A Finite Element Approach of Stability Analysis of Internal Dump Slope in Wardha Valley Coal Field, India, Maharashtra

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Abstract Designing of a stable overburden disposal slope is vital in large open cast coal mines. Spoil generated during extraction of coal which is dumped externally requires larger land to remain stable and also poses problems to surrounding environment due to limited land availability. This has lead to the preference of internal dumping in which the waste is dumped in de-coaled region which is beneficial during extraction and reclamation of mine. Internal dumping is also the most economical and environment friendly method of waste disposal and is being adopted everywhere. It has certain limitations and inherent dangers of failures posing operational and safety threats. In this paper, a numerical study for stability of 80 m high internal dump slopes from an open cast coal mine of Wardha Valley Coal Field, Maharashtra, India has been carried out using Finite Element Method (FEM). Different scenarios as per the dump heights have been accounted and simulated using Plaxis2D-8 to understand the failure mechanism and the changes in factor of safety with variation in bench height and the number of benches.

Keywords: internal dump, slope stability, numerical modeling, Coal Field


1. Introduction

Surface mining activity in India is increasing at a rapid rate to bridge the gap between demand for and supply of coal to the energy sector. During the process of surface mining operations, huge amount of waste material is generated, hauled and then loosely dumped on the ground surface or used to fill unused open pits. Overburden/waste generated during extraction of coal are being dumped both internal as well as on external dump. Internal dumping is the most economical and environment friendly waste management being adopted widely. But it has certain limitations and inherent danger of dump slides posing operational and safety threats [1,2]. The presence of water reduces the frictional strength of the slope material, and the geo-mechanical properties are reduced further due to the presence of pore water pressure. The migration of water may augment the seepage, leading to the formation of tension cracks parallel to the internal dump slopes. Tension cracks are also generated due to shocks and vibration caused by poor blasting in slopes [3,4,5].

With the increase in size and the stripping ratio of the opencast mines, the amount of overburden generate has also increase considerably. Coal India Limited (CIL) is the chief coal producing organization in India. CIL has removed 21, 160, 462 and 695 million cubic metre of overburden during 1976, 1986-87, 1999-2000 and 2009-2010 respectively. The paucity in the land area availability for dumping the waste rock has compelled the mine managers to think ways for the safe, stable and economic disposal of the dump material. Overburden dumps can be external dumps created at a site away from the coal bearing area or it can be internal- dumps created by in-pit dumping (IPD) concurrent to the creation of voids by extraction of coal. Practice of dumping overburden in the external dumps have some serious problems [6] foremost amongst them are requirement of additional land, involves very high transport and rehandling cost which will increase the cost of coal production substantially, stability and reclamation at the site. It is not possible to eliminate the external dumps concept completely, even if we adopt internal dumping practice.

Waste material dump stability is essential to ensure the safety of haul trucks during placement and long term safety. Many research articles had been published since the publication of the first method of analysis by [7] that were either related to slope stability or involved slope stability analysis subjects. Among the available analysis methods, ordinary method of slices [7], Bishop’s modified method [8], Janbu’s generalized procedure of slices [9] and Spencer’s method [10].

The demerit with all the equilibrium methods is that they are based on the assumptions that the failing soil mass can be divided into slices, which necessiates further assumptions relating to side force directions between slices, with consequent implications for equilibrium.
Because of the certain advantages of finite element method like no assumptions needs to be made in advance about the shape or location of failure surface, it has been used widely used for slope stability analysis over traditional equilibrium methods. [11,12,13,14] have used the finite element method for slope stability analysis for further confidence in the method for dum material as well as rock slopes.

In this paper, a study of numerical analysis for stability of internal dump slope (Figure 1) has been carried out using FEM with Strength Reduction approach. A case from an opencast coal mine has been considered in which in-pit dumping is taking place, currently at 80 m height formed of two benches of 60m and 20m height. The dump has been executed at an angle of 40°, composed of weak sandstone and shale rocks. As the amount of dump material is increasing day by day, efficient and stable disposal of the dump material will be a key factor for sustainable production. Hence, in the present study the effect of increase in height and inclusion of benches in the dump slope have been studied in a finite element code to reach conclusive methodology for proper dumping.

![Figure 1. An opencast mine with internal dumping in progress](image)

Finite element method has been increasingly used in slope stability analysis. The method can be applied with complex slope configurations and dump deposits in two or three dimensions to model virtually all types of mechanisms. General debris material models that include Mohr-Coulomb and numerous other tools can be employed. The equilibrium stresses, strains, and the associated shear strength in the dump mass can be computed very precisely and accurately. The critical failure mechanism developed can be extremely general and need not be simple circular or logarithmic spiral arcs.

