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Design of embankment for high concentration ash slurry filling in opencast mines – a case study

Disposal of coal ash on surface comes as a part and package for meeting the society needs for thermal power. The conventional method of disposing it in ash ponds leads to requirement of more than 3 lakh acres of valuable land for its construction and can have damaging consequences with respect to water, air and land pollution. Hence, the need of the hour is to utilize this ash in an environment friendly manner. This paper throws light on the scheme for high concentration slurry disposal of ash in abandoned portion of the mine and design of embankment to contain it against the highwall. Two most common method for embankment construction, viz. upstream and downstream was modelled to evaluate its factor of safety with the help of PLAXIS software. Downstream method of embankment construction showed promising results and was selected for further analysis. Numerical simulation was carried out with downstream mode of construction in drained condition with and without the incorporation of vertical and horizontal drains. The embankment with drains exhibited higher safety factor which decreased when the embankment was raised. The construction scheme involves raising of embankment with slope angle of 27^0 in eight stages of ten meters height each and filling it with high concentration ash in layers. In the final stage, the top soil of 5m thick is proposed to be spread for revegetation.

1.0 Introduction

In India, presently there are about 145 thermal power plants with an installed capacity of 1, 38,915 MW consuming about 550 Mt of coal and generating 184 Mt of ash per annum [1]. Over 100,000 MW additional generation capacity needs to be added in the next ten years to bridge the gap between demand and supply of power. With this anticipated growth in the generation of thermal power, the demand for coal and hence the generation of ash will increase simultaneously. Despite of rigorous efforts by Government of India through mission mode activities and notifications of MoEF (14th Sept. 1999, 27th Aug. 2003 and 3rd Nov. 2009) floated and amended from time to time, the desired target of 100% ash utilization by the year 2014 could not be achieved. The current utilization of ash in India is about 58% which is lesser than China (67%), Japan (96%) and Europe (91%) [2]. Coal ash is mainly utilized in agriculture, cement, concrete, reclamation, mine filling etc. and the contribution of mine filling towards ash utilization is mere 13% [1]. The option of large scale environment friendly utilization of ash in opencast mine as high concentration slurry fill can lead to a quantum jump to achieve the set target.

In this paper an attempt has been made to device a scheme for construction of embankment to facilitate ash disposal at high concentration in de-coaled portion of Gare IV/I mine at Tamnar, Chhattisgarh. This mine is located between longitudes 83°31'50" and 83°33'49" and latitudes 22°05'37" and 22°07'44. The coal seam at sub-block IV/1 belongs to the Barakar formation and has a general strike of the beds is North-West 30^0 to 55^0 to South-East 30^0 to 55^0 dipping towards south-west at an angle of 3^0 to 4^0. There are six coal seams of varying thickness from 3 to 8 m and of which, seam no VIII and IX are exposed in this block. The general lithology of the area is shown in Table 1. This opencast mine is divided into two pits, in Pit - I complete extraction of coal had been done with a depth of 80-85m. Out of the two location options for proposed erection of embankment at Pit-I as shown in Fig.1, the location across section B-B' was selected as it offered larger area and ideals with high wall at the dip side and with one sidewall along the strike.

2.0 Methodology

Different samples of pond ash (PA) and overburden (OB) soil were collected from the mine site and were subjected to various physico-mechanical tests in the laboratory. The studies included determination of specific gravity, bulk density, porosity, grain size distribution, permeability,

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Table 1: General lithology of the area

Seam/ parting	Variation in thickness (m)	Grade/formations
X	0.53-2.73	G
Parting	3.72-9.17	Fine-coarse SS and shale
XA	0.91-3.17	G
Parting	34.02-48.60	Fine-medium SS and shale
IX	2.51-9.00	F
Parting	1.09-8.12	Fine-medium SS and shale
VIII	0.58-5.64	G
Parting	2.00-12.11	Fine-medium SS and shale
VII top	0.34-4.99	G
Parting	1.14-6.16	Fine-medium SS and shale
VII bottom	0.16-2.74	G

