Retrofitting of Existing Earthen-Fly Ash Dam by Finger Drains & Gabion Wall

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Abstract. Coal based power plant generates huge amount of fly ash as residual waste for ash ponds with significant dam heights have been constructed over a period of operation. Sometimes in long run, seepage may threaten the stability of dam due to internal erosion or clogging of filters. This paper presents a case study on fly ash dam where seepage and distress of dam section had a concern for the Owner. The entire pond had raised by up-stream method of construction with earthen as well as pond ash material. One stretch of dam settled including starter dam and moved horizontally under heavy seepage during monsoon. The root cause of problem had been identified through new geotechnical investigations and engineering solution was proposed to stabilize dam section. The rectification measures involved revival of old rock toe, strengthening of dam by constructing gabion wall at toe of starter dam with geotextiles and graded filters. The internal drainage was streamlined with provision of PVC perforated finger drain wrapped with non-woven geotextile material inside trenches filled with graded filters. The networks of finger drain at different elevations were ultimately channelized to drain out trapped seepage water and release the pore water pressure on dam section. The revived existing rock toe with new gabion wall had stabilized the toe and stopped the starter dam movement further. New piezometers and settlement monuments were installed on entire dam section at different elevation for monitoring. The proposed solutions had appropriately addressed seepage problems and strengthened dam toe to improve the stability.

Keywords: PVC Finger Drains, Gabion Wal, Non-woven Geotextile

1 Introduction

The power plant facility comprises captive power plants with ash ponds at different locations. During monsoon, heavy seepage and minor subsidence was observed for a stretch of about 60 m at the starter dam of one of the ash ponds. It was analyzed that the starter dam in this affected area would have inadequate stability considering continued seepage and would cause global instability to the dam. Therefore, strengthening of the dam section was necessary to prevent possibility of failure of the dam. This paper describes the study carried out to assess the site condition and the remedial measures to be adopted for strengthening the dam. It also emphasizes that availability of material and appropriate resources have great impact while developing design philosophy & execution strategy.

2 Background of Dam Construction & Problem Definition

The starter dam of height 10-12m was built with excavated soil from the pond footprint area. It had rock toe at bottom, but no vertical chimney or horizontal blanket drains were found in the construction documents. Subsequent 3 heights raising of 4m each by up-stream method were done by using same earthen material without any internal drainage system. Pond was operated and filled up to the third raising and further 2-stage height raising of 6m each by up-stream method were planned. Before that buttressing with relief well, filter drain with soil cover along slope face connected to a small rock toe were done from starter dam top to third raising. Afterwards, dam was raised by pond ash material with soil cover all around including proper internal drainage systems with rock toe.

Fig.1. Ash Pond after 3rd Raising (Source Bing Satellite Image)

The pond was operated and filled up to the 5th stage raising. However, at the end of operation minor seepage were observed for a stretch of about 60m at the starter dam. The seepage continued to increase during the monsoon period. The situation was further aggravated by subsidence of dam at top of the buttressing portion which resulted in horizontal sliding of mass at starter dam top. It was analyzed that part of the starter dam could be on the verge of collapse. Therefore, the total area was immediately covered with sand bags from toe up to the distressed portion. Three borewells were made inside the pond for dewatering purpose, but pumping was not fruitful due to less water in borewells. The seepage problem was caused by accumulation of water inside dam body due to choking of filters in chimney, relief well and sand blankets and further connectivity to existing rock toe.

