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Design considerations for ash pond dyke construction in the Hilly terrain for high concentrated slurry disposal: a case study

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ABSTRACT

Designing an ash pond for the High Concentrated Slurry Disposal (HCSD) in hilly terrains poses a unique set of challenges. In such regions, the availability of barren land adjacent to the project sites is limited, making it difficult to locate suitable sites for ash pond construction. Furthermore, the hilly terrain and complex topography demand careful planning and design to ensure the long-term stability and safety of the ash pond and associated infrastructure. This paper discusses the design considerations for the construction of ash pond dykes in a hilly region of Vietnam for the HCSD disposal. The case study highlights detailed geotechnical design investigations, such as soil type, slope stability and groundwater conditions. In addition, geotechnical instrumentation to monitor the performance of ash pond dykes and the subsoil supporting it during and after construction is also discussed. The paper also examines the environmental and hydrological design aspects of the ash pond, including the development of drainage and channelization concept along the hilly terrain to manage storm water and prevent the mixing of rain water with ash slurry. Such mixing could otherwise create an environmental hazard.

Keywords: *Ash pond, Hilly terrain, High concentrated slurry disposal, Ge-otechnical investigation.*

1. Introduction

The disposal of high concentrated slurry from coal-fired power plants is a major environmental concern, and constructing an ash pond is a common method to manage this waste. However, designing and constructing an ash pond in the hilly terrains poses unique challenges due to limited availability of barren land and complex topography. With increased coal-based power plants in hilly terrains, particularly in the north-eastern parts of Vietnam, the use of valley portions formed by the natural hills for containment of ash disposal is practiced as an economically viable solution. The natural hills themselves act as the dykes for the ash contained in the valley, thereby reducing the huge cost involved in the construction of earthen dykes for impoundment of the ash pond. Nevertheless, designing and maintaining ash dykes in hilly regions is quite complicated, as it involves not only geotechnical considerations, but also hydrological and environmental aspects [1-3].

The case study presents geotechnical design investigations, such as soil type, slope stability, and groundwater conditions, which are crucial in ensuring the long-term stability and safety of the ash pond and its associated infrastructure. The paper also examines the environmental and hydrological design aspects of the ash pond, including the development of drainage and channelization concepts along the hilly terrain to prevent environmental hazards. In addition, geotechnical instrumentation is also discussed, which is used to monitor the performance of the ash pond and the subsoil supporting it during and after construction. The findings of this study will provide valuable insights into the challenges and best practices for designing and constructing ash ponds dykes in the hilly regions for the HCSD disposal. A holistic approach that balances geotechnical, hydrological, environmental, and slurry-specific considerations, along with diligent geotechnical instrumentation, is discussed for successful ash pond design and operation in such challenging terrains.

2. Geotechnical Design

2.1. Site location

The Power Plant facility is situated in the northeastern region of Vietnam, with the Ash Pond located approximately 500 meters to the north-east of the power plant. The Ash Pond area is surrounded by natural hills on the north and south sides, with a natural valley in between. The highest elevation of the hills, according to the topographical survey data, is EL +70.0 meters. The hilly region is entirely covered with natural vegetation, such as trees and bushes, making it difficult to access. The valley ground is uneven, with RL's varying from EL +4.50 meters to EL +0.5 meters. Embankments have been constructed on the east and west sides to contain the ash disposal area, while the hills on the north and south sides serve as natural dykes. Figure-1 displays the layout of the Ash Pond and the location of the boreholes.

2.2. General Geology

The general geology of project area comprises two formations:

• Jurassic system, lower division, Ha Coi formation J1hc: The main composition of this Ha Coi formation is conglomerate, gritstone, quartz sandstone; light green Aleurolite (claystone), siltstone somewhere

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contains carbonate.

- Triassic system, Upper division, Middle Hon Gai suite T3hg2: It comprises gritstone, conglomerate, sandstone somewhere intercalated with thin layer of Aleurolite, argillite, and lens of coal, coaly claystone.

