INFLUENCE OF ENGINEERING BEHAVIOUR OF COAL ASH ON DESIGN OF ASH DYKES

Aali Pant
Manoj Datta
Venkata Ramana Gunturi
Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi – 110 016.
aali.pant@gmail.com; mdatta@civil.iitd.ac.in; ramana@civil.iitd.ac.in

ABSTRACT: Currently nearly 170 million tonnes of coal ash is generated annually in India from 85 thermal power plants and because of the limited availability of land, vertical expansions of ash dykes are unavoidable. The present paper compares the variability in engineering behaviour of coal ash from two different thermal power plants (TPP) A & B and highlights the influence of the variability in coarse particle content on design of ash dykes. Using the geotechnical properties of compacted ash as well as hydraulically deposited ash, ash-dyke sections have been designed and a series of stability runs are carried out to map the factor of safety at various stages of ash-dyke raising. The results indicate that slopes of ash dykes have to be made flatter as bottom ash content decreases in pond ash due to increased utilization or separate storage of bottom ash.

Keywords: Ash dyke, Slope Stability, Upstream method

1 INTRODUCTION

Indian coal is of low grade having high ash content of the order of 30 - 45% generating large quantity of coal ash at coal based thermal power stations in the country. At present nearly 184.14 million tons of coal ash is being generated annually in India and more than 70000 acres of land is presently occupied by ash ponds. Similar trends can also be observed in many other developing countries. Although the scope for use of coal ash in cement, concrete, brick making, soil-stabilization treatment and other applications has been well recognized [Ahmaruzzaman, 2010; Naganathan et al., 2015] and the utilization of coal ash has increased from 6.64 million ton in 1996-97 to a level of 102.54 million-ton in 2014-15 [CEA, 2015], but till date huge quantities of coal ash have to be disposed off suitably on land by creating engineered ash pond to take care of environmental concerns.

This disposal problem can be minimized by utilizing ash in large earthworks for geotechnical applications like construction of highways, embankments and filling low lying areas, and by reclaiming old abandoned ash ponds for constructing parks, parking areas and low weight structures. However, increasing use of ash in geotechnical engineering applications requires detailed understanding of its engineering behaviour.

Due to limited availability of land, the ash pond dykes are raised in stages once it is filled with ash to take care of further quantities of generated ash. Apart from the drainage facilities, the shear strength characteristics and compacted density of the coal ash used as construction material for raising of dyke plays an equally important role in stability of the raised dyke.

2 OBJECTIVE & SCOPE

The present paper compares the variability in engineering behavior of coal ash from two different thermal power stations (TPP) A and B & highlights the influence of the variability on design of ash dykes.

Experimental investigations have been carried out on representative ash samples from TPP-A and TPP-B. Influence of grain size variation in the shear strength parameters and the compaction characteristics of the samples are studied from laboratory results.

Using the geotechnical properties of compacted ash as well as hydraulically deposited ash, a four stage ash-dyke section has been analyzed. Slope stability in steady state seepage condition with water inside the pond up to full height of the hydraulically deposited ash has been carried out. A series of stability runs are carried out for static and seismic condition to check for the impact of shear strength on the downstream slope of incrementally raised dykes.

3 VARIABILITY IN COAL ASH

Coal ash produced in a thermal power plant is basically of two types: bottom ash and fly ash. Bottom ash is the coarser ash which is collected from the bottom of a furnace, after being ground in a clinker grinding unit. Fly ash is the finer ash which is collected from hoppers beneath electrostatic precipitators (ESPs). The ratio of bottom ash to fly ash production in thermal plants is approximately 20:80 [ACAA, 2001].

Conventionally the unutilized volumes of ash (both bottom ash and fly ash) are mixed with large amounts of water and then disposed onto the ash ponds, which have already occupied 65,000 acres of valuable land in India [Parswal et al., 2003] and many million acres of land all over the world. This ash is referred to as pond ash. It is the ash stored in ash ponds deposited by hydraulic fill method. In the ash ponds spatial variation of the pond ash characteristics can be observed. Near the slurry inflow point, the ash is predominantly sand sized while near the decant pond zone the ash is predominantly silt sized [Skarzynska et al., 1989; Datta et al., 1996].

4 DESIGN ISSUE

The coal ash from the filled ash ponds is generally used as construction material in the raising of dyke by upstream method in order to save the borrow material and its transportation cost from the borrow site. The raising of dyke at one time may vary from 3 to 5 m and the final total height may reach upto 20-25 m.

Bottom ash is the coarser ash that is being widely used by the construction industry. The amount of bottom ash discharged into the ash pond is thereby reducing. At many thermal plants in India separate lagoons have been constructed for storage of bottom ash and fly ash.

At present, in the ash ponds at some sites 20% bottom ash is present in pond ash, while at other places its amount is less than 10% and even nil at other locations. Thus most of the ash deposited in the lagoons is of fine sized (silt size). In this paper the issue of stability of slopes with reference to the variability of ash deposited in pond has been addressed.

