the entire section will be divided into 10000 small triangles called mesh, so that it covers a maximum area with a high level of precision. For the study, uniform 3 Noded triangles are considered.

Case 1: 120 m Dump

1 Saturated condition

In case 1, the dump height is assumed as 120 m, and the trench width is 120 m. In this case, the highest factor of safety is obtained when the trench is positioned inside the toe. Analysis result for different conditions under dry and saturated conditions is shown in Figure 5 to Figure 15.

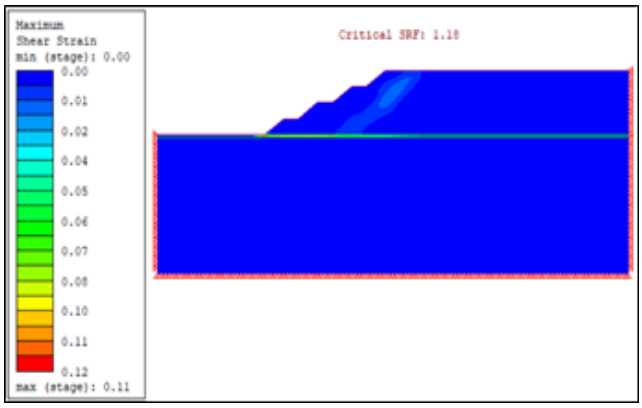


Figure 5. The factor of safety of a designed dump without a trench.

Figure 5 shows that the value of the factor of safety obtained for the designed dump in dry conditions without a trench is 1.18.

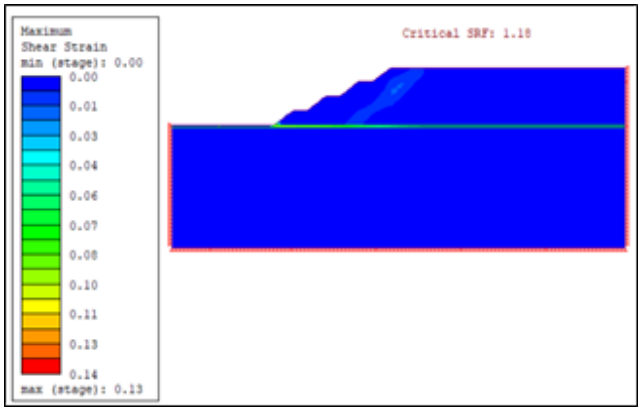


Figure 6. The factor of safety designed dump with trench position outside toe.

From Figure 6, the value of the factor of safety obtained for the designed dump in dry condition with a trench positioned outside the toe is 1.18.

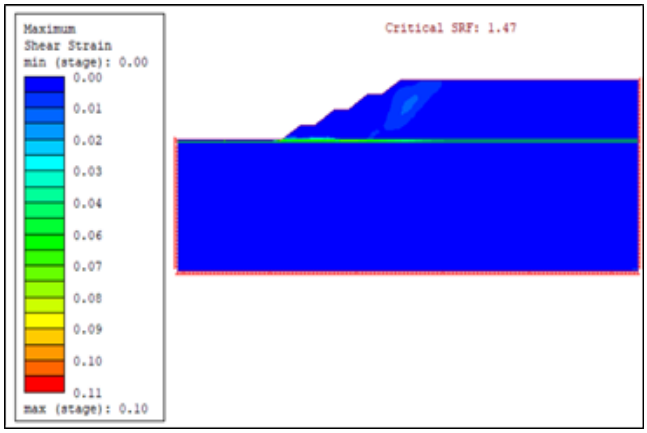


Figure 7. The factor of safety designed dump with trench position inside toe.

From Figure 7, the value of the factor of safety obtained for the designed dump in dry condition with a trench positioned inside the toe is 1.47.

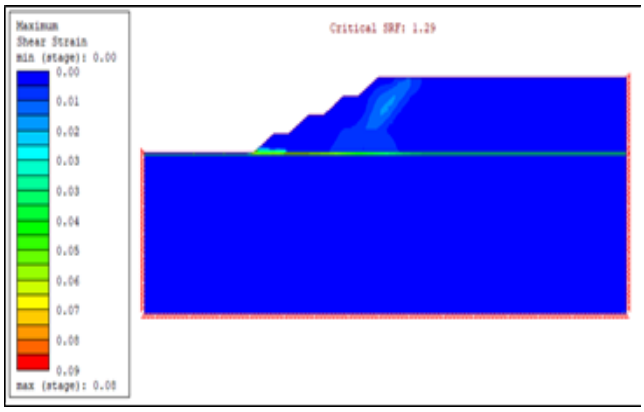


Figure 8. The factor of safety designed dump with the middle of the trench position at the toe.

From Figure 8, the value of the factor of safety obtained for the designed dump in dry condition with the middle of the trench positioned at the toe is 1.29.

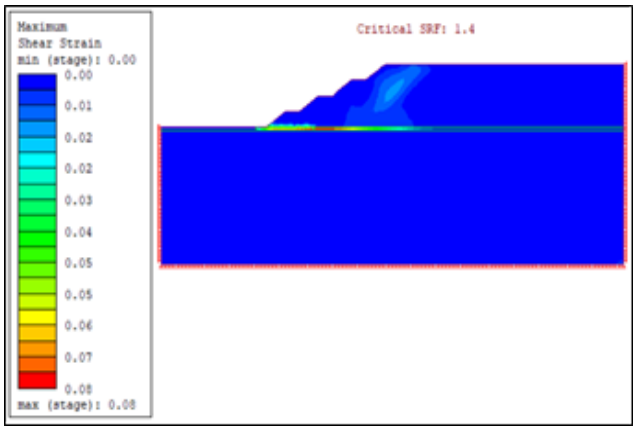


Figure 9. The factor of safety designed dump with 20 m of the trench position outside toe and 100m inside.

From Figure 9, the value of the factor of safety obtained for the designed dump in dry condition with 20 m of trench positioned outside the toe and 100 m inside the toe is 1.4.

2.2 Saturated Condition

From Figure 10, the value of the factor of safety obtained for the designed dump in saturated conditions without a trench is 0.98.

From Figure 11, the value of the factor of safety obtained for the designed dump in saturated condition with trench positioned outside toe is 0.95.