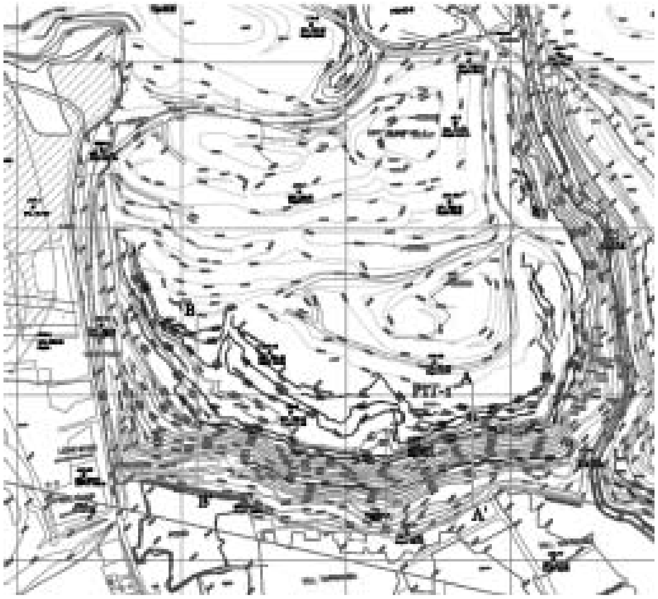

Fig.1 Part plan of Gare IV/I mine showing section B-B' across which the embankment is proposed

compaction characteristics, shear strengthand Atterburg's limits test. Different configuration of embankment construction viz. upstream method, downstream method and centreline method is well-known to us, out of these, downstream method (as shown in Fig.2.) for embankment construction was selected for stability analysis as it is most stable under dynamic loading. Downstream embankment starts with a pervious (free draining) starter dyke foundation and the high concentration ash slurry would be deposited behind the dyke and subsequent dyke raising is carried out in stages on the downstream side, so that the embankment crest is shifted towards downstream. This method also offers advantages like enhanced stability, control of placement and compaction as required over the entire filling operation.

Stability analysis of embankment was carried out by finite element numerical simulation using PLAXIS software to find out its factor of safety (FOS). The data required to be fed into finite element models were determined during laboratory studies as mentioned above.

3.0 Results and discussion

The specific gravity and bulk density of PA was found to be 2.24 and 1.08 t/m^3 and that of OB material was found to be 2.50 and 1.6 t/m^3 respectively. The result indicated that the OB material is much denser and heavier than PA. From the results of grain size distribution it was found out that PA and OB material have an average grain size (D_{50}) of 110 µm and 450 µm respectively.

The porosity of PA was found to be 51.79% whereas that of OB material was found out to be 36%, this may be attributed to the fact that PA is more uniformly graded as shown in the Fig.3. The permeability of PA was found to be 10.5 cm/hr and of OB material was found to be 13.76 cm/hr as measured by constant head permiameter. Low infiltration rate of water in the ash can be due to hydration of calcium in the ash when in contact with water, which leads to change in its porosity. The direct shear test on OB sample indicated an average cohesion value of 0.012 kg/cm^2 and an angle of internal friction of 28^0 as shown in Fig.4 whereas that of PA material was found out to be 0.12 kg/cm^2 and 19.7^0 respectively. Consistency limits or Atterberg's limit test designed by Casagrande [3] on PA and OB material were

