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FLY ASH MIXING WITH MINE OB DUMPS: AN ENVIRO-FRIENDLY, CLEAN AND GREEN METHOD OF DISPOSAL

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Abstract

Fly ash generation, its utilization and safe disposal is a major problem faced by thermal power plants (TPP) in India. Despite several efforts of the government, the utilization of fly ash is reached to only 55% of the total fly ash generated and remaining 45% fly ash is still being dumped into poorly designed and maintained ash ponds. At present, fly ash is mainly being utilized for making cement, bricks, concrete, roads and small quantity in mine void filling. The consumption of fly ash in construction *activity has reached to almost saturation level and there is not much potential to consume more fly ash in these segments. Mine void filling is the only potential area where bulk quantity of fly ash can be utilized and 100% utilization target can be achieved. This paper investigates the suitability of fly ash to be disposed off by mixing it with overburden (OB) dumps in coal mines. Characterization of both the OB dump material and fly ash were carried out in the laboratory. The compaction and shear tests were performed on OB dump material and the same mixed with 25% fly ash by volume as per the guidelines issued by Ministry of Environment Forest and Climate Change, Govt. of India. The stability condition of both OB dump and fly ash mixed OB dump at varying slope angles were analyzed using FLAC 3D slope stability software and dump angle were optimized for safe disposal of the fly ash.*

Keywords

Stability, Overburden Dumps, Fly Ash, Shear Strain, Plasticity

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1. Introduction

Power sector in India has been undergoing a monumental change which has redefined the outlook of power industry. Sustained economic growth continues to drive electricity demand in India. Union government has launched an ambitious programme called 'Power for All'. The programme requires accelerating the addition in generation capacity. The total installed power generation capacity of India in March 2016 stood at 288,665 MW. The coal based thermal power plants (TPP) account for 175,858 MW which stands at 60.92% of total installed capacity (Ministry of Power, 2016). Indian coal is low in calorific value and high in ash content (30% to 45%). Generation of same units of energy therefore lead to a production of a huge quantity of fly ash in coal based TPP in India vis-a-vis to other countries. Low utilization of the fly ash causes a substantial quantity of the same to be disposed off in the ash ponds. resulting in permanent degradation of land. Fly ash generation has increased from 85 million tonnes in the year 2000-01 to 185 million tonnes in 2014-15. Utilization of fly ash has also increased from 20% to 55% during the same years. Though the percentage utilization of the ash has increased over the years, the quantity of the unutilized fly ash is increasing every year because of the increased generation. Pandey et al. (2011) have assessed that the quantity of unutilized fly ash of 1500 million tonnes (approx.) lying in the ash pond is occupying 65000 ha of land in India. The concern of degradation of land is aggravating with the current utilization pattern. More efforts are required to ensure increased fly ash utilization. Statistics for the year 2014-15 indicates that a maximum of 42.26 % of the ash is utlized by the cement sector followed by 13.00% for mine filling and 11.72% for making bricks and tiles (Ministry of Power, 2015). Stagnation in the production of the cement and brick over the last five years has lessened the consumption. As per an estimate, a thermal power plant of 1000 MW capacity produces 1.6 to 1.8 million tonnes of fly ash per annum at 29% and 40% ash content respectively (Chattopadhyay 2015). Enhanced consumption of coal by TPP in the coming years may lead to the generation of fly ash to nearly 600 million tonnes by 2030 (Krishnan 2013).The quantity of unutilized fly ash is therefore increasing every year.

Fly ash disposal, its utilization and management has been a long-standing challenge for the Indian power sector. Making a more productive use of fly ash or its safe disposal would have considerable environmental benefits, whilst reducing both air and water pollution. It is therefore vital that new and feasible methods of disposal and utilization of fly ash must be explored. Ministry of Environment, Forest and Climate Change (MOEFCC), Govt. of India is making continuous effort to promote and increase fly ash utilization and now it has set 100% utilization target for all the thermal power plants vide notification dated Nov. 3, 2009 (MOEFCC, 2009). It also compels all the mines located within 50 km by road from thermal power plants, to mix at least 25% fly ash by volume in the external and internal overburden (OB) dumps in the mine. Even after passing of several years, disposal of fly ash by mixing it in OB dumps in the coal mines has not yet received the impetus inspite of the fact that almost one third of the thermal power plants in India are located in the close vicinity of the opencast coal mines. Location of thermal power plants and huge availability of fly ash in the proximity of coal mines can ensure economic disposal of fly ash by mixing it with OB dumps in open cast coal mines.