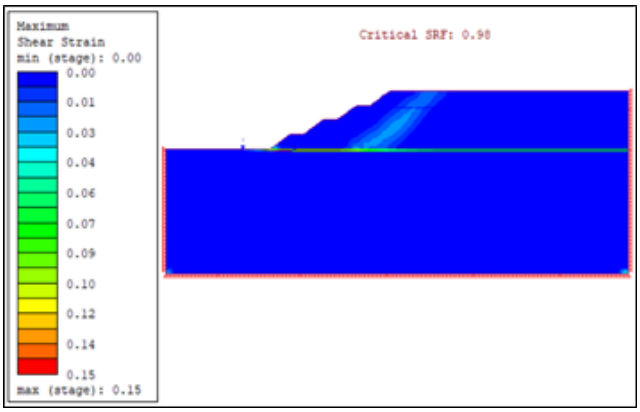


Figure 10. The factor of safety designed dump without trench.

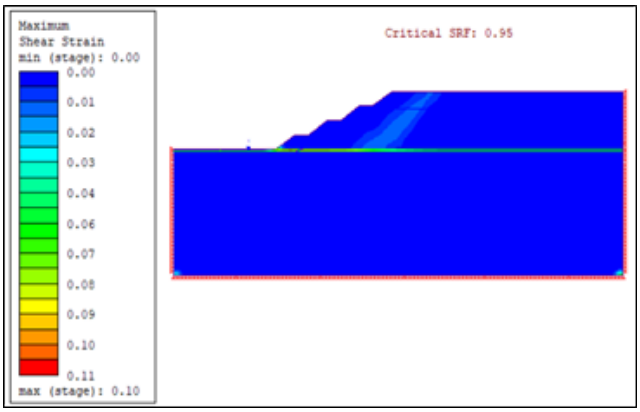


Figure 11. The factor of safety designed dump with trench position outside toe.

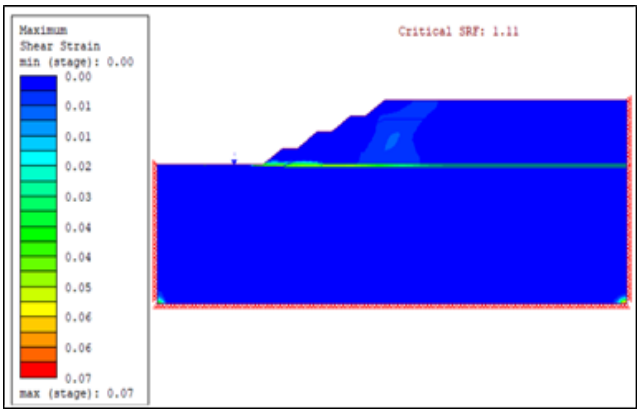


Figure 12. The factor of safety designed dump with trench position inside the toe.

From Figure 12, the value of the factor of safety obtained for the designed dump in saturated condition with a trench positioned inside the toe is 1.11.

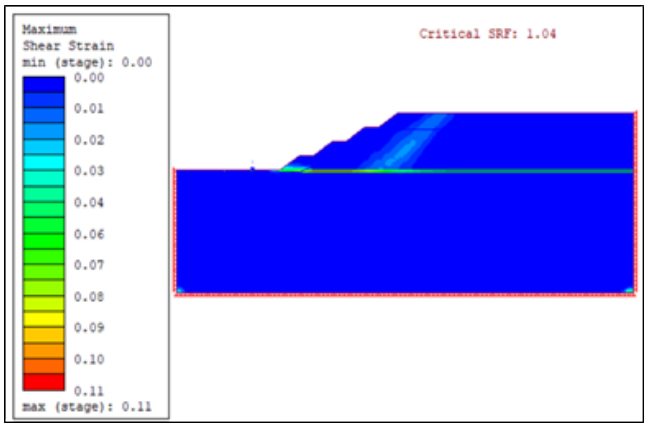


Figure 13. The factor of safety designed dump with the middle of the trench position at the toe.

From Figure 13, the value of the factor of safety obtained for the designed dump in saturated condition with the middle of the trench positioned at the toe is 1.04.

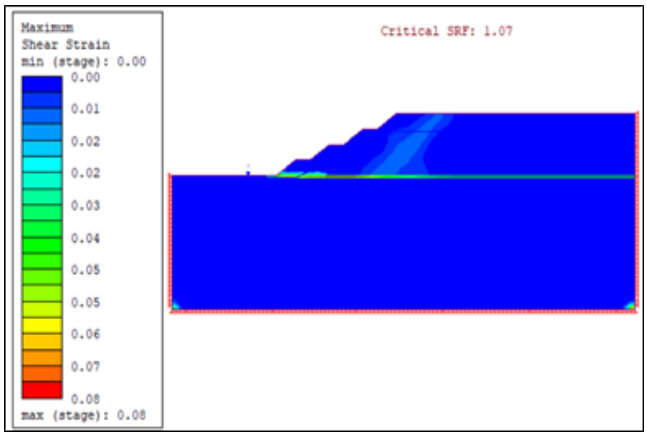


Figure 14. The factor of safety designed dump with 20 m of the trench position outside toe and 100 m inside.

From Figure 14, the value of the factor of safety obtained for the designed dump in saturated condition with the middle of the trench positioned at the toe is 1.07.

Case 2: 90 m Dump

In case 2, the dump height is assumed as 90 m, and the trench width is 90 m. In this case, the highest factor of safety is obtained when the trench is positioned inside the toe. The analysis is done like Case 1 and the result reveals that the implementation of the trench on the weak floor can improve the safety of the overburden dump (Figure 15). The same overburden dump under saturated conditions shows the reduced value of the factor of safety. Under saturated conditions, the implementation of the trench improves the overall factor of safety (Figure 16).

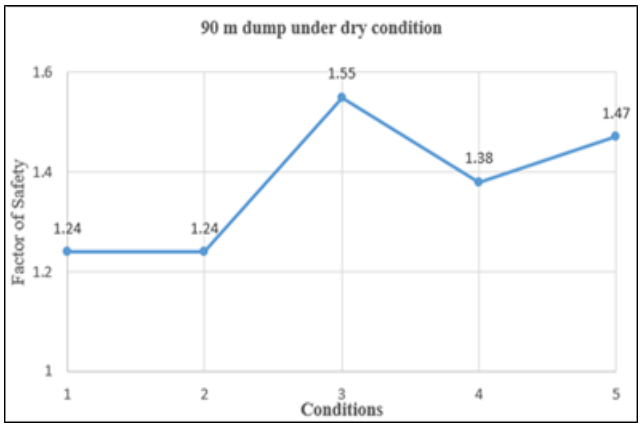


Figure 15. The factor safety of 90 m dump in dry conditions under different trench locations.