5 EXPERIMENTAL INVESTIGATION

Ash samples collected from the ash ponds of two different thermal power plants (TPP) in India: TPP-A and TPP-B, were considered for the investigations to study their variability in engineering behaviour. In addition, one more set of samples, without bottom ash were obtained from TPP-B which will be referred to as TPP-B(F).

Representative ash samples were tested for complete geotechnical characterization. All the ash samples are non-plastic in nature. Specific gravity values of ash from TPP-A, TPP-B and TPP-B(F) were 2.29, 2.24 and 2.22 respectively. It can be observed that the specific gravity values of all the three ash samples are considerably lower than that of the natural soils (e.g. Yamuna sand). Nature of particles and their grain size distribution were studied for all the materials. Both sieve analysis and hydrometer analysis were performed.

The pond ash samples from TPP-A have higher sand content (50-55 %) and can be classified as silty sand. On the other hand, pond ash samples from TPP-B have predominantly silt content (10-15 % sand content) and can be classified as sandy silt. Since TPP-B(F) does not have bottom ash mixed in it and hence has only 5-10% sand content in it.

Table 1. Engineering Properties of Ash Samples

Property	TPP-A	TPP-B	TPP-B(F)
Sand size (4.75-0.075 mm), %	52.5	10.27	5.87
Silt size (0.075-0.002 mm), %	45.3	84.86	80.43
Clay size (<0.002 mm), %	0.9	4.86	13.7
MDD (Std. Proctor), kN/m^3	12.7	12.6	11.9
OMC, %	27.5	26.9	30.2
MDD (Vibratory), kN/m^3	12.6	11.9	10.7
Minimum dry density, kN/m^3	8.4	8.1	8.0

Compaction characteristics of the ash samples have been studied using standard Proctor and vibratory table tests as per the Indian standard specifications. The results of grain size distribution and compaction test are reported in Table 1.

Table 2. Material Properties used in Stability Analysis

Materials		Total Unit Weight, (kN/m^3)	c' kPa	φ', degree
Foundation Soil		20.00	10	31
Starter Dyke (Local Soil)		19.00	9	28
TPP-A	C*	16.20	0	39
	HD**	13.7	0	29
TPP-B	C*	16.00	0	34
	HD**	13.50	0	28
TPP-B(F)	C*	15.50	0	30
	HD**	13.3	0	27

*Compacted ash (at OMC).

**Hydraulically Deposited ash; fully saturated.

Effective-stress strength parameters c' and ϕ' of the ash samples were evaluated by performing direct shear tests on saturated samples in the loose and dense state. Loose samples were prepared by slow pouring and then saturating while dense samples were prepared by rodding and tamping and then saturating. The local soil is saturated silty clay and the soil parameters have been obtained from the site investigation report. Table 2 shows the material properties used for the stability analysis.

6 UPSTREAM RAISING OF ASH DYKES

Dykes of ash pond are raised by upstream method to take the volumes of further ash in stages. Since the pond ash is abundantly available on the construction site itself, it is the economical choice to use the ash as construction material for raising the ash dyke embankment. Top cover of natural earth are provided to take care of erosion and gully formation For analysis purpose, a four-stage dyke raising was considered by upstream method on the starter dyke. Following are the salient features of the ash dykes:

The downstream slope of the starter dyke has an inclination of 2.5H: 1V.
The downstream slope of all the four raising has equal inclination. For each of the ash type, stability has been analyzed for 3 cases characterized by different slopes of the ash dyke raisings:

- Case 1: Inclination of the four ash dyke raising is 3H:1V.
- Case 2: Inclination of the four ash dyke raising is 2.5H:1V.
- Case 3: Inclination of the four ash dyke raising is 2H:1V.

The starter dyke and each raising is 5m high making the total height of ash dyke 25m above ground level. The crest width of each raising is of 6m. One more set of stability analysis has been done with crest width of 3m.

7 RESULTS OF STABILITY ANALYSIS

Slope stability analysis was performed for both static and seismic conditions (Zone III) using GEOSLOPE version Slope/W 2007. The design values of horizontal seismic coefficient and vertical seismic coefficient have been calculated using seismic coefficient method and taken as 0.12 and 0.06 respectively. The minimum acceptable factor of safety (FOS) for steady state seepage condition in static and with seismic loading condition are kept 1.5 and 1.0 respectively.

The FOS obtained for the different ash samples are listed in Table 3 to 6. As observed, FOS increases with increase in the shear strength parameter of the ash raising for both static and seismic condition. As the percentage of coarser particles reduce, the raisings get restricted to have a flatter slope. As the slopes become steeper, slopes made of coal ash with higher shear strength remain stable. (FOS_{static}>1.5 & $FOS_{seismic}$ >1.0).