Fly ash is a fine powdery non-plastic material having negligible cohesion, whereas coal mine OB dump material consists of fragments of natural soils, sandstone, siltstone, and shale. The addition of fly ash in the OB dump material changes its shear strength behaviour thereby affecting the stability of dumps. Limited research has been carried out to assess the effect of mixing the fly ash with OB dump material on its slope stability (Singh 2011, Jayanthu et al. 2012, Pradhan et al. 2014, Gupta and Paul 2016, Dewangan et al. 2016). Singh (2011) studied the effect of mixing 30% fly ash on factor of safety for OB dump slope of a height of 120 m under dry and wet conditions using numerical simulation. It was found that the slope remains stable under dry condition, while under wet condition, dump becomes critically stable. Jayanthu et al. (2012) studied the dump stability of fly ash (25% by weight) mixed OB dumps of an opencast coal mine having a total height of 120 m. Two types of dumps were formed. One with alternate layer of fly ash and OB whereas the other by mixing fly ash in the OB dumps. They reported that the dumps remain stable in both conditions. Pradhan et al. (2014) also analyzed the stability of dump slope of 60 m height having an overall slope angle of 32° made up of OB dump material randomly mixed with 20% fly ash by weight and found the slope stable. Gupta and Paul (2016) conducted direct shear tests on OB dump material mixed with 10%, 20% and 30% fly ash by weight and concluded that mixing of fly ash in the range of 10% to 20% by weight improves the shear strength of the mixture. The limitations of all the above studies were the inclusion of only sand and silty fractions of OB dump material for preparing fly ash OB mixture and the use of small scale shear tests for measurement of shear strength of the mixture.

In this study, a series of compaction and large scale direct shear tests were conducted to evaluate the effect of mixing 25% fly ash by volume on the shear strength behaviour of coal mine OB dump material and the results are compared with direct shear tests conducted on OB dump material without fly ash. The effect of mixing fly ash on stability of external OB dumps were assessed with FDM based slope stability software FLAC 3D and dump angle were optimized for their safe disposal by mixing it with OB dumps.

2. Material and Methods

OB dump material and fly ash were collected from an opencast coal mine and thermal power plant respectively. The characterisation of both OB dump material and fly ash is essential for addressing various issues related with design and stability of fly ash mixed OB dumps. Geotechnical tests were performed in the laboratory to classify the investigated material as per IS standards. OB dump material was uniformly mixed with 25% fly ash by volume. Compaction and direct shear tests were conducted on both OB dump material and fly ash mixed OB dump material. Using determined shear strength parameters, stability of external dumps of OB dump material and fly ash mixed OB dump material were assessed with FDM based slope stability software FLAC 3D and the results are compared.

3. Results of Geotechnical Investigation and Discussions

The results of various tests conducted to characterize the OB dump material and fly ash is summarized in Table 1 and the results of compaction and shear test conducted on OB dump material and the same mixed with 25% fly ash by volume are presented in Table 2.

Table 1: *Summary of geotechnical properties of OB dump material and fly ash*

Properties	OB Dump Material	Fly Ash
Specific gravity	2.65	2.10
Liquid limit, %	18.60	38.6
Plastic limit	Non-plastic	Non-plastic

Point load strength index, MPa	0.4 to 1	NA
Slake durability index, %	78.06	NA
Maximum unit weight, kN/m^3	19.83	13.34
Optimum moisture content, %	9.00	25.00

The specific gravity of OB dump material and fly ash was found 2.65 and 2.10 respectively. The low values of point load strength index and slake durability index reveals that the rock fragments present in dump material are relatively weak in strength and moderately durable.

Addition of 25% fly ash by volume in the OB dump material decreases the maximum dry unit weight of the sample from 19.83 kN/m3 to 18.11 kN/m3and increases the OMC from 9% to 16%. The reduction in maximum dry unit weight with the mixing of fly ash occurs mainly due to lower specific gravity of the fly ash as compared to OB dump material and the immediate formation of hardened products which reduces the density of the treated mixture (Lees et al. 1982; Bell 1996). The other reason for reduction in maximum dry density is the cation exchange reaction. The reaction causes the flocculated and agglomerated particles to occupy larger spaces, thereby increasing the volume of voids and consequently reduces the maximum dry density of the sample. The cation exchange reaction causes an increase in the affinity of the mixture to the water required for reaction. Therefore, the OMC of fly ash mixed OB dump material sample increases with the fly ash addition.

Table 2: *Results of compaction and shear test*

Sample Name	**Maximum Dry Density (kN/m^3)**	**Optimum Moisture Content (OMC) (%)**	**Cohesion (kPa)**	**Angle of Internal Friction (°)**
OB dump material	19.83	9	18.36	29.11
Fly ash mixed OB dump material	18.11	16	83.22	17.69

Results of shear test reveals that cohesion of OB dump material increases and friction angle reduces with the mixing of fly ash. The improvement in cohesion is attributed to greater degree of void filling in between the rock particles by the fly ash and some hardening of the sample due to fly ash - water reaction. Mixing of fly ash replaces part of the coarser fragments present in the dump material and increases the percentage of fines. The fly ash gets trapped in between rock particles and reduces particle to particle contact causing decrease in its friction angle.