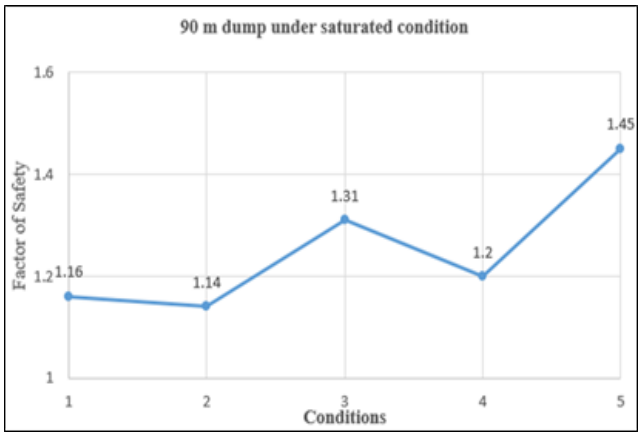


Figure 16. The factor safety of 90 m dump in saturated conditions under different trench locations.

Case 3: 60 m Dump

In case 3, the dump height is assumed as 60 m, and the trench width is 60 m. The analysis is done like Case 1 and the result reveals that the implementation of the trench on the weak floor can improve the factor of safety of the overburden dump (Figure 17). The same overburden dump under saturated conditions shows the reduced value of the factor of safety. Under saturated conditions also the

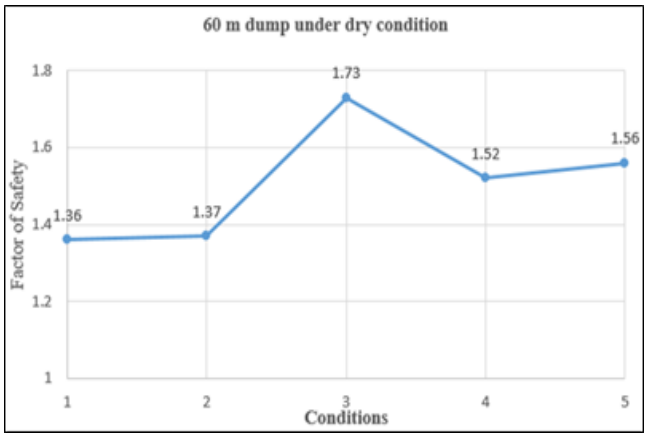


Figure 17. The safety of 60 m dump in dry conditions under different trench locations.

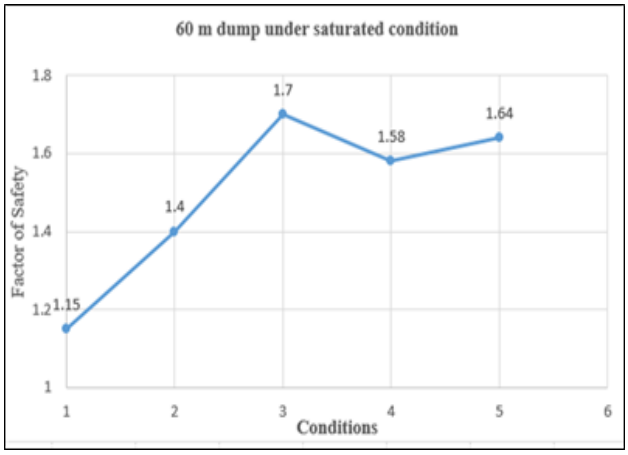


Figure 18. The safety of 60 m dump in saturated conditions under different trench locations.

implementation of the trench improves the overall factor of safety (Figure 18).

3.0 Implementation of the Trench on the Existing Dump

The feasibility of an overburden filled trench on the existing dump is analyzed by simulating the external dump of the Padmapur Opencast Coal mine in the Chandrapur Area of Maharashtra state. The part plan of the dump section is shown in Figure 19. Initially, the existing dump is analyzed without providing the trench (Figure 20) and then it is simulated under different combinations of trench width (40 m, 55 m, 65 m, 90 m, and 120 m) and trench locations represented in Figures 21 to



Figure 19. Part plan of an external dump of Padmapur open cast coal mine.

Table 2. Geomechanical properties of existing dump of Padmapur open cast coal mine

Material	Unit weight (MN/m^3)	Modulus of elasticity (MPa)	Cohesion (MPa)	Friction angle (degree)
Overburden dump	0.0187	90	0.033	33^0
Black cotton soil layer	0.0197	30	0.028	13^0
Rock fill	0.0187	90	0.033	33^0
Strong floor layer	0.0228	800	0.250	24^0

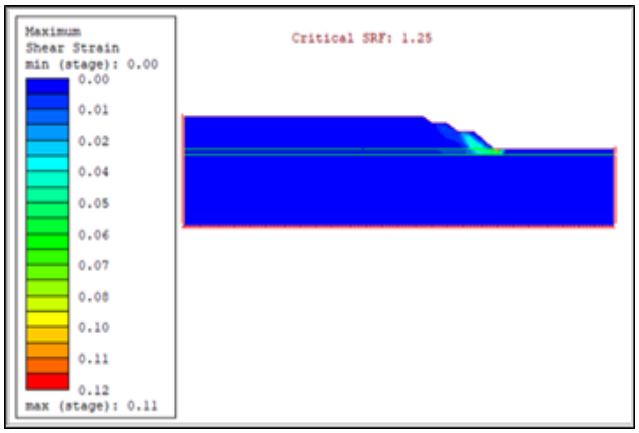


Figure 20. Existing dump without trench.

Figure 35. The geomechanical properties of the dump are shown in Table 2.

Different trench locations considered for the analysis are as below:

1. Trench positioned outside the toe.
2. Trench positioned inside the toe.
3. Middle of the trench positioned at the toe.

Case 1: 40 m trench

From Figure 21, the value of the factor of safety obtained when a 40 m trench is positioned outside the toe is 1.46.