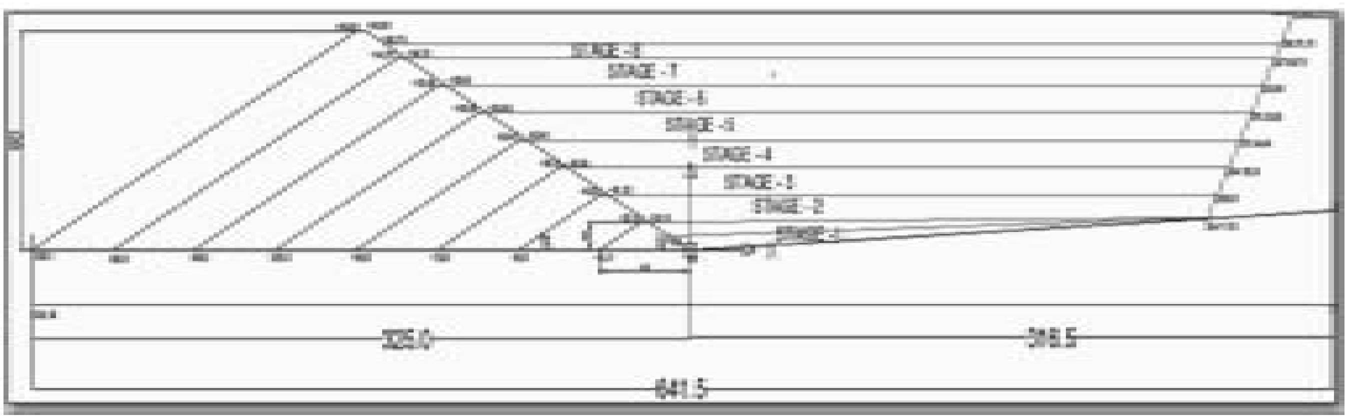

Fig.2 Downstream embankment construction method

carried out in the laboratory to determine its plastic properties and was found that both material were non-plastic in nature. Standard Procter Test [4] was carried out in the laboratory to determine the compaction characteristics.

It was observed that the maximum dry density (MDD) of 1.242 g/cc by PA is reached at optimum moisture content (OMC) of 23.25% and for OB material the MDD of 1.83g/cc is reached at 14.73% OMC.

The results of laboratory studies were fed in the numerical modelling software (PLAXIS) and the stability of downstream embankment was carried out both in drained and undrained conditions. The space available for constructing the embankment along section B- B' was calculated and a realistic geometry of the same was fed into the model. The slope angle of the embankment was kept at 27^0 and it was raised in stages of 10m up to a height of 80 m in eight stages. Immediate floor of sandstone up to a depth of 20 m and water table at 2.5 m below the mine floor was also incorporated in the model. The slope angle of highwall was kept at 60^0 and vertical drains were places at an interval of 20m from each other and the horizontal drains at the centre of each stage to facilitate pore water dissipation as shown in Fig.8. The volume of void, time to fill each stage was calculated at an assumed filling rate,