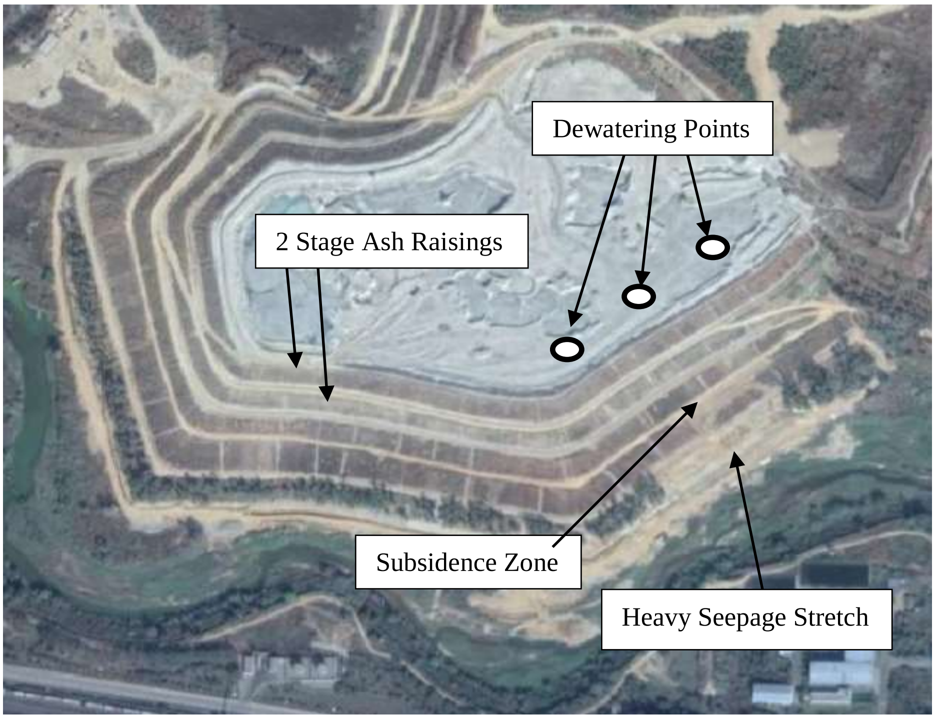

Fig.2. Ash Pond after 5th Raising (Source Google Satellite Image)

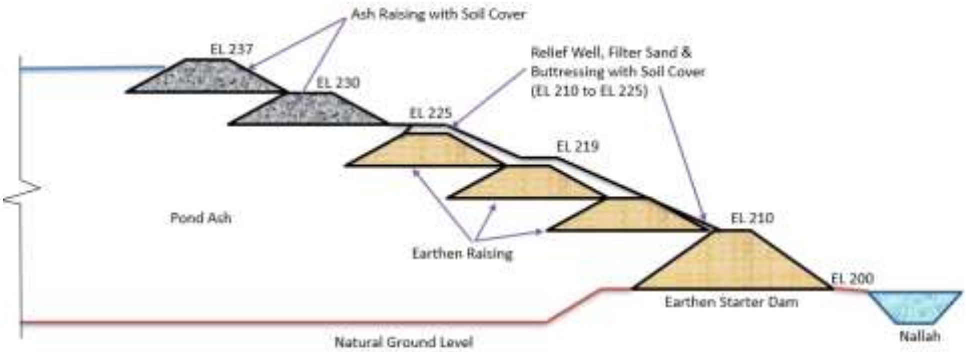

Fig.3. Schematic Diagram for Typical Cross Section of Dam (Not to Scale)

Fig.4. Subsidence Stretch at Upper Bench above Starter Dam

Fig.5. Seepage Zone of Starter Dam Toe & Downstream Slope with Sand Bags

3 Space Constraint & Retrofitting Challenges

It is checked from the construction drawings and subsequent site visits that barely 10m space was available at the toe of starter dam within the Owner's land. Therefore, there was no option of making earthen counter-berm or buttressing by down-stream method of construction. Heavy seepage at distressed portion made it impossible for any strengthening of existing dam by compaction. It was apprehended that high energy from impact or vibratory rollers would also trigger sliding of soil mass, which would further destabilize the starter dam. Other possible solution involving use of geosynthetic cutoff walls, slurry wall, sheet pile wall at upper benches were not taken into consideration in view of higher project cost, non-availability of skilled resource and material and construction difficulties. The design and construction methodology of retrofitting scheme could not be developed without knowing the internal condition of dam. This could only be done through proper investigation, study of dam material and internal drainage system.

4 Topographical Survey & Geotechnical Investigations

Existing drawing, contours and old geotechnical reports of the ash pond were studied for preliminary planning and design. Uncertainties in design inputs were eliminated by carrying out new topographical survey and geotechnical investigations. The field work was comprised of 11 augured boreholes of depth ranging from 27 to 40 m sunk at various locations along the dam and inside the pond. Standard Penetration Test (SPT) was conducted at every 1.5m intervals throughout the borehole up to termination depth. 18 nos of field permeability tests were carried out in boreholes at different depths. Laboratory tests on selected samples were carried out to determine moisture content, specific gravity, unit weight, Atterberg limits, grain size, strength parameters, consolidation-swell parameters and water quality. Additionally, 15 nos piezometers were installed at different elevations for entire dam section to monitor the phreatic surface within the dam. After detail analysis of the geotechnical report, the following parameters were assigned for various layers for carrying out slope stability analysis.

