Study of Slope Stability of Ash Dyke Raisings Under Pseudo Static Conditions

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Abstract: The present paper describes pseudo static analysis carried out on the ash-dyke sections with various raising stages using Bishop's Method of analysis. Based on the state of the art practice in the India, starter dyke section and subsequent raising geometry is selected. Using the in-situ test data performed on the existing ash-dykes, geotechnical properties of the deposited ash ponds are selected to perform the seismic analysis of the ash-dyke sections. Considering the various seismic zones as per IS: 1893:2002, Part 1, series of stability runs are carried out to map the factor of safety at various stages of ash-dyke rising. Sensitivity analysis is carryout out to examine the influence of the geotechnical properties of the deposited ash in the ash-dyke. The present study helps the geotechnical professionals to choose better geometries of ash-dykes during the planning stage to ensure sustainable performance.

Keywords: flyash, ash pond, ash dyke, sensitivity analysis

1. Introduction

In India, there are more than 100 thermal power plants out of which majority are coal based producing approximately around 150 million tons of coal ash yearly. With increased utilization of generated ash through usage in concrete, brick making, agriculture, reclamation of low lying areas and other embankment constructions, the utilization of the ash has increased considerably. However, the percentage of utilization is still insufficient and for most of the powerplants, ash is deposited in the form of ash-pond in the vicinity of powerplant as waste material covering several acres of valuable land. Moreover, for new power plants the land acquisition is a major issue and with limited area, rapid vertical expansions of Ash- dykes are inevitable. Table 1 given below shows data related to its generation and use in a different year.

Table 1: Progressive fly ash generation and its utilization during the period from 1996-97 to 2017-18(CENTRAL ELECTRICITY AUTHORITY, 2018)

SN	Year	Fly Ash Generation (MT)	Fly Ash Utilization (MT)	Fly Ash Utilization (%)

1	1996-97	68.88	6.64	9.63
2	2006-07	108.15	55.01	50.86
3	2016-17	169.25	107.1	63.28
4	2017-18	196.44	131.87	67.13

The utilization of fly ash in India varies between 50-60 % and rests are disposed of and are restored. Fly ash storage requires a huge amount of land area. So to reduce the land wastage, it is stored using ash dyke construction, ash dyke is an important structure, located few kilometres away from the hydraulic power stations for storing the coal ashes. Ash dyke construction is a continuous process and it is raised each step through dyke construction.

Ash dyke construction is a great challenge for civil engineers as the failure of ash dyke has an adverse effect on the surrounding environment as well as it can affect the smooth functioning of power stations. It also causes havoc among the surrounding people about the safety of their life. It causes economic losses. It pollutes the surrounding river water which is dangerous for aquatic life as well as a human being. So ash dyke should be constructed with proper safety and precautions. (Gandhi S. R., 2005) in his paper explained various methods of raising the dyke by describing their advantages and disadvantages. He also suggested that ash dyke should be supervised regularly and necessary remedial measures should be taken. (Jakka R. S., 2016) in his paper checked dynamic stability of ash embankments raised by the upstream and downstream methods of construction with coarse and fine pond ash materials and found that embankments constructed with coarse ash exhibited responses similar to earthen embankment in many respects. However, it is found that the embankments with the fine ash exhibits higher vulnerability to liquefaction related slope failures.

2. Material Properties

Material properties used for the study and analysis are as shown in Table 2 below.

Table 2: Material properties used for the analysis

Soil Type	Cohesion (KN/m^2)	Phi	Unit Weight (KN/m^3)	k (m/sec)
Clayey Silt (Foundation Soil)	90	0	18	1×10^{-7}
Fill Material (Starter Dyke)	35	0	17	1×10^{-7}
Sand (Filter)	0	36	17.8	1×10^{-3}
Loose Flyash	0	29	12.2	1×10^{-5}
Compacted Flyash	0	32	14.2	1×10^{-7}

3. Objectives

a) To design an ash dyke for an optimum factor of safety by analyzing the dam section using finite element based software SLIDE using Bishop's method of analysis.

b) To recommend the optimum design for the ash dyke.

4. Analysis

For the analysis purpose, a three-stage dyke was constructed stage wise by upstream method on the starter dyke with different U/S and D/S slopes. Soil properties were assigned and slope stability was carried out for Pseudo Static condition by considering various Peak Ground Acceleration (PGA) values as per IS:1893:2002, Part 1 and the seepage study along with sensitivity analysis were also carried out. In all the raisings of different slopes for the computation of slip surface, global failure of ash dyke is taken into consideration. Figure 1 & Figure 2 below shows the typical layout with Starter Dyke D/S (1:2) U/S (1:2) Stage I D/S (1:2) U/S (1:2) Stage II D/S (1:2) U/S (1:2) Stage III D/S (1:2) U/S (1:2) and Reference Analysis of ash dyke with Starter Dyke D/S (1:2) U/S (1:2) Stage I D/S (1:1) U/S (1:1) Stage II D/S (1:1) U/S (1:1) Stage III D/S (1:1) U/S (1:1) respectively.Table 3 below shows the Factor of safety of all slopes in Pseudo Static conditions.