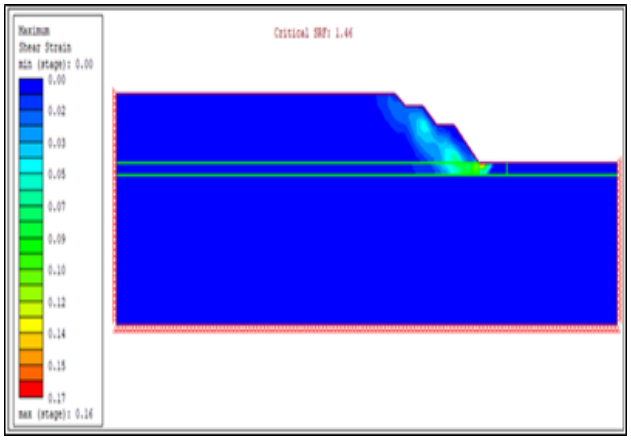


Figure 21. Existing dump with trench position outside toe.

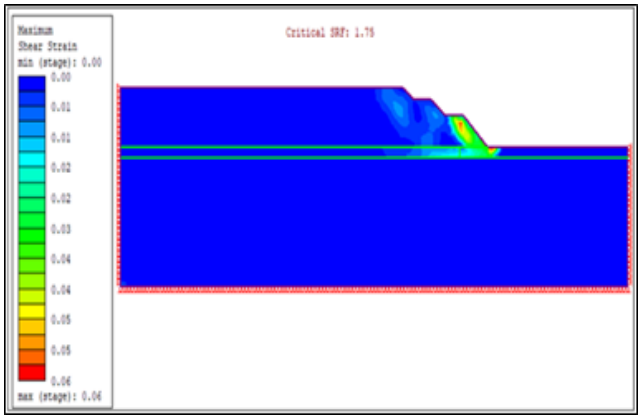


Figure 22. Existing dump with trench position inside toe.

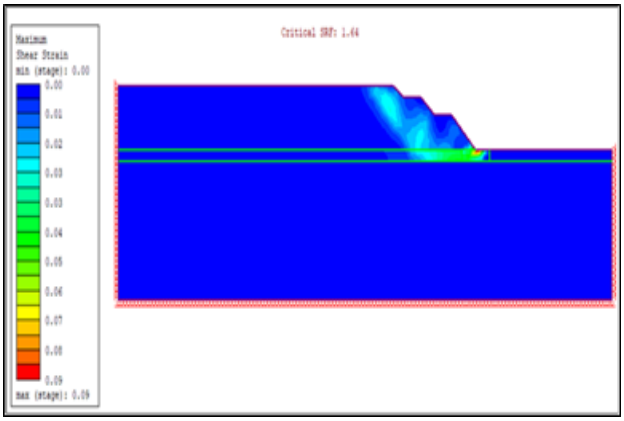


Figure 23. Existing dump with a middle of trench position at the toe.

From Figure 22, the value of the factor of safety obtained when a 40 m trench is positioned inside the toe is 1.75.

From Figure 23, the value of the factor of safety obtained when the middle 40 m trench is positioned at the toe is 1.64.

Case 2: 55 m trench

From Figure 24, the value of the factor of safety obtained when a 55 m trench is positioned outside the toe is 1.42

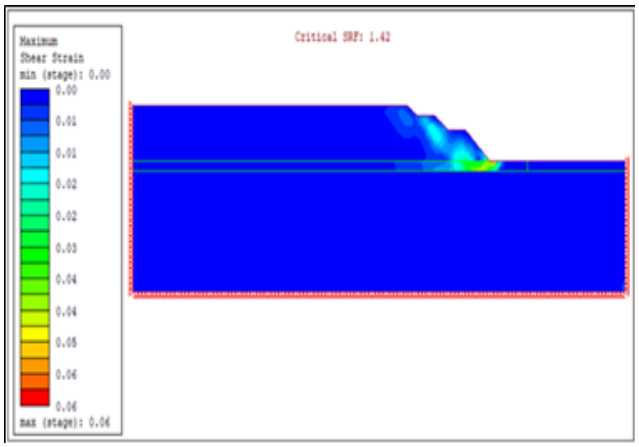


Figure 24. Existing dump with trench position outside toe.

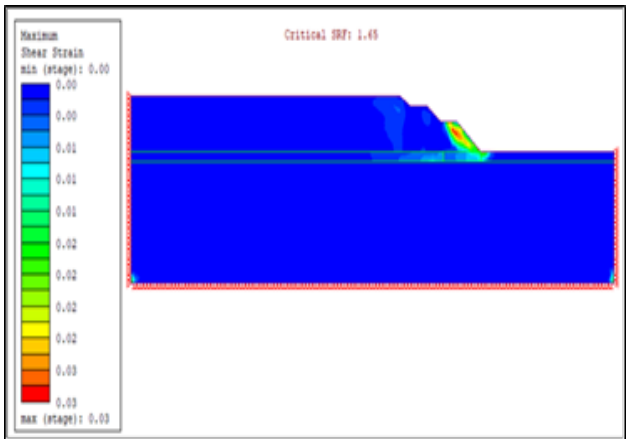


Figure 25. Existing dump with trench position inside toe.

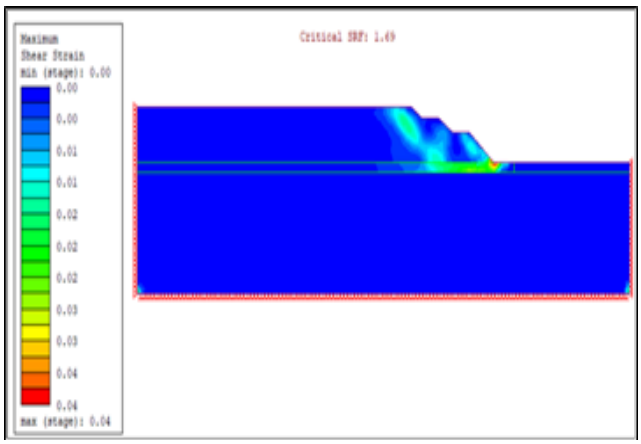


Figure 26. Existing dump with 25 m of trench inside toe and 30 m outside.

From Figure 25, the value of the factor of safety obtained when a 55 m trench is positioned inside the toe is 1.65.

From Figure 26, the value of the factor of safety obtained when 25 m of the trench is positioned inside and 30 m outside the toe is 1.69.

Case 3: 65 m trench

From Figure 27, the value of the factor of safety obtained when a 65 m trench is positioned outside the toe is 1.44.