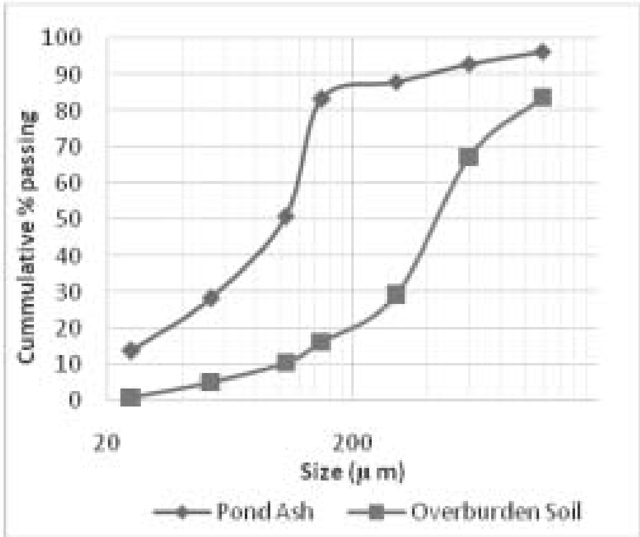

Fig.3 Grain size distribution of OB and PA

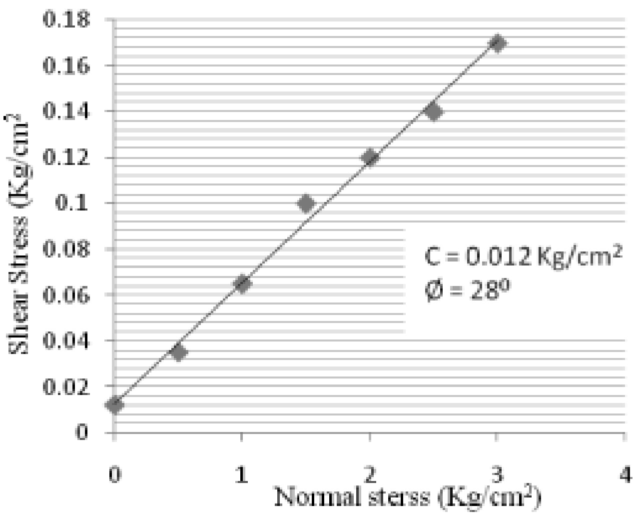

Fig.4 Shear strength test on OB sample

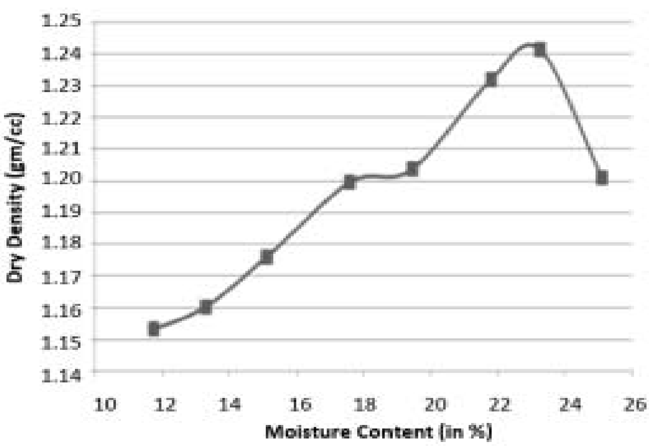

Fig.5 Dry density vs water content of PA

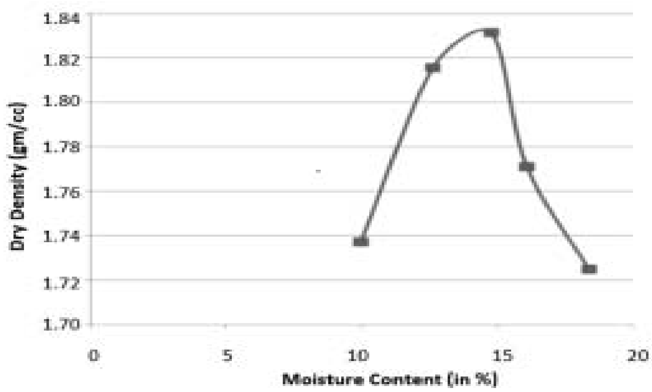

Fig.6 Dry density vs water content of OB

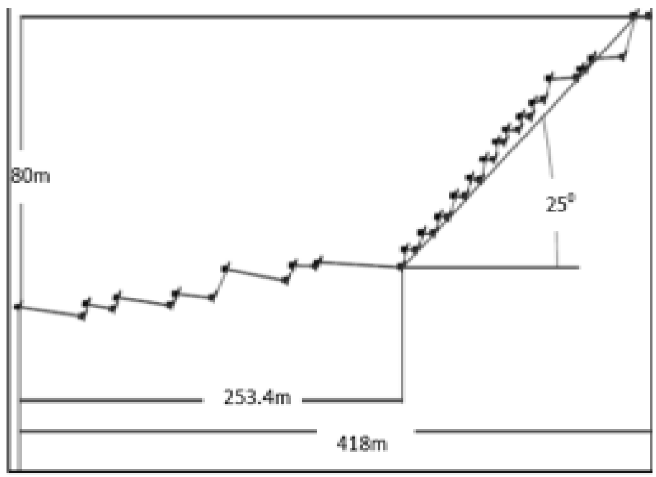

Fig.7 Section along B-B' at Gare IV/I

concentration and working hours. In the pre-processing stage of PLAXIS, boundary conditions, time required to fill each stage, time available for consolidation of fill and embankment was incorporated in the model. During calculation stage, analysis type is chosen such as plastic, dynamic, consolidation and phi-c reduction. The loads of different stage of filling and embankment raising are activated step wise as per construction schedule. In the post processing stage, curves are plotted between various calculated parameters such as load vs displacement. In PLAXIS phi-c reduction method is used to compute FOS for embankment stability.The total multiplier ΣMsf is used to define the value of the embankment strength parameters at a given stage in the analysis. This parameter is increased in a step-by-step procedure until failure occurs.