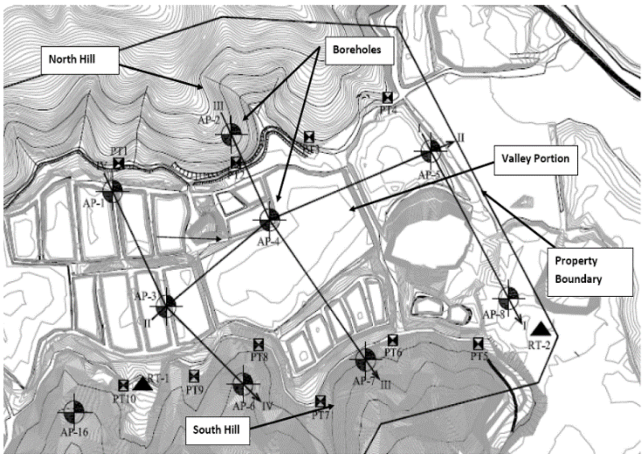

Fig. 1 The layout of Ash Pond and Borehole Location Plan.

2.3. Soil Conditions

To delineate the subsurface soil conditions, a total of 13 boreholes were drilled at the ash pond location. Borehole locations are shown in Figure-1. Results from the borehole investigation indicated that the subsoil beneath the Ash Pond area consisted of fill material (Sandy Clay with fragments of weathered rock) (Layer 1) from ground level (EL +0.0) to EL -1.00 m. This layer was underlain by very soft to soft sandy clay (Layer 2) with an average thickness of 6.50 m, i.e., up to EL -7.50 m, which in turn is underlain by highly to completely weathered rock formation (Layer 3) down to the termination depth of the boreholes (~15.0 m). The standard penetration test (SPT) values of layer 1 and layer 2 were very low, ranging from 1 to 8. The typical N values are shown in Figure 2. The generalized subsurface profile along the hilly region comprises stiff to very stiff sandy clay formation with average thickness of 4.00 m.

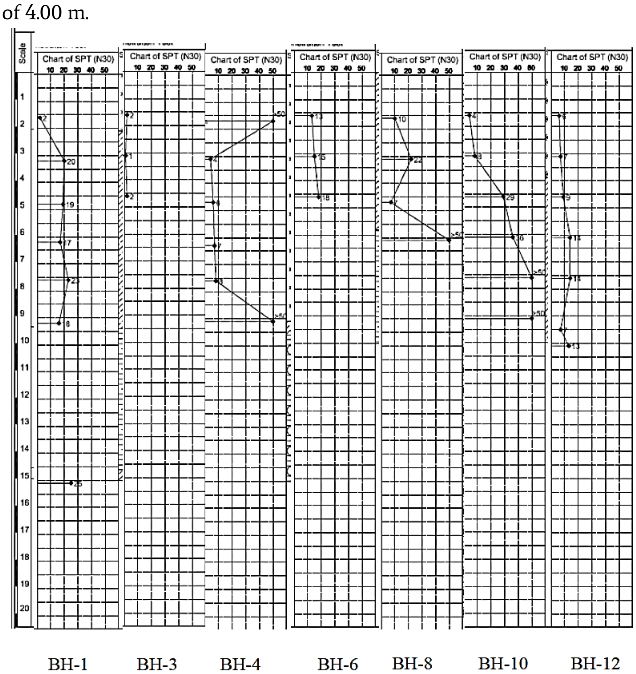

Fig 2. Typical Borehole Summary.

2.4. Dyke/Embankment Design Criteria

Following parameters were considered for the design of ash pond dykes/embankments:

a) Design has been done in accordnace with IS:7894-1975 (Reaffirmed 2002).

b) The dykes were designed to withstand the ash and water pressure.

c) The top elevation of the dykes/embankments was kept at EL +15.0 m.

d)The interior and exterior slope of 2 horizontal on 1 vertical were considered.

e) For the cut area (hilly side), a minimum slope of 1H:1V was taken. Also, the slope of hilly areas above the elevation was stabilized to prevent sliding and erosion.

f) The top width of the dykes was taken as 5.0 m

g) Minimum 500 mm free board was provided and considered in the pond capacity calculations.

h) The thickness of the HDPE liner covering the entire bottom of the pond and all interior slopes up to an elevation of 15.0 m was 1.5 mm. Also, the liner was properly anchored at the top of the dyke and cut areas. The HDPE liner serves a dual function. Firstly, it prevents the infiltration of ash slurry into the dyke, ensuring a dry environment. Secondly, it confines the percolation of ash-laden water within the pond. This raised embankment serves as the initial structure built to contain the HCSD Slurry. It is the original dyke, erected prior to the commencement of ash disposal operations.

i) The exterior slopes of the east dyke and west dykes were protected by planting vegetation, such as native grass.