From Figure 28, the value of the factor of safety obtained when a 65 m trench is positioned inside the toe is 1.74.

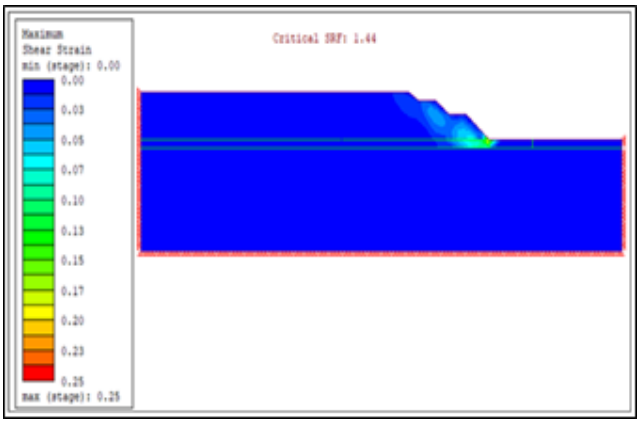


Figure 27. Existing dump with trench position outside toe.

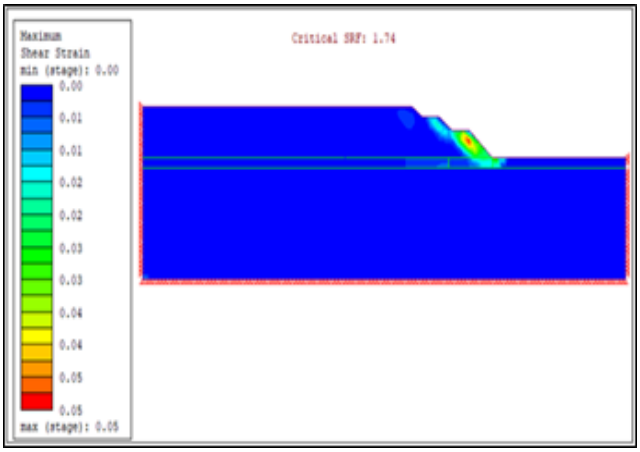


Figure 28. Existing dump with trench position inside toe.

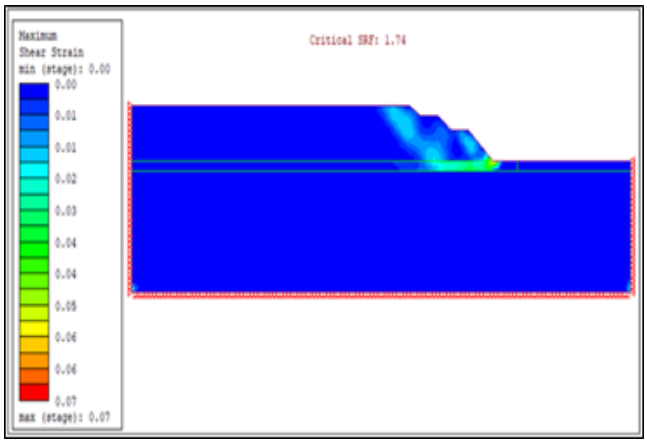


Figure 29. Existing dump with 30 m trench position inside and 35 m outside toe.

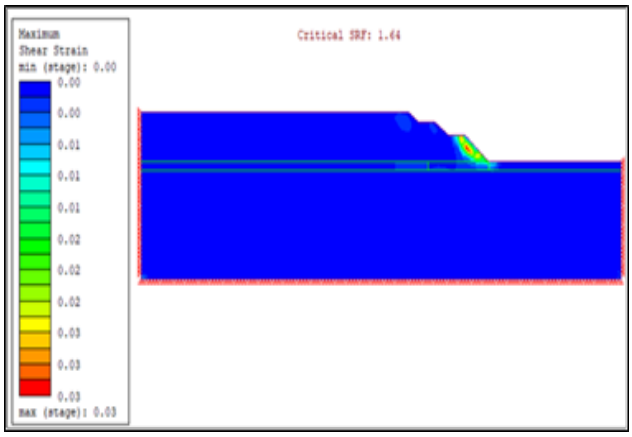


Figure 31. Existing dump with trench position inside the toe.

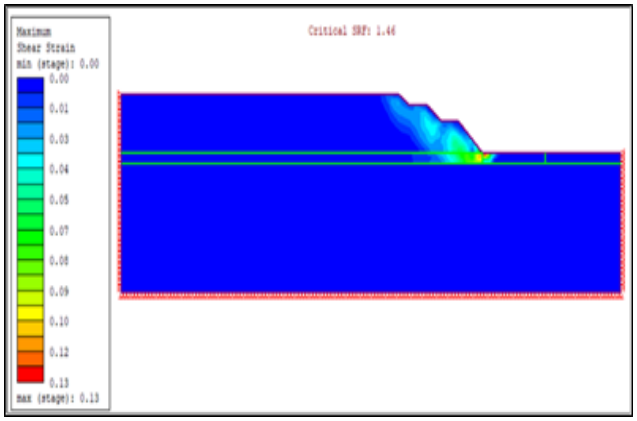


Figure 30. Existing dump with trench positioned outside toe

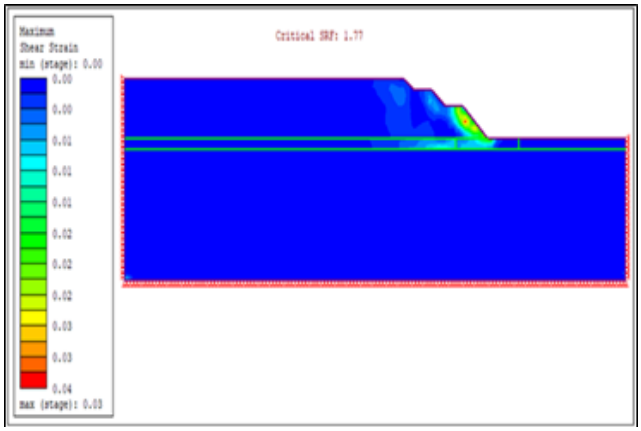


Figure 32. Existing dump with the middle of trench position at the toe.

From Figure 29, the value of the factor of safety obtained when a 30 m trench is positioned inside and 35 m positioned outside the toe is 1.74.