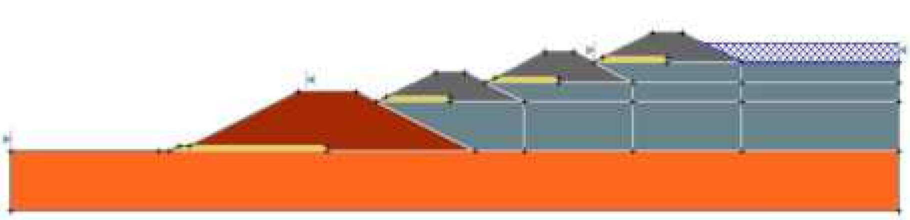

Figure 1: Typical Layout with Starter Dyke D/S (1:2) U/S (1:2) Stage I D/S (1:2) U/S (1:2) Stage II D/S (1:2) U/S (1:2) Stage III D/S (1:2) U/S (1:2)

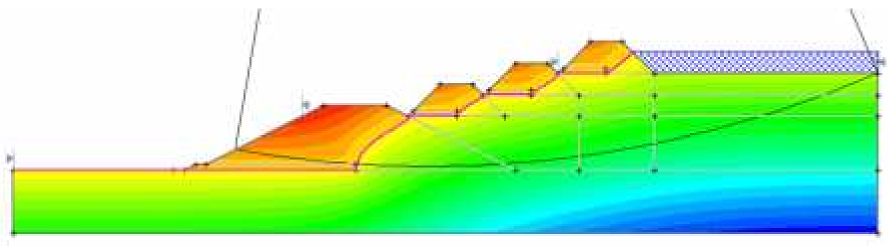

Figure 2: Reference Analysis of ash dyke with Starter Dyke D/S (1:2) U/S (1:2) Stage I D/S (1:1) U/S (1:1) Stage II D/S (1:1) U/S (1:1) Stage III D/S (1:1) U/S (1:1)

Table 3: Factor of Safety for all slopes in Pseudo Static conditions

Starter Dyke	Stage I	Stage II	Stage III	FOS in Seismic Condition using Bishop's Method				Remarks
				PGA				
				0.1	**0.16**	**0.24**	**0.36**	
D/S & U/S (1:2)				1.93	1.67	1.42	1.16	D/S Slope

D/S & U/S (1:2)	D/S & U/S (1:2)			1.84	1.49	1.2	0.93	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)		1.57	1.28	1.04	0.81	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)	1.38	1.11	0.89	0.69	Global Failure
D/S & U/S (1:2)				1.93	1.67	1.42	1.16	D/S Slope
D/S & U/S (1:2)	D/S & U/S (1:2.5)			1.87	1.51	1.21	0.93	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)		1.61	1.3	1.06	0.82	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	1.54	1.13	0.9	0.7	Global Failure
D/S & U/S (1:2)				1.93	1.67	1.42	1.16	D/S Slope
D/S & U/S (1:2)	D/S & U/S (1:3)			1.89	1.51	1.2	0.92	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:3)	D/S & U/S (1:3)		1.74	1.34	1.04	0.79	Global Failure
D/S & U/S (1:2)	D/S & U/S (1:3)	D/S & U/S (1:3)	D/S & U/S (1:3)	1.41	1.12	0.89	0.69	Global Failure
D/S (1:2) U/S (1:1.5)				1.92	1.66	1.42	1.14	D/S Slope
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2)			1.78	1.45	1.17	0.91	Global Failure
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2)	D/S & U/S (1:2)		1.54	1.27	1.04	0.8	Global Failure
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)	1.35	1.09	0.88	0.69	Global Failure
D/S (1:2) U/S (1:1.5)				1.92	1.66	1.42	1.14	D/S Slope
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2.5)			1.83	1.38	1.06	0.8	Global Failure