## 2. Stability Features of Internal Dump

In the case of open pit mines, the underground minerals are accessed by removing the overburden material which is placed in the de-coaled area. Many of these waste dumps possess environmental or extraction problems, slope stability concern and undesirable aesthetic attributes. There is an increased need for basic information, understanding of construction, characterization and its stability status as unplanned dumping can be a threat to life and property [15, 16, 17, 18]. The Internal dumps are affected by the particle size of the waste material, geometry, unit weight, shear strength, pore pressure, and the foundation of the dump material [1,19,20]. Therefore it is necessary to study important feature in respect of the construction of dump, factor influencing shear strength of dump, characterization of dump as well as stability of dump.

## 3. Stability Assessment Using FEM

There are three major aspects involve in slope stability analysis. The first is about the material properties of the slope forming material. The second is the calculation of factor of safety and third is the definition of the slope failure [21].

### 3.1. Model Material Properties

The Mohr-Coulomb constitutive model has been used to describe the dump material properties. The criterion of Mohr-Coulomb model relates the shear strength of the material to cohesion, normal stress and angle of internal friction.

### 3.2. Factor of Safety (FOS) and Strength Reduction Factor (SRF)

Slope fails because its material shear strength on the sliding surface is insufficient to resist the actual shear stresses. Factor of safety is a value that is used to examine the stability of slopes. If FOS is greater than 1, it means the slope is stable, while values lower than 1 indicates unstable slope.

### 3.3. Slope Collapse

Non-convergence within a specified number of iterations in finite element program can be taken as a suitable indicator for slope failure, which means that no stress distribution can be achieved to satisfy both the Mohr-Coulomb criterion and global equilibrium. Slope failure and numerical non-convergence take place at the same time and are joined by an increase in the displacements. Usually, value of the maximum nodal displacement just after slope failure has a sharp rise as compared to the one before failure.

For the present work detailed systematic sampling has been carried out. The dump material was tested in the laboratory for the assessment of their strength properties as per standards [22,23,24]. The samples were tested in dry as well as saturated condition when pores were fully charged. The dump material mainly consists of sandstone, shale and carbonaceous shale. The geo-mechanical properties of material are listed in Table 1. There are six type of model prepared with different height and angle using the geo-mechanical properties listed below in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation weight (kN/m³)</td>
<td>γsat</td>
<td>1.9</td>
</tr>
<tr>
<td>Unsaturation weight (kN/m³)</td>
<td>γunsat</td>
<td>1.7</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>E</td>
<td>57</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>ν</td>
<td>0.28</td>
</tr>
<tr>
<td>Angle of Internal Friction(°)</td>
<td>φ</td>
<td>22.4</td>
</tr>
<tr>
<td>Cohesion (kPa)</td>
<td>C</td>
<td>91</td>
</tr>
<tr>
<td>Dilatancy Angle(Degrees)</td>
<td>ψ</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1. Input Parameters used in simulation
4. Results and Discussion

Case 1: In this case an internal dump slope with the height of 60m and slope angle of 40 degrees is considered. Results obtained from numerical analysis of this slope using Table 1 parameter are shown in Figure 2.

It is seen that mesh has been deformed (Figure 2a) which represents consolidation and subsequent subsidence by 7m in the dump material due to the effect of gravity on the dump slope is stable with factor of safety 1.784. Shear strains are higher in bottom and toe region of the dump slope (Figure 2b) due to weight of OB and corresponding normal force from the platform below. The possible failure plane can be seen from Figure 2c, the total displacement of the dump region is shown along with their scaling. The mean stresses (Figure 2d) the amount of stresses at the bottom of the dump is more due to the overburden weight. A possible toe failure is predicted with the FEM analysis of the dump slope in the current state.

Case 2: In this case, materials are dumped as a bench of height 20m and slope angle is 40 degrees above existing internal dump slope of 60m depth. Results obtained from numerical analysis of this model using Table 1 parameter are shown in Figure 3.

Mesh has been deformed more (Figure 3a) with compared to (Figure 2a) which represents consolidation of material due to addition of one bench, yet slope is stable with factor of safety 1.378. The displacement of the materials has been scaled up by $20\times10^6$ times. Shear
strains are more densely packed at near bottom of the dump and the toe region; it has also extended towards the center due to a additional weight of the 20m bench (Figure 3b). The probable failure plane can be seen from (Figure 3c), the total displacement of the dump region is shown along with their displacement scaling. Displacement zone is more at the top of the bench and has more probability of failure in this region. The mean stress distribution is shown in the (Figure 3d). The stress concentration is more near the bottom of the dump, the value of which is -180 KN/ft², the negative value indicates that stress is compressive in nature.

Case 3: In this case one more bench of height 20m is added keeping same slope angle. Results obtained from numerical analysis of this model using Table 1 parameter are shown in Figure 4.

Deformed mesh is shown in the Figure 4a, it can be seen that material is falling down from the top of the dump but still the whole model has become critical with a factor of safety 1.161. The displacement of the materials has been scaled up by $50 \times 10^6$ times, which is twice when compared to previous case (Figure 3a).