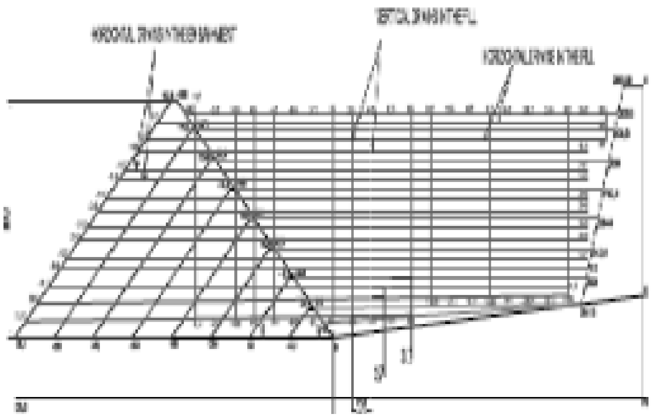

Fig.8 Vertical and horizontal drains in embankment

$$\frac{c}{c_r} = \frac{\tan\varphi}{\tan\varphi_r} = \Sigma Msf$$

where,

c and φ – input strength parameters,

c_r and φ_r – residual strength parameters

Analysis of FOS of embankment was done both with and without drains, the results of modelling without drains are shown in Fig.9.

During drained analysis, it was observed that maximum compressive stress was developed below the embankment and at the toe of the highwall. The top portion of the fill mass experiences a tensile stress and excess pore pressure was found to be concentrated at the centre of embankment filled with PA slurry. Excess pore pressure is mainly attributed to the fact that there are no drainage pipes incorporated in this model run.

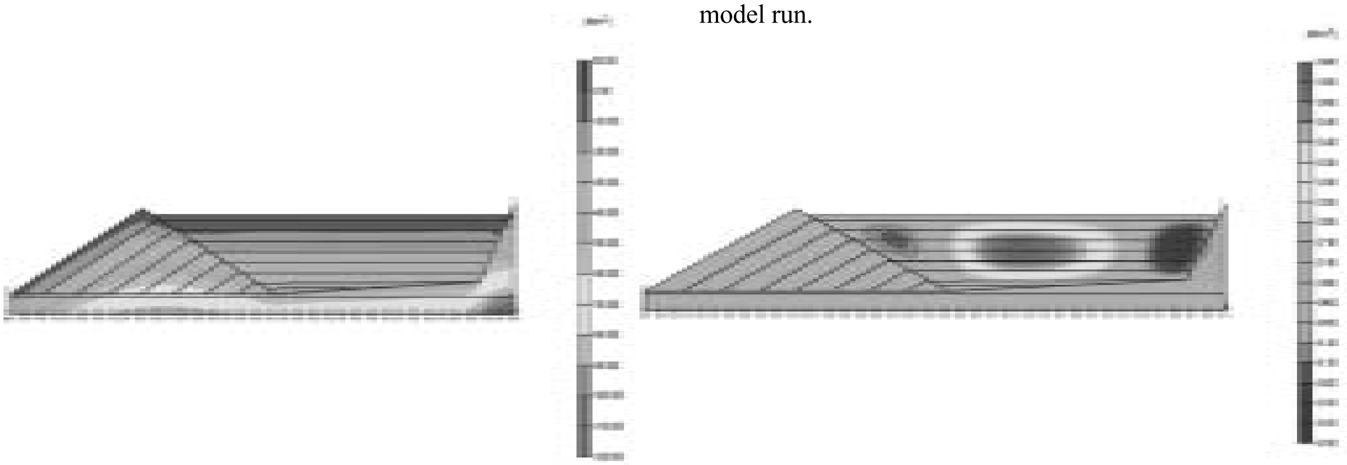

Fig.9 Effective mean stress and excess pore water pressure in drained state without drains