The typical embankment configuration adopted for the east and west banks of the ash pond is shown in figure 3.

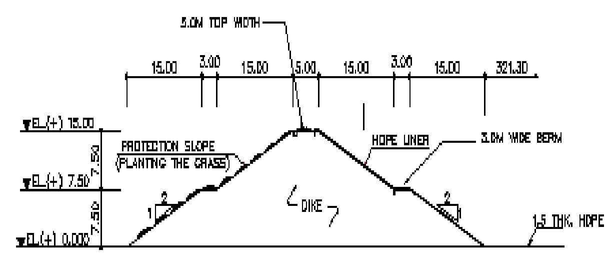

Fig. 3. The typical Embankment Configuration adopted for the east and west dykes.

2.5. Slope Stability Analysis of Dykes

The adopted slopes for the east and west dykes were checked for stability using Geoslope Software (Geostudio Module-2012) [4]. A berm of 3.0 m width was provided at 7.5 m height to enhance the stability of the slopes. The minimum factor of safety was taken as 1.4. Table 1 presents the properties of the fill materials and virgin ground adopted for slope stability analysis.

Table 1. The properties of soil for Slope Stability Analysis.

S. No	Layer	Thickness of the Layer, m	Parameters Adopted for Modelling		
			C, Kpa	Φ, deg	γ, KN/m³
1	Top Layer	7.5	10*	26*	18.5*
2	Bottom Layer	7.5	10*	24*	18.0*
3	Virgin Ground	7.0	10#	18#	16.5#

*Lower bound parameters were selected based on testing conducted in the borrow area
#Parameters were selected based on the soil investigation report.

The Mohr-Coulomb theory of materials was adopted for analyzing the stability of the slopes. The Morgenstern and Price method, which takes into consideration interslice shear forces, was adopted for stability analysis [5]. The typical modelling of dykes using Geostudio 2012 is presented in figure 4.

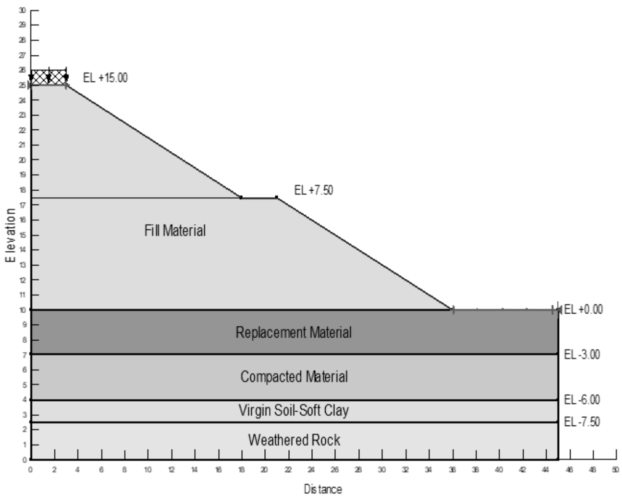

Fig. 4. Typical modelling of dykes using Geostudio.

2.6. Stability of Hilly Slopes

On hilly sides, a slope of 1Vertical:1Horizontal (1V: 1H) was proposed due to the presence of consolidated overburden soil and weathered rock formations. Subsequently, the slopes were checked for stability. The detailed configuration along the hilly area and the slope stability analyses are shown in figure 5. The Bird's eye view of the ash pond is shown in the Fig.6.