Total displacement of the dump in the form of shadings are shown in Figure 4b, the maximum displacement of the materials will occur at the left top of the dump and along the slopes it comparatively lesser.

The total displacement of the materials are shown in the form of arrows in Figure 4c, the materials at the top tends to move down, where as the materials near the slope tend to move towards right side due to free face. Horizontal displacement near the slope side is due to the over burden and vertical displacement is due to force of gravity.

The shear stress shown in Figure 4d points out that the stress is more near the bottom of the dump, it is comparatively lesser near the top and at the middle section of the lower most benches.

Case 4: In this case an internal dump slope with the depth of working 80m and slope angle of 40 degrees is considered. Results obtained from numerical analysis of this slope using Table 1 parameter are shown in Figure 5.

In the deformed mesh (Figure 5a) the displacement has been scaled up by $100 \times 10^5$ times, which is five times more than that of case 1 ($H_1=60m$), this suggests that the material has displaced more and also FOS reduced due to the increase in height.

The effective stresses are shown in Figure 5b, the development of stress is higher and it is confined at the toe of bench due to the overburden weight from the top and also increases in height of the dump.

Case 5: In this case materials are dumped as a bench of height 20m and slope angle is 40 degrees above existing internal dump slope of 80m depth. Results obtained from numerical analysis of this model using Table 1 parameter are shown in Figure 6.
The deformed mesh is shown in the Figure 6a. In this case, mesh is getting loosened and node points are expanding as compared to the previous case, the displacement of the materials has scaled up $50 \times 10^{-6}$ times. The materials fall along the slope reducing the height, slope angle also the stability of the dump.

The horizontal displacement of the materials (Figure 6b) at H2 bench is very less as we can see very few resultant vectors but the horizontal displacement near the slope side of H1 bench is large due to free face of the slope.

Total displacement (Figure 6c) of the material is large at the left top of the dump and hence the material falls towards the slope side making dump slope unstable. Since the FOS is 1.130 the model is in a critical state and may collapse with high displacement in the material.

Mean stresses of the dump (Figure 6d) shows that the stresses are more near the bottom of the bench due to the increase in dump height (H1) and also addition of one more bench (H2).

**Case 6:** In this case an internal dump slope with the depth of working 100m and slope angle of 40 degrees is considered. Results obtained from numerical analysis of this slope using Table 1 parameter are shown in Figure 7.

The deformed mesh shown in the Figure 7a indicates the displacement of the material, which is scaled up by $20 \times 10^{-6}$ times, the mesh is widened hence the material is more loosely packed, large materials overflows along the slope resulting in the change of dump shape. FoS, in this case, is 1.098 which shows that slope is very much likely to fail. The triangles near the bottom of the dump has distorted in their shape which shows high probability of failure in that region.

The total displacement of the dump in the Figure 7b shows the probable failure plane. More displacement is occurring near slope edge, which has its effects in the
center also, this suggests that even a small load from the top may lead to collapsing of the dump, which can also be further confirmed by its FoS, which is 1.098; small disturbance in the present model may collapse the structure.

Total displacement can also be seen in Figure 7c, which is shown in the form of arrows.

Vertical displacement of the materials (Figure 7d) shows the movement of the material in the vertical direction, materials at the top of the bench moves in the vertical direction due to force of gravity and increase in dump bench height (H1). Materials along the slope side displace very little in the vertical direction due to free face availability.

Table 2 shows the factor of safety obtained and corresponding analysis of stability for all dump slope models.

<table>
<thead>
<tr>
<th>Case</th>
<th>Height-H (m)</th>
<th>Slope angle (°)</th>
<th>Factor of safety (FOS)</th>
<th>Analysis result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>40</td>
<td>1.784</td>
<td>Stable</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>40</td>
<td>1.161</td>
<td>Critical</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>40</td>
<td>1.335</td>
<td>Stable</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>40</td>
<td>1.130</td>
<td>Critical</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>40</td>
<td>1.098</td>
<td>Most Critical</td>
</tr>
</tbody>
</table>

5. Conclusion

In this paper, number of numerical models were generated to simulate the Internal dump in an opencast coal mine of Wardha Valley Coal Field, Maharashtra, India, to analyse their stability with varying height of the bench slopes. It is found that the FOS reduces drastically with increase in height of the dump slope. FOS were also depend on the nature of material and its geomechanical properties, but here the dump material is mainly consisting of sandstone, shale and carbonaceous shale. The height of working is 60m the slope was found stable. As the mine goes deeper the waste materials generated also increases, which can be dumped over the existing Internal dump slope. It is found that the over all dump slope becomes unstable after addition of two increased overburden benches on existing Internal dump slope. In case of 80m high Internal dump slope FoS decreased to less than one after addition of one bench. When the depth of working increases to 100m, the stability of Internal dump slope becomes critical and addition of overburden results in dump slope failure. It can be concluded from the study that an internal dump is more stable when it is composed of a number of benches rather than a single slope.

References