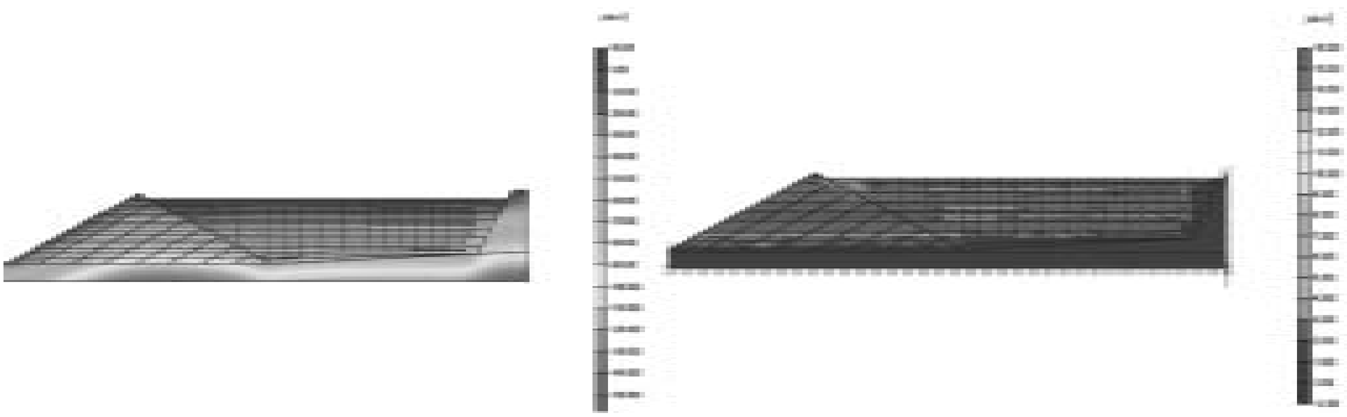

Fig.10 Effective mean stress and excess pore water pressure in drained state with drains

During drained analysis of embankment with horizontal and vertical drains as shown in Fig.10, it was found out that maximum compressive stress was developed at the base of embankment and toe of highwall, but no excessive pore water pressure developed within the fill mass. This suggests that drainage pipes facilitated dissipation of excess pore water pressure. FOS at different stages of filling and embankment raising was also evaluated for design with and without drains, the results are shown in the Table 2

TABLE 2: FOS OF DIFFERENT STAGES OF CONSTRUCTION OF EMBANKMENT BY DOWNSTREAM METHOD

Construction stage	FOS by downstream method	
	Without drains	With drains
1st stage	1.481	2.37
2nd stage	1.303	1.58
3rd stage	1.279	1.56
4th stage	1.246	1.408
5th stage	1.259	1.407
6th stage	1.217	1.387
7th stage	1.196	1.333

The FOS obtained from numerical modelling indicated that the embankment was stable up to 7th stage of construction viz. up to a height of 70m, beyond that the deformed mesh of the model indicates collapse at the top edge.

4.0 Conclusion

The laboratory and numerical analysis indicate that PA can be safely deposed at high concentration in the worked out part of Gare IV/I opencast mines. Downstream method of embankment construction was found to be suitable for containing the high concentration ash fill. However, it is recommended that the height of the embankment should not be raised beyond 70m and both horizontal and vertical drains should be incorporated in the design. It is also recommended that regular monitoring of the embankment and filling process should be carried out during

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