Fig.6. Approximate Location of Boreholes on Google Image

Table- 1: Geotechnical Properties of Different Materials for Analysis

Material Description	**Unit Weight (kN/m^3)**	**Cohesion (C) (kN/m^2)**	**Angel of Internal Friction (ϕ)°**	**Hydraulic Conductivity (cm/sec)**
Foundation Soil	20	20	35°	7.441×10^{-6}
Earthen Dam (Starter Dam, 1st,2nd &3rd Raising)	19	10	32°	1.453×10^{-5}
Ash Dam (4th & 5th Raising)	17	0	30°	2.257×10^{-5}
Pond Ash	16	0	28°	7.685×10^{-5}
Soil Cover (Buttressing)	19	15	32°	1.554×10^{-5}

5 Engineering Analysis for Pre-& Post-Retrofitting

Stability of the dam was assessed under worst condition to simulate the seepage problem by established classical limit equilibrium methods using professional software. Analysis revealed that the dam in existing condition would have inadequate global stability considering persistent seepage through the dam body. It was evident that horizontal movement of starter dam would occur progressively and trigger ultimate failure of dam in the susceptible stretch. Therefore, it was essential to reduce seepage through the dam body and strengthen it to increase stability of the dam. Finger drains made up of perforated PVC pipe wrapped with geotextile were inserted within the dam body and these were connected to the collection drains at downstream Afterward, next course of action was to stabilize the movement of toe portion by providing a heavy counter-berm within the limited space. Without proper seepage connectivity from existing toe through the new counter-berm could lead to collapse with major consequences. Therefore, gabion wall with geotextile & graded filters scheme was developed after thorough study of different situations that could arise during progress of execution or thereafter. Stability of starter dam with new gabion wall under all possible conditions that could arise during and after execution under controlled seepage condition were analyzed and the results of minimum Factor of Safety (FOS) are summarized in Table 2.

FOS was calculated considering R_u = 0.2 for "End of Construction" condition and peak ground acceleration = 0.12 was considered for "Seismic (Pseudo-Static)" analysis.

Table - 2: Variation of Factor of Safety (FOS) for Method of Analysis

Cases	Dam Condition	Fellenius Method	Bishop Method	Janbu Method	Spencer Method
Static	Existing (Steady Seepage)	1.09	1.08	1.01	1.09
Seismic	Existing (Steady Seepage)	0.82	0.83	0.77	0.85
Static	Gabion Wall (Steady Seepage)	1.44	1.49	1.36	1.50
Seismic	Gabion Wall (Steady Seepage)	1.04	1.10	0.99	1.13
Static	Gabion Wall (End of Construction)	1.68	1.66	1.62	1.68
Seismic	Gabion Wall (End of Construction)	1.23	1.21	1.18	1.24

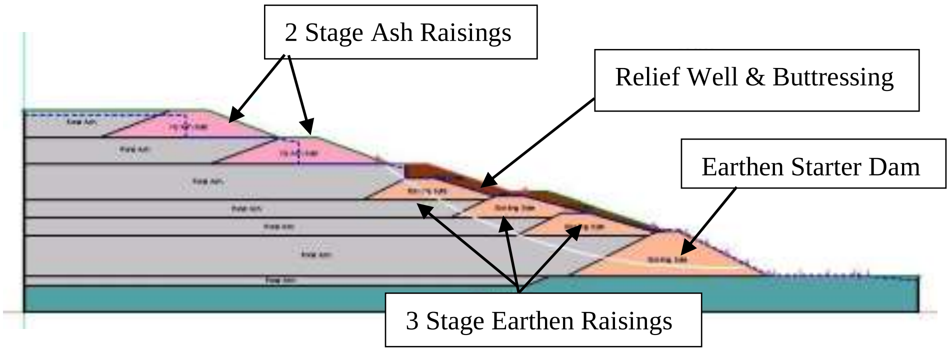

Fig. 7. Static FOS under Steady Seepage Condition with Existing Dam (Bishop Method)

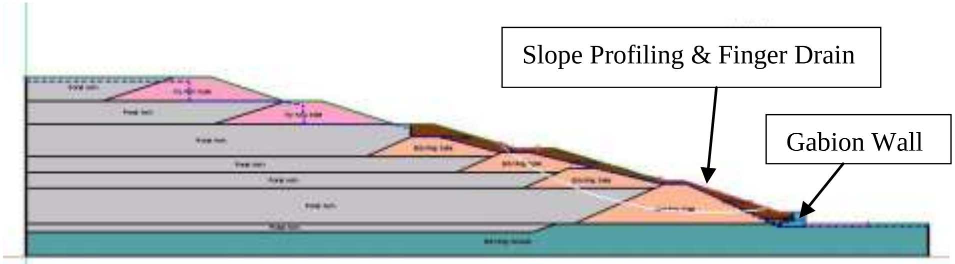

Fig. 8. Static FOS under Steady Seepage Condition with Gabion Wall (Bishop Method)