Case 4: 90 m trench

From Figure 30, the value of the factor of safety obtained when a 90 m trench is positioned outside the toe is 1.46.

From Figure 31, the value of the factor of safety obtained when a 90 m trench is positioned inside the toe is 1.64.

From Figure 32, the value of the safety factor obtained when the middle of a 90 m trench is positioned at the toe is 1.77.

Case 5: 120 m trench

From Figure 33, the value of the factor of safety obtained when a 120 m trench is positioned outside the toe is 1.39.

From Figure 34, the value of the factor of safety obtained when a 120 m trench is positioned inside the toe is 1.67.

From Figure 35, the value of the factor of safety obtained when the middle of the 120 m trench is positioned at the toe is 1.82.

The above results in each condition are represented in tabular form as shown in Table 3

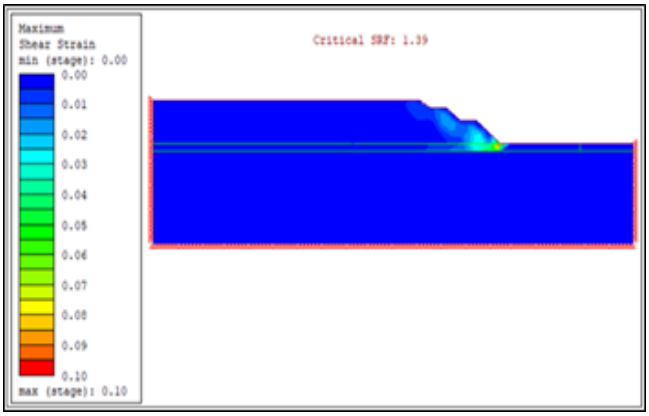


Figure 33. Existing dump with trench position outside the toe.

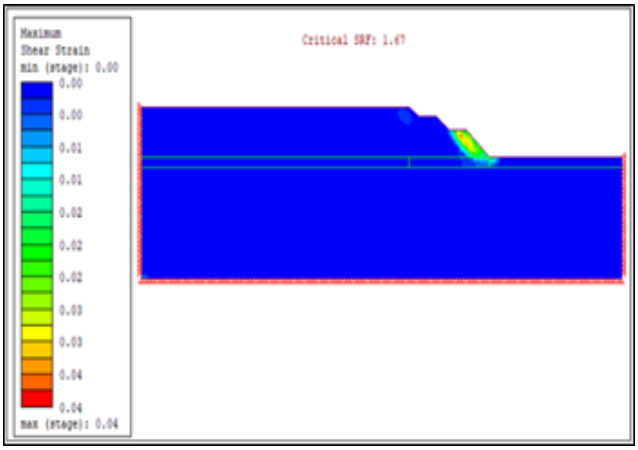


Figure 34. Existing dump with trench positioned inside toe.

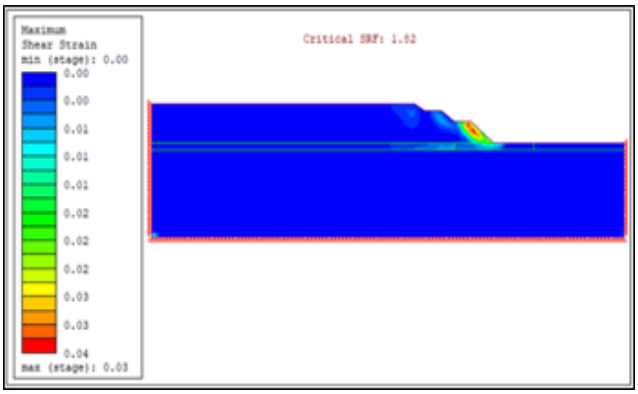


Figure 35. Existing dump with a middle of trench position at the toe.

*(for 65 m wide trench 30 m inside and 35 m outside toe and for 55 m wide trench, 25 m inside and 30 m outside toe)

From Table 3, it can be concluded that the existing dump which was originally having a factor of safety of 1.25 can be raised to the higher factor of safety as per the requirement. Depending upon the land availability, amount of overburden material, properties of floor and overburden material the mine authority will fix the dump height and factor safety.

3.1 Analysis of migrated dump geometry

In this study, dump geometry is suggested by migrating the existing dump geometry to numerous other dump heights such as 120 m, and 90 m. So, for the existing

Table 3. The factor of safety values obtained under various conditions

Conditions	Factor of safety				
	40 m trench	55 m trench	65 m trench	90 m trench	120 m trench
Without trench	1.25	1.25	1.25	1.25	1.25
Trench positioned outside toe	1.46	1.42	1.44	1.46	1.39
Trench positioned inside toe	1.75	1.65	1.74	1.64	1.67
Middle of trench placed at toe (*)	1.64	1.69	1.74	1.77	1.82

dump, a designed width of the trench is constructed at the periphery of the existing overburden dump profile. After excavating and refilling the trench with excavated material, the existing dump is advanced towards the trench. For determining the best and economical dump profile and trench widths following analyses are conducted (Figures 36 to 44).

Case 1: 120 m dump height, 120 m wide trench

From Figure 36, the value of the factor of safety obtained when a 120 m wide trench is positioned outside the toe is 1.3.

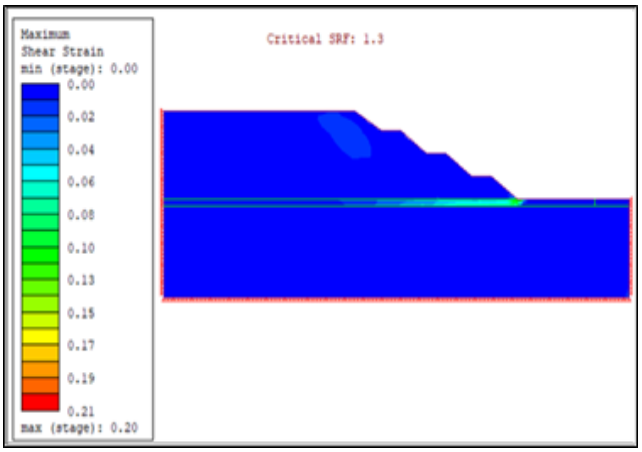


Figure 36. The factor of safety of migrated dump with 120 m wide trench placed outside toe.