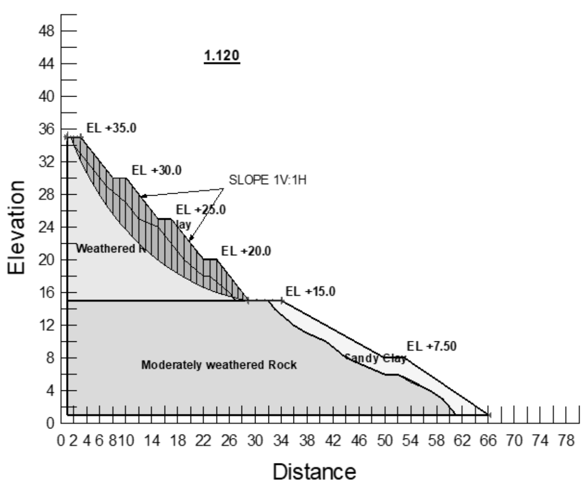

Fig. 5. The slope stability analyses of Hilly slopes.

Fig. 6. The Bird's Eye View of The Ash Pond.

3. Geotechnical Instrumentation

To monitor the performance of ash pond dykes and the subsoil supporting them during and after construction, geotechnical instrumentation and monitoring were installed. The typical section of the dyke showing instrumentation arrangements adopted for monitoring the east and west dykes/Embankments is presented in Fig.7.

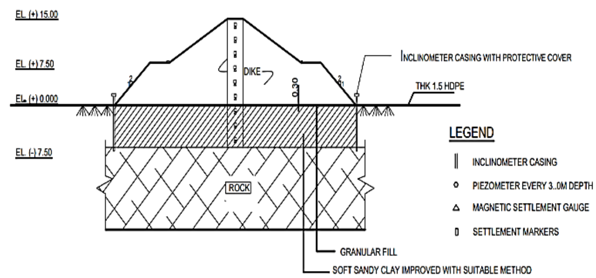

Fig.7. Geotechnical Instrumentation arrangements for the Ash Dykes/Embankments.

Inclinometers were installed at regular intervals to monitor the lateral displacements of the dykes. The collected data from inclinometers provide real-time information about any horizontal movements or shifts in the dyke. During construction, if significant lateral displacements are detected, it may indicate potential stability issues, and corrective measures can be taken immediately to prevent slope failures or structural damage. After construction, ongoing monitoring of inclinometer data helps ensure the long-term stability of the dyke. Piezometers were installed at various depths to monitor the pore water pressures and to control the fill height. During construction, piezometer data helps in controlling the fill height and ensuring that the water pressures are within safe limits. After construction, continued monitoring of pore water pressures is essential to detect any abnormal increases that might indicate seepage or other problems. This data is crucial for making timely decisions to prevent potential dam failures. Settlement markers were provided to monitor the ground settlement of the dyke post construction. Settlement can occur due to various factors, including consolidation of the underlying soil and changes in moisture content. Monitoring settlement markers allows engineers to assess whether the dykes are settling within acceptable limits. Excessive settlement may indicate issues with the dyke's stability or the need for maintenance. The frequency of instrumentation adopted for the east and west dykes is presented in the Table 2.

Table 2. The Frequency of Geotechnical Instrumentation arrangements for Dykes/Embankments.

S. No.	Instrument	Frequency
1.	Inclinometer Casing	@ Every 150 m
2.	Piezometer @every 3.0 m depth	@ Every 150 m
3.	Magnetic settlement Gauge	@ Every 150 m
4.	Settlement Markers	@ Every 150 m

4. Environmental Aspects

To minimize the environmental impact of using pond ash in hilly areas, it is important to carefully manage its storage, handling, and disposal. It is also important to ensure that disposal the technique should be such to minimize the environmental impact on local ecosystems. The HCSD (Dense Phase) and Conventional Wet Slurry Ash Disposal are two different techniques for transporting and disposing of coal ash. In wet slurry, the water content is quite high, whereas for the HCSD, dewatering of the slurry is done in a sequential approach of thickening, filtration, and dewatering. The key differences are mentioned in Table 3 [6-8].

Table 3. Comparison between the HCSD (Dense Phase) and Conventional Wet Slurry Ash.