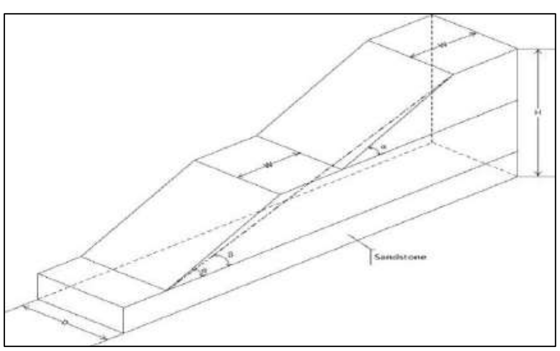
4. Stability Analysis using Numerical Modelling

Numerical modelling techniques have been widely used to assess stability of dumps. FLAC3D is a three-dimensional explicit finite-difference numerical modelling tool for engineering mechanics computation and used for solution of three-dimensional problems in geotechnical engineering. FLAC3D simulating the behaviour of three-dimensional structures built of soil, rock or other materials that undergo plastic flow when their yield limits are reached. Materials are represented by polyhedral elements within a three-dimensional grid that is adjusted by the user to fit the shape of the object to be modelled. Each element behaves according to a prescribed linear or non-linear stress/strain law in response to applied forces or boundary restraints. The material can yield and flow and the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Lagrangian calculation scheme and the mixed-discretization zoning technique used in FLAC3D ensures that plastic collapse and flow are modelled very accurately (Itasca 2005).

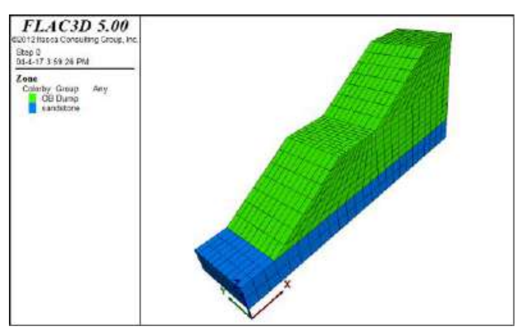
The dumps of fly ash mixed OB dump material for stability analysis were designed following the guidelines of MOEFCC. As per the guidelines, the external dumps were designed using fly ash mixed OB dump material in all the benches. The determined parameters of OB dump material and fly ash mixed with OB dump are used as input parameters for analysis.

4.1 Dump Geometry

The stability of external dump slopes was evaluated for OB dump height (H) of 60 m having two benches of 30 m high each and having berm width (W) of 30m. The stability of the dump slope with bench slope angle (α) of 30° was initially examined and then increased to 35° and 37° (angle of repose of dump material). The overall slope angle (β)for 60m high dump with berm width of 30 m was found 24.1°, 27.4° and 28.7°. Figure 1 (a) and (b) shows the geometry of a model of dump slope having a height of 60 m with two benches of 30 m height each and bench slope angle of 30°.



(a)



(b)

Figure 1 (a) & (b): *Geometrical model of OB dump (H= 60 m, α= 30°, β= 24.1°, W= 30 m and D= 40)*

The FOS, plots of shear strain rates, velocity vector distribution, displacement profile and plasticity of the dump material were used to analyze the stability condition and failure behaviour of slope.

4.2 Dumps with Overall Slope Angle of 24.1°

The plot of FOS and shear strain rate contours for OB dump is shown in Figure 2. The FOS and maximum shear strain rate values obtained are 1.54 and 6.27E-05 s-1 respectively. It is evident from the plot that both the upper and lower benches are subjected to accumulation of shear strain. The shear strain rate contour at limiting condition identifies failure surface in both benches. Plot of maximum velocity vector and displacement contour is shown in figure 3. It is evident from the plot that displacement in upper bench is comparatively higher than lower bench. Maximum displacement value obtained is 0.235 m at rear side of upper bench. To assess the overall health of the dump and to identify any distinct failure surface, plastic model of OB dump is shown in figure 4. No distinct failure surface is identified here.

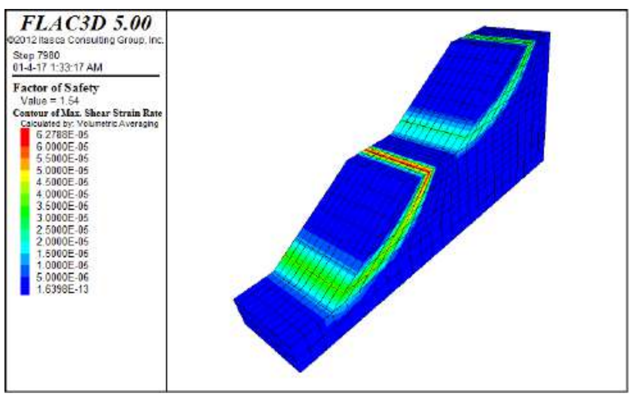


Figure 2: *FOS and Shear strain rate contours of OB dump (H= 60 m, α= 30°, β= 24.1° and W= 30 m)*

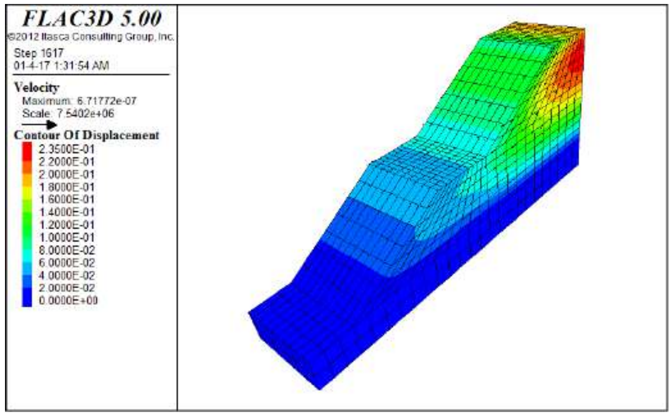


Figure 3: *Max. Displacement & displacement contours of OB dump (H= 60 m, α= 30°, β= 24.1° and W= 30 m)*