D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)		1.55	1.22	0.95	0.73	Global Failure
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	1.22	1	0.81	0.64	Global Failure
D/S (1:2) U/S (1:1.5)				1.92	1.66	1.42	1.14	D/S Slope
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:3)			1.88	1.41	1.08	0.81	Global Failure
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:3)	D/S & U/S (1:3)		1.61	1.27	0.98	0.75	Global Failure
D/S (1:2) U/S (1:1.5)	D/S & U/S (1:3)	D/S & U/S (1:3)	D/S & U/S (1:3)	1.14	0.91	0.78	0.65	Global Failure
D/S (1:2.5) U/S (1:2)				2.1	1.81	1.52	1.21	D/S Slope
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2)			1.97	1.46	1.11	0.83	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)		1.6	1.24	0.96	0.73	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)	D/S & U/S (1:2)	1.28	1.02	0.81	0.64	Global Failure
D/S (1:2.5) U/S (1:2)				2.1	1.81	1.52	1.21	D/S Slope
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2.5)			2.01	1.5	1.13	0.85	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)		1.68	1.28	1	0.76	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	D/S & U/S (1:2.5)	1.35	1.07	0.85	0.66	Global Failure

D/S (1:2.5) U/S (1:2)				2.1	1.81	1.52	1.21	D/S Slope
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:3)			2.03	1.59	1.16	0.88	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:3)	D/S & U/S (1:3)		1.73	1.32	1.02	0.77	Global Failure
D/S (1:2.5) U/S (1:2)	D/S & U/S (1:3)	D/S & U/S (1:3)	D/S & U/S (1:3)	1.32	1.07	0.86	0.67	Global Failure

5. Sensitivity Analysis

For the Sensitivity analysis in Pseudo Static condition, for Starter dyke D/S (1:2) & U/S (1:1.5), Stage I D/S & U/S (1:2.5) slopes the properties of flyash which are taken into consideration for loose flyash, and Compacted flyash are given in Table 4 and the graphs of comparison of unit weights v/s Factor of Safety and Phi v/s Factor of Safety for different materials are shown in Figures 3 and 4 respectively.

Table 4: Ash properties for consideration in the Sensitivity Analysis

Material Name	Property	Mean	Rel. Min	Rel. Max
Loose Flyash	Phi	29	26	32
	Unit Weight	12.2	10.5	14.5
Compacted Flyash	Phi	32	28	35
	Unit Weight	14.2	11	16

6. Conclusions

In Pseudo Static condition the ash dyke constructed using upstream method gives a factor of safety well above 1.14 for all Starter dykes for different values of Peak Ground Acceleration (PGA). For raisings, ash dykes are found to be safe and the factor of safety is found to be greater than 1 for Peak Ground Acceleration (PGA) values 0.1 and 0.16, for the Peak Ground Acceleration (PGA) value of 0.24 the ash dykes are found to be unsafe in Stage II and Stage III as their values of factor of safety lies just below 1 and for Peak Ground Acceleration (PGA) value 0.36 the ash dykes are found to be unsafe in every stage except the starter dyke.

Also, the raiser dyke may rest on loose ash for upstream construction practice, which may prone to liquefy during an earthquake.

For the Sensitivity analysis in Pseudo static condition, for Starter dyke D/S (1:2) & U/S (1:1.5), Stage I D/S & U/S (1:2.5) slopes the value of Factor of Safety decreases from 2.09 to 2.06 and 2.10 to 2.02 for loose ash and compacted ash respectively with increase in the unit weight from 10.5 to 16 KN/m^3 in both compacted ash and loose ash. While the value of FOS increases from 2.06 to 2.10 and 2.06 to 2.11 for loose ash and compacted ash respectively with an increase in the value of phi from 26° to 35° for both compacted ash and loose ash.

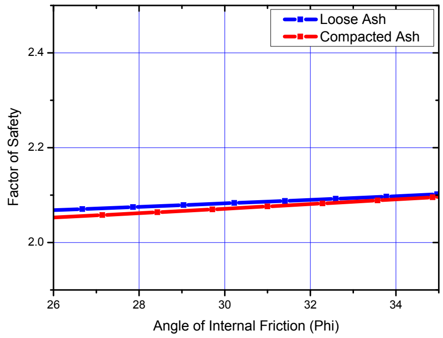

Figure 1: Comparison of Phi v/s Factor of Safety for Loose and Compacted ash in Pseudo Static condition

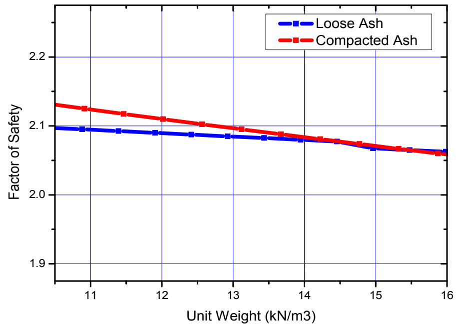

Figure 2: Comparison of unit weights v/s Factor of Safety for Loose and Compacted ash in Pseudo Static condition

7. Acknowledgement

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8. References

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