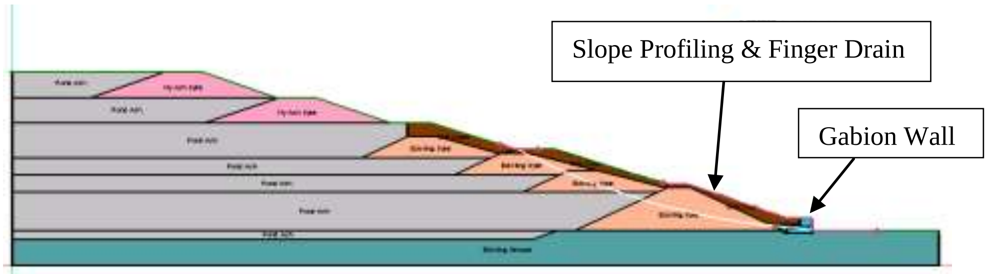

Fig. 9. Static FOS under End of Construction Condition with Gabion Wall (Bishop Method)

6 Retrofitting Scheme

The dam strengthening and retrofitting scheme was formulated in context of short term action plan and long-term monitoring of dam.

- Immediate dewatering of surface water from pond to decantation pond and safe channelization of surface run-offs of rain water away from the affected zone.
- Cleaning of existing rock toe from overburden soil, vegetation and rearrangements of rock ripraps to reduce pore water pressure.
- Excavation at toe portion and placing of finger drains with geotextiles and filters for safe channelization of seepage water through existing rock toe.
- Construction of gabion wall at starter dam toe with placement of graded filters up to the existing rock toe.
- Engineering fill above gabion wall with slope profiling with vegetation, boulder pitching.
- Installation of piezometers and settlement gauges at various benches for appropriate measurement of phreatic surface and further settlement.

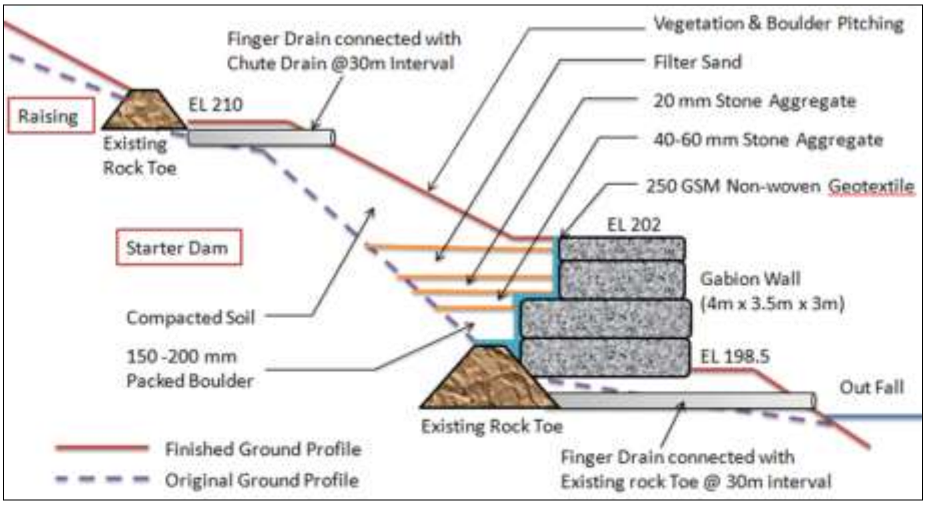

Fig. 10. Schematic Drawing for Retrofitting Scheme (Not to Scale)

Fig. 11. Gabion Wall and Slope Profiling during Retrofitting at Subsidence Stretch

Fig. 12. Gabion Wall at Toe of Starter Dam and Grown Vegetation on Slope

Fig. 13. View of Ash Pond Side above Gabion Wall

7 Conclusion

The study included review of existing dam structure, study of old and new geotechnical data, seepage and stability analysis of existing dam. The proposed retrofitting scheme by gabion wall, geotextiles with graded filters and use of finger drains achieved the required FOS without endangering the safety of the dam during execution. The engineering solution was finalized after study of locally available material from suppliers and resources from local contractor. It was also concluded that attempt for safe dissipation of seepage water through the gabion wall and finger drains would be essential in long run. The continuous monitoring through piezometers and settlement gauges would ensure safety and stability after retrofitting work. The FOS would improve further with dissipation of pore water pressure through the internal & external drainage system that and would ensure stability of the dam in future.

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References

1. Abramson, L.W., Lee, T. S., Sharma, S., Boyce, G.: Slope Stability and Stabilization Methods. Second Edition. John Wiley & Sons Inc, New York (2002)
2. Dayal, U., Sinha, R.: Geo Environmental Design Practice in Fly Ash Disposal & Utilization. First Edition. Allied Publishers Private Ltd, India (2005)
3. Vick, S. G.: Planning, Design and Analysis of Tailings Dams. BiTech Publishers, Canada (1990)