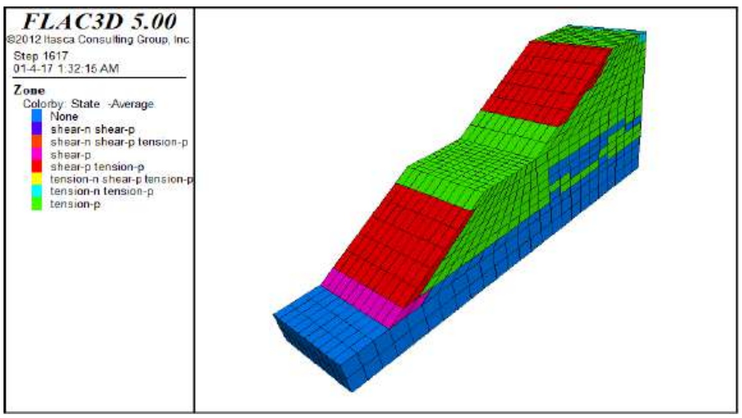


Figure 4: *Plastic model of OB dump (H= 60 m, α= 30°, β= 24.1° and W= 30 m)*

Figure 5 shows the plot of FOS and shear strain rate contours of external dumps containing 25% fly ash by volume which shows its FOS is 1.81.

As compared to OB dump, the FOS for external dump models improve significantly due to reduction in overall weight of the dump material. Even though the FOS is found higher in the external dump models, there is a clear demarcation of a semicircular shear strain zone extending from top to the bottom indicating chances of rotational failure at limiting condition. At limiting condition, cohesion and friction angle reduces to 46 KPa and 10º.

The base of the slope (near toe) is subjected to maximum shear strain concentration at shear strain rate of 2.70E-6. Maximum displacement of 0.222 m on the upper bench is found as compared to 0.235 m observed in the upper bench in case of OB dump (Figure 6). Also max. velocity vector magnitude reduces from 6.72E-7(OB dump) to 5.49E-7(OB+25% Flyash). The plasticity plot (Figure 7) shows some accumulation of tensile stress on the top rear part of the slope surface.

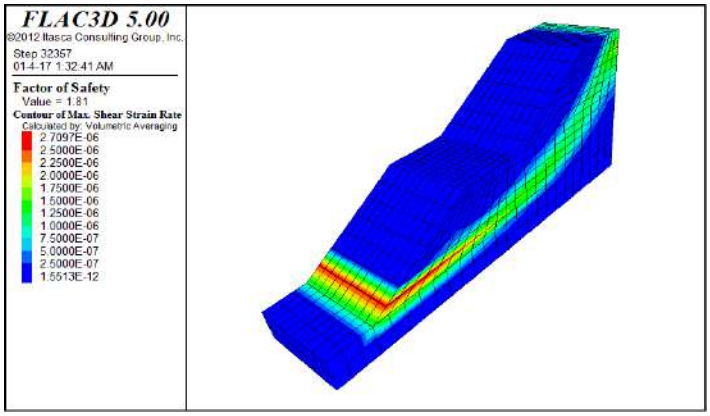


Figure 5: *FOS and Shear strain rate contours of external dump containing 25% fly ash by volume (H= 60 m, α= 30°, β= 24.1° and W= 30 m)*

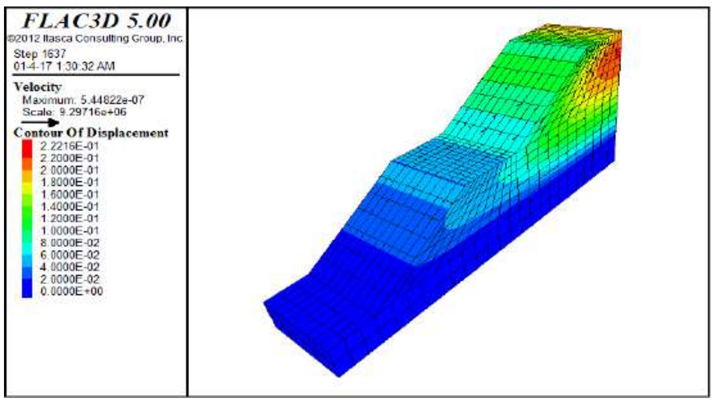


Figure 6: *Max. velocity vector& displacement contours of external dump containing 25% fly ash by volume (H= 60 m, α= 30°, β= 24.1° and W= 30 m)*