Item Description	HCSD (Dense Phase)	Conventional Wet Slurry
Quantity of water	Less Water	More Water
Concentration of Slurry	Approximately 65% to 75%	Approximately 7.5%
Water content	< 35%	> 90%
Pumping Technology	Positive displacement (piston diaphragm) or Centrifugal (> 2m/s)	Volumetric (< 2 m/s)
Filling mode	Continuous compacting, drying and sloping	Continuous settling
Overflow	No overflow	Overflow when pond is filled up with water
Leachate	Minimal even without liner, low contamination potential as the ash solidifies within few days of dumping	Fully dependent on liner, possible contamination; ash remains in loose form
Recycling of leachate	Initial formation of leachate is minimal, no overflow, no minimum recycling needed, therefore no increase in pollutant concentration	Leachate and overflow are relevant and similarly contaminated and have to be recycled, pollutant concentration increases
Storm water runoff	Forms compact surface, causes minimal contamination	Results in contaminated overflow when pond is filled with water,
Item Description	HCSD (Dense Phase)	Conventional Wet Slurry
Compaction	Continuously and active, good compaction and curing properties, can be sloped to 6%	Only after closure, compaction depends on dry-out rate, deep depths inhibit good compaction and curing
Reuse for cultivation	Immediately after closing one section	Years after closing
Economic efficiency	Initial investment cost similar to conventional wet slurry, operation and maintenance costs are lower	Initial investment similar to HCSD, operation and maintenance costs significantly higher

Based upon advantages offered by the HCSD system, it has been proposed to use it for transporting and disposing coal ash. Unlike other methods, this system does not require the use of environmental control technology to treat waste streams from the ash pond, although environmental standards must be periodically monitored. This transportation method is also unlikely to generate dust, as the waste is saturated during filling and the ash pond is covered with topsoil and vegetation after filling is complete to prevent dust emissions. However, heavy pumps may be required to pump the slurry. Because the power plant area receives heavy rainfall, the High-Density Polyethylene liner (HDPE) liner is used to protect against potential contamination of the ground from the mixture of the HCSD and surface water run-off.

5. Hydrological Aspects

When designing ash ponds in the hilly terrains, it is essential to consider not only geotechnical aspects at the project site but also hydrological and environmental factors. Storm water management is a critical hydrological factor that needs to be considered during the ash pond design process [9-10]. This involves studying the probability of rain-fall occurrence, estimating runoff and evaporation losses, estimating discharge quantities, and economically sizing storage structures [11-12]. To address storm water management, two drainage systems were proposed a) Drainage system for storm water from hilly portions and dykes b) Drainage system for storm water accumulated in the ash pond.

(A) Drainage System for Storm Water from Hilly Portions

Since natural valley was utilized for the ash pond, the surface run-off from natural hill slopes outside the pond area was not allowed to enter the ash pond area. Instead, it has been suitably diverted to the surrounding area by constructing catch drains so that the load on the return water pump house dose not increase during the monsoon and to prevent the possible contamination of run-off water with the HCSD.

The drainage system for storm water from the hilly areas has been designed to cater the catchment area up to EL +50.0 on both hills (north & south), covering the entire land within the boundary limits of the Ash Pond. The discharge calculations were carried out for rainfall intensity corresponding to a duration of one hour, for a return period of five years. A runoff coefficient (C) of 0.3 was adopted for calculations. Primary ditches 0.6 m width and depths ranging from 0.6 m to 1.10 m were provided at EL +15.0 and EL +25.0 m. The pictorial view of the storm water drainage concept adopted along the hilly sides is shown in Figure 8. Secondary ditches of 0.3 m were provided at every 5.0 m interval of elevation between and above primary ditches to intercept the rain water and channelize the water to primary ditches. The entire Hilly surface within property limits is benched to a slope of 1V: 1H. The stability of slopes was checked and found to be satisfactory.

All the storm water accumulated in the primary ditches was discharged to the collection pit provided on the east side of the embankment; from there, the water will be diverted to the seawater canal on the east side.

Fig. 8 The Storm Water Drainage and Benching along the Hilly Slopes of Ash Pond.

(B) The Drainage System for Storm Water Accumulated in the Ash Pond

The Ash Pond is designed to cater the HCSD ash disposal system which has minimal or no water causing contamination. The disposal system would be in the form of dry stacking which practically requires no return water pump house. However, the Return Water Pump House (RWPH) has been provided to handle the storm water that accumulates within the Ash Pond.