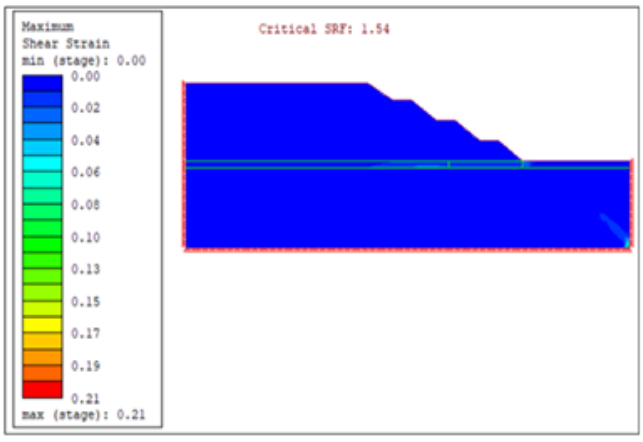


Figure 37. The factor of safety of migrated dump with 120 m wide trench placed inside the toe.

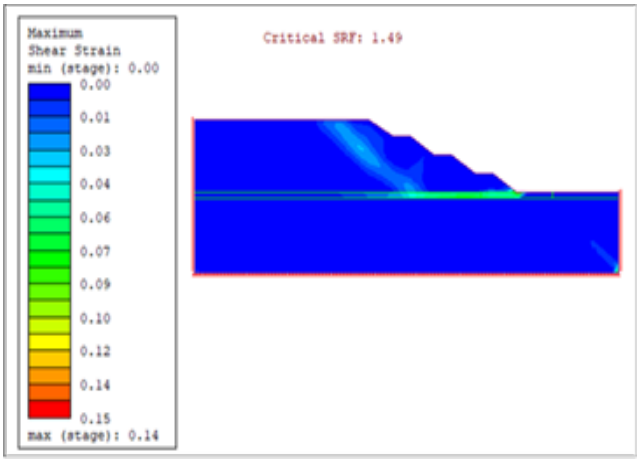


Figure 38. Factor of safety of migrated dump with a middle of 120 m wide trench at the toe.

From Figure 37, the value of the factor of safety obtained when a 120 m wide trench is positioned inside the toe is 1.54.

From Figure 38, the value of the factor of safety obtained when the middle of a 120 m wide trench is positioned at the toe is 1.49.

Case 2: 90 m dump height, 90 m wide trench

From Figure 39, the value of the factor of safety obtained when a 90 m wide trench is positioned outside the toe is 1.31.

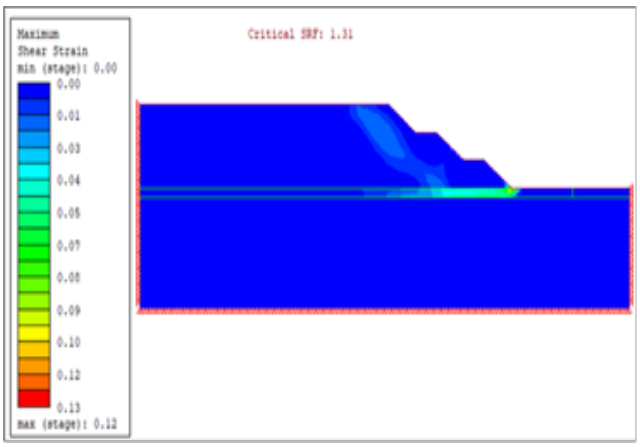


Figure 39. The factor of safety of migrated dump with 90 m wide trench placed outside toe.

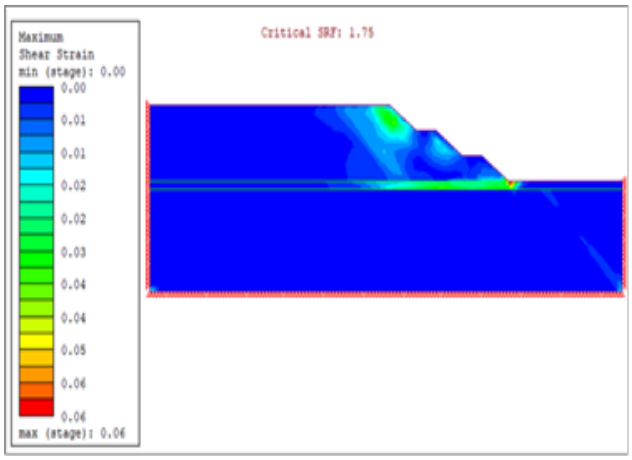


Figure 40. The factor of safety of migrated dump with 90 m wide trench placed inside toe.

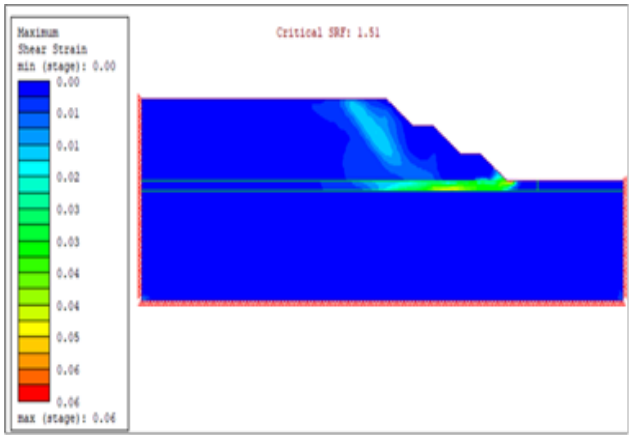


Figure 41. Factor of safety of migrated dump with a middle of 90 m wide trench positioned at the toe.

From Figure 40, the value of the factor of safety obtained when a 90 m wide trench is positioned inside the toe is 1.75.

From Figure 41 the value of the factor of safety obtained when the middle of a 90 m trench is positioned at the toe is 1.51

Case 3: 90 m dump height, 120 m wide trench

From Figure 42, the value of the factor of safety obtained when a 120 m trench is positioned outside the toe is 1.31.

From Figure 43, the value of the factor of safety obtained when a 120 m trench is positioned inside the toe is 1.77.