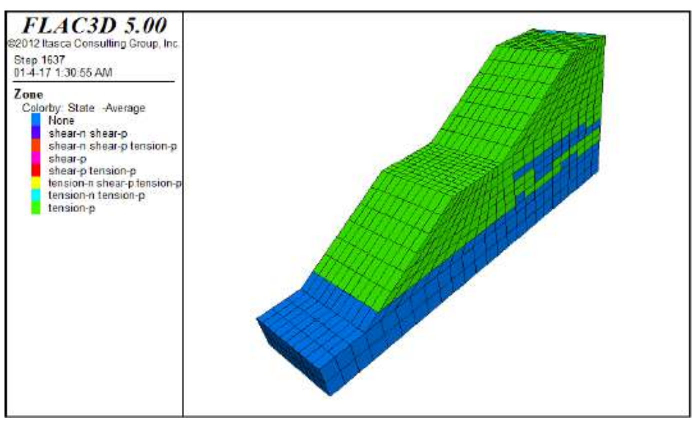


Figure 7: *Plastic model of external dump containing 25% fly ash by volume (H= 60 m, α=30°, β= 24.1° and W=30m)*

The analysis reveals the addition of fly ash improves the stability and overall health condition of slope.

4.3 Dumps with Overall Slope Angle of 27.4°

The plots of FOS and shear strain rate contours of OB dump are shown in figure 8. The FOS is found to be 1.36. Velocity vector & displacement contours and plasticity plot for the model is shown in Figure 9 and 10 respectively.

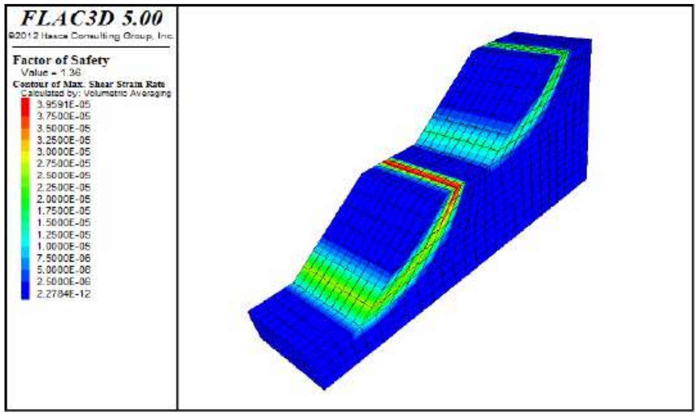


Figure 8: *FOS, Shear strain rate contours and Velocity of OB dump (H= 60 m, α= 35°, β= 27.4° and W= 30 m)*

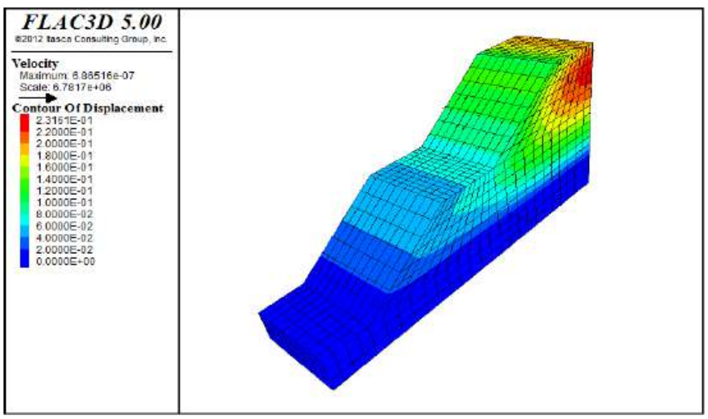


Figure 9: *Displacement contours for OB dump (H= 60 m, α= 35°, β= 27.4° and W= 30 m)*

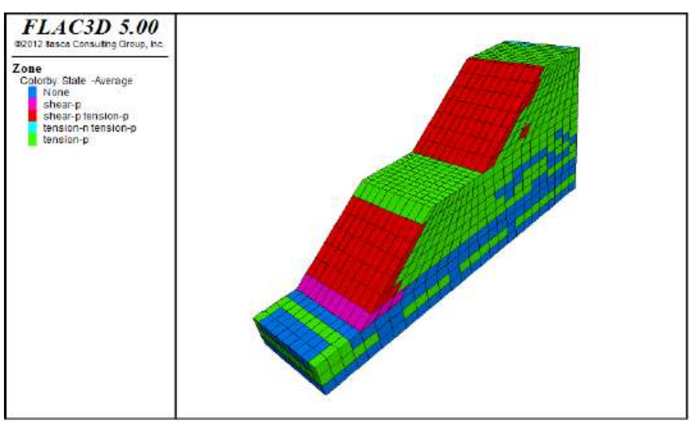


Figure 10: *Plasticity plot for OB dump (H= 60 m, α= 35°, β= 27.4° and W= 30 m)*

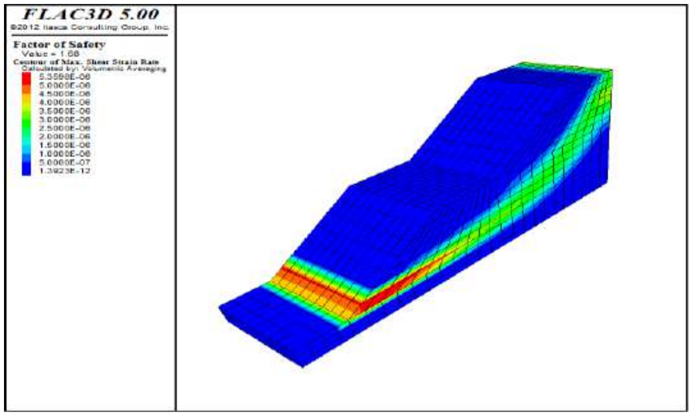


Figure 11: *FOS plot of shear strain rate contours and velocity vectors of external dump containing 25% fly ash by volume (H= 60 m, α= 35°, β= 27.4° and W= 30 m)*