Return Water Pump Facility

The transportation of ash-slurry through dense phase mode can eliminate the need for returning water transportation. Therefore, only rain or storm water collected in the pond catchment area needs to be addressed. Rain water can be reused for ash transportation within the plant area. To facilitate this, two return water pumps have been installed in the Return Water Pump House in a 2 x 100% configuration (1 working + 1 standby). The proposed ash pond has a storage capacity of 1749203 m^3. Based on an average annual rainfall of 2.26 m, the amount of rainwater collected in the ash pond during its lifespan will be approximately 340,000 m^3. However, due to evaporation losses of 35-40%, which is around 800 to 1000 mm annually, the actual available rainwater quantity will be approximately 221,000 m^3. Therefore, the entire ash-pond return water can be used for ash-transportation. The Return Water Pump House is also equipped with two sludge recycle pumps in a 2 x 50% configuration, which facilitate the discharge of sludge from the settling pit back to the ash pond.

Other Important Aspects

Following are the other important design aspects of the ash pond.

1) The entire area of the ash pond was enclosed with fencing (2

m high PVC coated chain link) and unauthorized entry within this area was strictly prohibited.

2) The entire dyke perimeter was equipped with an accessible road of 5.0 m width with Water Bound Macadam topping for inspection purpose.
3) The lighting in ash pond area was provided according to contract requirements.
4) The ash return pump house was provided with the firefighting system.

6. Conclusion

The research paper provides a comprehensive finding related to the design and construction of ash ponds in hilly terrains, particularly in the North-Eastern regions of Vietnam. The disposal of highly concentrated slurry from coal-fired power plants poses environmental challenges, which have been addressed through the innovative use of natural hilly terrains and valleys for ash containment.

The study involved drilling 13 boreholes to assess the subsurface soil conditions. These investigations revealed three distinct layers, including fill material (Layer 1), soft sandy clay (Layer 2), and highly weathered rock (Layer 3). The low standard penetration test (SPT) values in Layers 1 and 2 indicated their low resistance.

The ash pond embankments were designed according to established standards, including a minimum top elevation, interior and exterior slopes, and a 500 mm freeboard to ensure structural stability. The High-Density Polyethylene (HDPE) liners were used to prevent the percolation of ash slurry into the embankment, ensuring a dry condition.

Geoslope Software was employed to analyze the stability of the slopes for the ash pond embankments, which included a 3.0 m wide berm at a height of 7.5 m to enhance stability. The factor of safety was maintained at a minimum value of 1.4, providing a safety margin against potential slope failures. Due to consolidated overburden soil and weathered rock formations, a slope configuration of 1Vertical:1Horizontal (1V:1H) was proposed for the hilly sides. Moreover, the extensive slope stability analyses were conducted, ensuring the safety of the ash pond in a challenging hilly environment.

The environmental aspects of the HCSD (Dense Phase) and Conventional Wet Slurry Ash Disposal techniques were compared, with the HCSD identified as the more environmentally friendly choice due to its minimal leachate production and immediate post-closure cultivation possibilities.

Detailed drainage systems were developed to manage stormwater. Two distinct drainage systems were proposed to address this concern: one for diverting runoff from the hilly portions and embankments, and another for managing storm water accumulated within the ash pond. Catch drains were constructed to prevent surface run-off from the natural hill slopes outside the pond area from entering the ash pond, thus reducing the load on the return water pump house and averting potential contamination of run-off water with the HCSD.

To ensure the stability of the embankments and ground, various instruments, such as inclinometers, piezometers, magnetic settlement gauges, and settlement markers were employed. These instruments provided real-time data, helping to identify and mitigate potential issues during and after construction.

Ethical Approval

The manuscript in part or in full has not been submitted or published anywhere and the submitted work is original and has not published elsewhere in any form or language.

Consent to publishing

All authors give their consent to publish this manuscript in this journal.

Author Contributions

All authors contributed to the study conception and design. The first draft of the manuscript was written by Anurag Goyal and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing Interest

The authors declare that they have no competing interests.

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