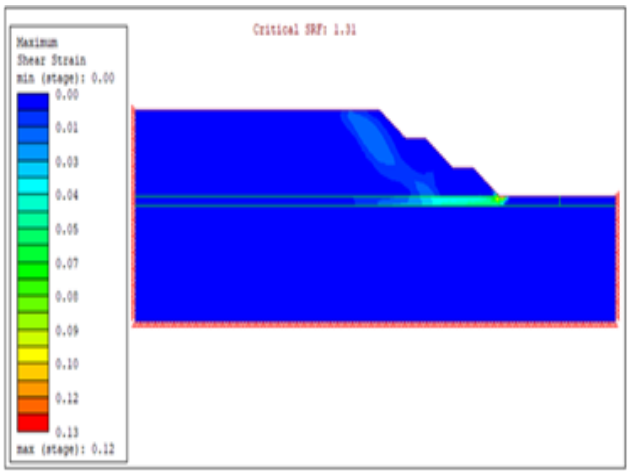


Figure 42. The factor of safety of migrated dump with 120 m wide trench placed outside toe.

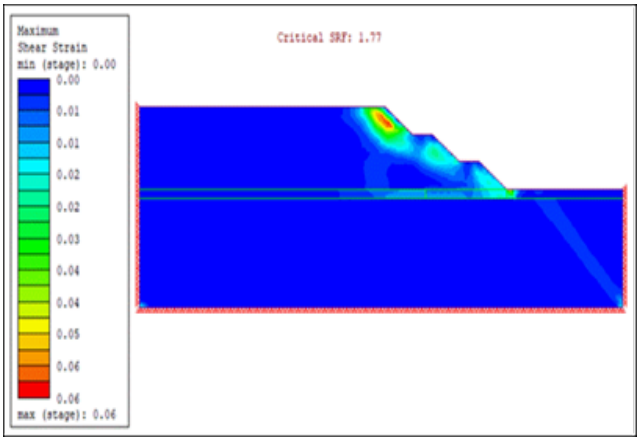


Figure 43. The factor of safety of the migrated dump with 120 m wide trench placed inside toe.

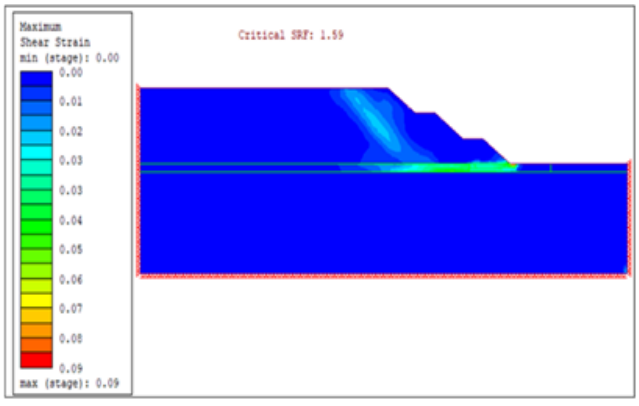


Figure 44. Factor of safety of the migrated dump with the middle of 120 m wide trench positioned at the toe.

From Figure 44, the value of the factor of safety obtained when the middle of the 120 m trench is positioned at the toe is 1.59.

4.0 Discussion

The results obtained in each case are represented in tabular form as shown in Table 4.

From Table 4, it can be concluded that it is ideal and economical in terms of safety factor to provide a 90 m dump with a trench width of 90 m. Providing a trench of 120 m for a 90 m dump is not economical and does not bring significant changes in the factor of safety. The dump height can also be increased to 120 m, by providing a trench of 120 m. But to keep the design on the safe side and\ also considering the hydrological parameters (as the simulation is done in dry conditions), it is advised to adopt a migrated dump with 90 m height and 90 m wide trench. The maximum factor of safety of 1.75 is obtained when the middle trench is positioned at the toe. The implementation of the trench not only improves the factor of safety but also the overburden volume of the dump. The dump which was initially 55 m in height has now improved to 90 m. The schematic picture is shown in Figure 45 of the migrated dump.

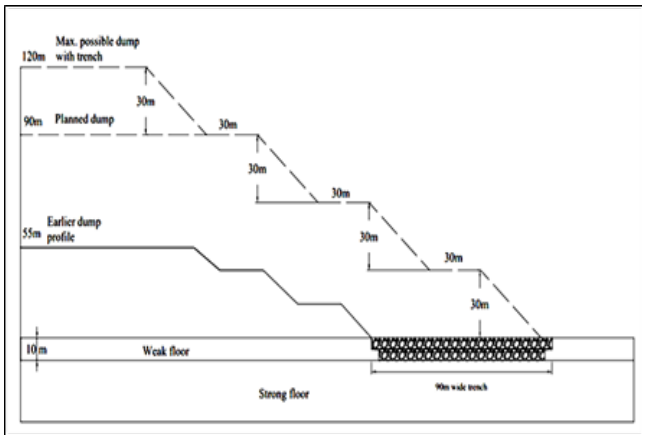


Figure 45. Schematic representation of the migrated dump of the case site

Based on results obtained from the analysis, the existing dump geometry is made more stable by migrating the dump profile to a height of 90 m (safe geometry). The suggested dump slope configuration as shown in Figure 45, includes a 30 m individual bench height and a 30 m berm width. This will also provide sufficient space for plantations.

5.0 Conclusions

The rock-filled trench method involves constructing a trench by removing the black cotton soil layer or weak floor layer of specified width and then refilling the trench using the same overburden material which is to be dumped at the site. The presence of a weak floor layer can be one of the several reasons for dump failure. The numerical modeling analysis done using RS2 reveals that the implementation of the trench near the toe area of the dump is effective in improving the overall stability. The value of the factor of safety obtained under saturated conditions shows a reduced value of factor safety than the model under dry conditions. This method of introducing rock filled trench near the toe not only improves the stability but also enables the improvement of the dump height. Thereby,

Table 4. The factor of safety obtained under various conditions

Conditions	Factor of safety		
	120 m dump with 120 m trench	90 m dump with 90 m trench	90 m dump with 120 m trench
Trench positioned outside toe	1.3	1.31	1.31
Trench positioned inside toe	1.54	1.75	1.77
Middle of trench positioned at the toe	1.49	1.51	1.59

ensuring that the construction of an overburden dump over the black cotton layer is possible by providing a trench. This can be introduced in new dump sites before placing the overburden material and in existing dump sites, by constructing the trench near the toe region and further migration of the dump geometry to the trench. As the trench is filled with the same overburden material, no additional trench filling materials are required. The limitation of this method is that, when the black cotton floor layer thickness extends up to 10 m, the construction of the trench will be impractical and expensive. New methods must be adopted in such a scenario to stabilize the black cotton soil.

6.0 References

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