The model exhibits maximum displacement of 0.231 m on the rear part of the top bench and some accumulation of tensile stress on its surface. Figure 11 shows the FOS and plot of shear strain rate contours of external dump containing 25% fly ash by volume. The FOS for external dump containing 25% fly ash by volume is found to be1.68 which is significantly higher than that of OB dump. Though the FOS is found higher in the external dump models, the plots of shear strain contours suggest that the toe portion is subjected to some accumulation of shear stresses in this region. But max. velocity vector magnitude marginally reduces from 6.86E-7(OB dump) to 6.40E-7(OB+25% Fly ash). Maximum displacement value obtained for the model is 0.219m (Figure 12). The plot of plasticity is observed for external dump model containing 25% fly ash by volume to assess the overall health of the dump (Figure13). The plasticity plot exhibits some accumulation of tensile stress on the top surface of both upper and lower bench surface.

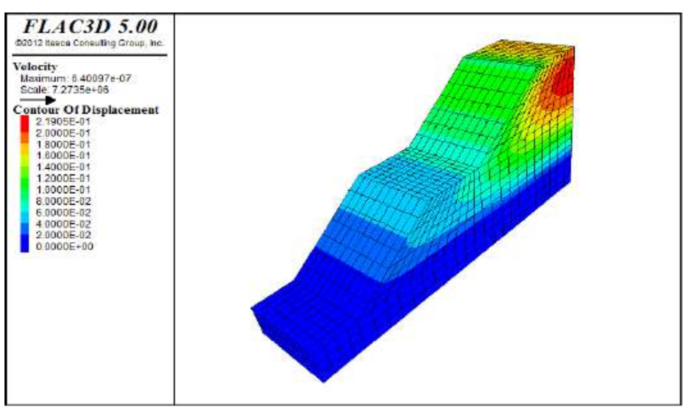


Figure12: *Displacement contours for external dump containing 25% fly ash by volume (H= 60 m, α= 35°, β= 27.4° and W= 30 m)*

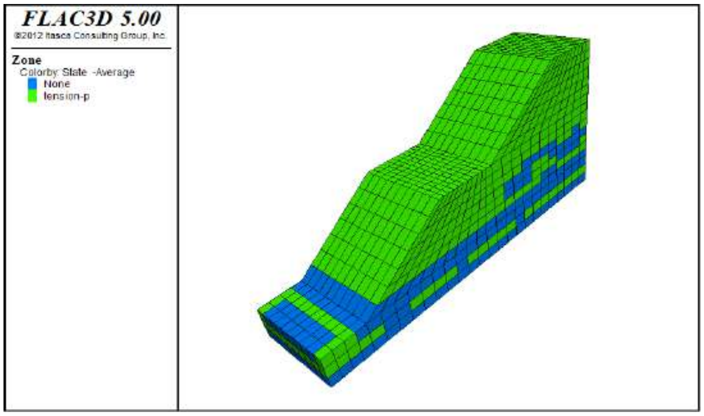


Figure13: *Plasticity plot for external dump containing 25% fly ash by volume (H= 60 m, α= 35°, β= 27.4° and W= 30 m). The analysis reveals the addition of fly ash improves the stability of overall health condition of slope.*

4.4. Dumps with Overall Slope Angle of 28.7°

The plots of FOS and shear strain rate contours for models of OB dump are shown in figure 14. The FOS is found to be 1.27. The velocity and displacement contour plots for the model is shown in figure 15. The plasticity plot shown in figure 16 exhibits that the face of the slope has resulted in some plastic deformation. Figure 17 shows the plot of FOS and shear strain rate contours of external dump containing 25% fly ash by volume. The FOS for external dump containing 25% fly ash by volume is found 1.61 which is significantly higher than that of models of OB dump. A significant reduction is observed in max. shear strain rate with the addition of fly ash. It reduces from 3.54E-5(OB dump) to 6.13E-7 (OB+25% fly ash) indicating improvement in the stability condition of the dump. The velocity and displacement contour plots for the model is shown in figure 18 indicating maximum displacement of 0.20 m in the top rear part of upper bench. Plasticity plot (Figure19) for external dump model containing 25% fly ash by volume identifies some accumulation of tensile stress.