Table 3. FOS in Static Condition (crest width =6m)

Case	Average Slope	Ash Type		
		TPP-A	TPP-B	TPP-B(F)
Case 1 (3H:1V)	4.7H:1V	1.871	1.768	1.651
Case 2 (2.5H:1V)	4H:1V	1.628	1.549	1.455
Case 3 (2H:1V)	3.7H:1V	1.484	1.391	1.191

Table 4. FOS in Seismic Condition (crest width =6m)

Case	Average Slope	Ash Type		
		TPP-A	TPP-B	TPP-B(F)
Case 1 (3H:1V)	4.7H:1V	1.144	1.082	1.013
Case 2 (2.5H:1V)	4H:1V	1.064	1.009	0.946
Case 3 (2H:1V)	3.7H:1V	1.006	0.958	0.902

Table 5. FOS in Static Condition (crest width =3m)

Case	Average Slope	Ash Type		
		TPP-A	TPP-B	TPP-B(F)
Case 1 (3H:1V)	4H:1V	1.605	1.512	1.409
Case 2 (2.5H:1V)	3.5H:1V	1.352	1.276	1.189
Case 3 (2H:1V)	3H:1V	1.229	1.155	1.075

Table 6. FOS in Seismic Condition (crest width =3m)

Case	Average Slope	Ash Type		
		TPP-A	TPP-B	TPP-B(F)
Case 1 (3H:1V)	4H:1V	1.041	0.989	0.923
Case 2 (2.5H:1V)	3.5H:1V	0.933	0.882	0.823
Case 3 (2H:1V)	3H:1V	0.883	0.835	0.776

With crest width of 6m (Tables 3 and 4), dykes constructed by either of the three ash samples remain stable when the downstream slope of the ash dyke is 3H: 1V (average slope of 4.7H:1V). As the downstream slope become steep, 2.5H:1V, ash dyke constructed using fly ash, TPP-B(F), become susceptible to failure with FOS of less than 1.5. Thus it is not advisable to construct ash dyke raising with fly ash or pond ash of equivalent shear strength parameters with a slope of 2.5H: 1V. For much steeper slope i.e. 2H: 1V, ash dyke constructed using any of the three ash samples does not remain stable in static steady state seepage condition (FOS of 1.484, 1.39, 1.19).

With crest width of 3m (Tables 5 and 6), the average slope of the ash dyke becomes steep. For 3m of crest width, dykes constructed by fine ash (TPP-B(F)) fails for all the cases analyzed. The ash dyke constructed with ash from TPP-A & TPP-B remains stable when the downstream slope of the ash dyke is 3H: 1V (average slope of 4H:1V). As the downstream slope become steep, 2.5H:1V, ash dyke constructed using either of the ash samples become susceptible to failure with FOS of less than 1.5.

Increasing the crest width reduces the average slope of a dyke. As seen in Table 5 & 6, with crest width of 3m, the average slope of the dyke increases. Hence, only those raising constructed of ash TPP-A and TPP-B, remain stable for static steady state seepage condition when the downstream slope of the ash dyke is 3H:1V (average slope of 4H:1V). In all the other cases the raisings are unstable in static as well as seismic condition.

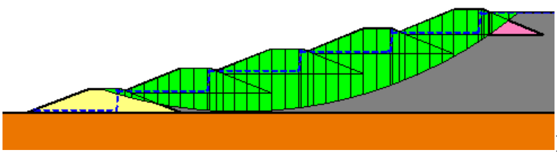

Figure 1. Critical failure surface of TPP-A ash dyke for berm width of 6m; FOS 1.628 (Case 2)

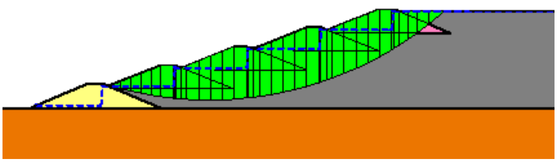

Figure 2. Critical failure surface of TPP-A ash dyke for berm width of 3m; FOS 1.352 (Case 2)

Typical failure surfaces can be seen for static condition for the TPP-A coal ash in Figures 1 & 2. It is noted that critical failure surfaces for all results of stability analysis look similar with almost the entire failure surface passing through the underlying hydraulically deposited ash which has lower strength than the compacted ash in the incrementally raised dykes.

8 CONCLUSIONS

At a time when the riverbed sand is getting scarce and expensive, use of bottom ash as a substitute for sand encourages sustainable development. As the utilization of bottom ash in construction industry is gaining acceptance, the coarse fraction in the pond ash is decreasing.

Strength parameters are largely influenced by the percentage of coarse ash particles. From the experimental investigation it is evident that as the percentage of bottom ash decreases in pond ash, the strength parameters of pond ash reduce. Thus, with reduced coarse fraction, slopes of the dyke raisings cannot be as steep as with pond ash containing 20% bottom ash particles. Also it can be concluded that larger berm widths are required in order to achieve stability of dykes constructed on ash having lower percentage of coarse fraction.

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