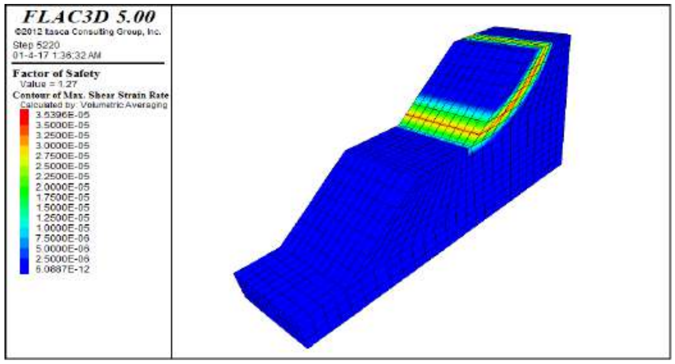


Figure 14: *FOS and Shear strain rate contours of OB dump (H= 60 m, α= 37°, β= 28.7° and W= 30 m)*

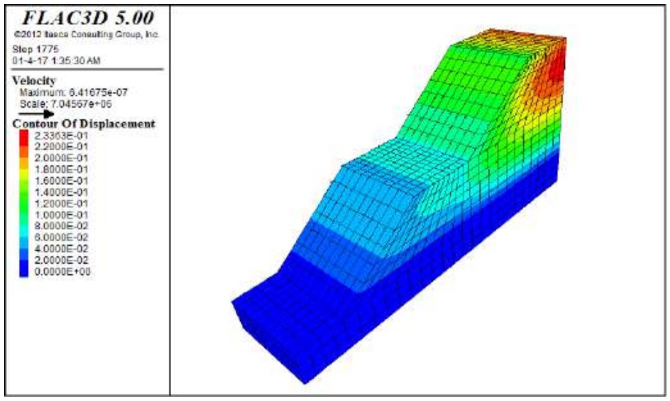


Figure 15: *Max. velocity vector & displacement contours of OB dump (H= 60 m, α= 37°, β= 28.7° and W= 30 m)*

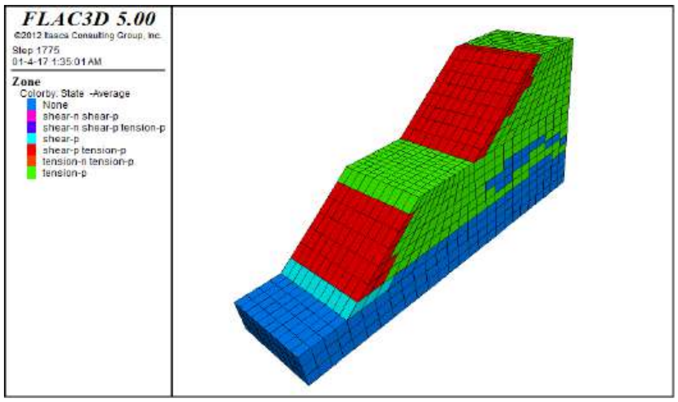


Figure 16: *Plastic model of OB dump (H= 60 m, α= 37°, β= 28.7° and W= 30 m)*

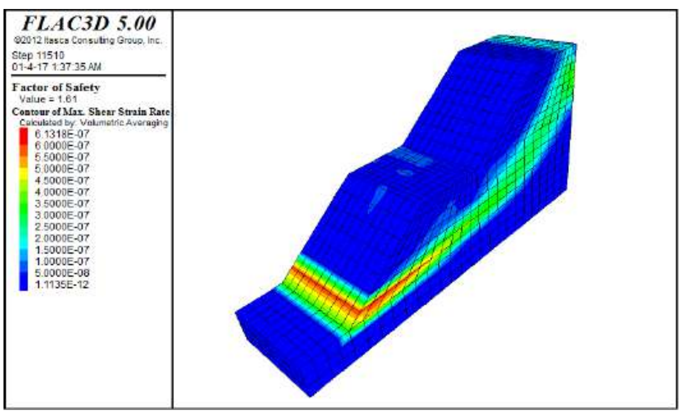


Figure 17: *FOS and Shear strain rate contours of external dump containing 25% fly ash by volume*
(H= 60 m, α= 37°, β= 28.7° and W= 30 m)

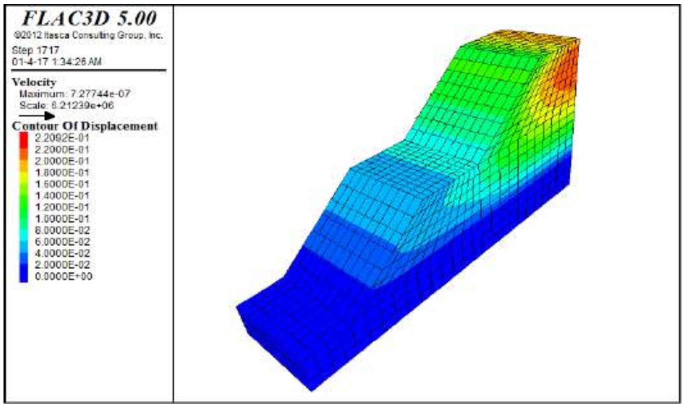


Figure 18: *Max. velocity vector & displacement contours of external dump containing 25% fly ash by volume (H= 60 m, α= 37°, β= 28.7° and W= 30 m)*

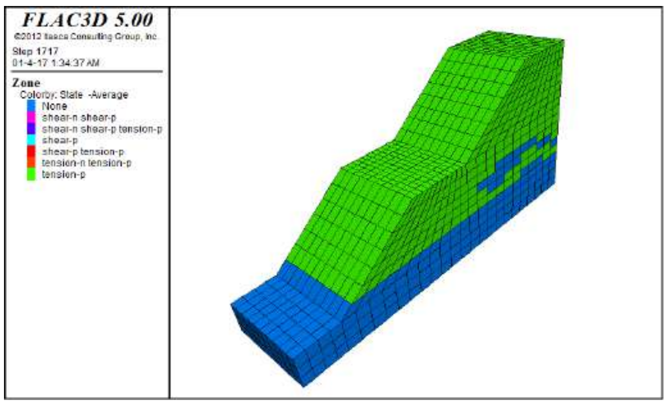


Figure 19: *Plastic model of external dump containing 25% fly ash by volume (H= 60 m, α=37°, β=28.7° and W=30 m)*

The analysis reveals that the addition of fly ash slightly improves the stability and overall health condition of slope.

When the uncertainty and the consequences of failure are both small, it is acceptable to use small factor of safety, of the order of 1.3 or even smaller in some circumstances. However, when the uncertainties or the consequences of failure increase, larger factor of safety is necessary. If the failure occurs due to some other triggering mechanism like excessive rain fall or heavy production blasting near such dumps or due to seismic forces, a large volume of material will slide up to a large distance and it can affect the men and machines as well as any important mine structures lying nearby. In addition, some fly ash particles may also wash out in case of heavy rains and can reduce the cohesion; hence it is not advisable to build external dump slopes using fly ash at steeper angles for which FOS is less than 1.5. Hence the simulation is stopped at this overall slope angle.

4.5 Variation of Factor of Safety with Overall Slope Angle

Figure 20 shows the variation in FOS of OB dumps and fly ash mixed OB dumps with the increase in overall slope angle. The plot indicates that w FOS decreases with the increase in overall slope angle for both OB dump and fly ash mixed OB dumps. However, FOS increases by approx. 20% when OB dump is mixed with 25% fly ash by volume.

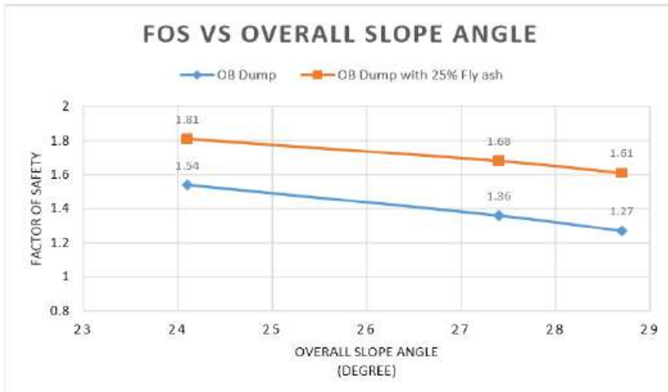


Figure 20: *Variation of FOS with Overall Slope Angle*

5. Conclusions

The investigations and numerical analysis conducted in this work lead to the following main conclusions:

- Mixing of fly ash causes decrease in maximum dry unit weight of OB dump material and increase in its OMC.
- With the addition of fly ash in the OB dump material, cohesion improves and friction angle reduces.
- Mixing of fly ash in the OB dump material marginally improves the stability of external OB dumps. Disposal of fly ash can be safely carried out by mixing it with OB dumps of 60 m high having an overall slope angle ranging between 24° and 28°.

The study conducted provides very useful information about the compaction and shear strength behaviour of fly ash mixed coal mine OB dump material. The findings of these investigations contribute new knowledge in this area and this will help the dump designer in designing a stable fly ash mixed OB dumps in open cast coal mines. It will also build up confidence among mine operators to dispose fly ash by mixing it with the OB dumps. One of the potential large volume disposal techniques for the huge quantities of fly ash generated in the country is to utilize the material as a fill material in the abandoned or in active opencast coal mines. It is the best alternative in the philosophy of putting back from where it has been taken out and is an enviro-friendly, clean and green method of disposal.

6. Limitations and Scope for Future Work

The study is conducted on the OB dump material and flies ash collected from a particular site. The characteristics of OB dump material and fly ash are site specific and may vary from site to site. Hence the factual data, interpretations and recommendations pertaining to the study will hold good only for the fly ash and OB dump material having similar characteristics. For designing of fly ash mixed OB dumps, it is recommended to characterize both OB dump material and fly ash and accurate shear strength parameters should be determined by conducting shear test on the mixture. This study is confined on homogenous mixture of fly ash mixed OB dump material containing 20% and 25% fly ash by volume. Similar study can be undertaken by laying fly ash in to alternate layers with OB dump material. . Shear strength parameters used for stability analysis are based on laboratory tests. For precise determination of shear strength parameters of fly ash mixed OB dumps, one may extend this work by conducting in situ shear tests.

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