Experiences gained from expansion of storage capacity of a lined pond at Hindustan Zinc Ltd

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ABSTRACT: Construction of embankments on soft sludge is a challenging task owing to the inferior strength of the foundation material and excessive total as well as differential settlements. In general, the construction of embankment on such soft deposits as part of an engineered landfill project becomes critical in terms of assuring the leak-proof lining system, avoiding the risk of failure and associated environmental disasters. The stability of the structure, as well as the integrity of lining system design and engineering needs, is to be critically analyzed prior to the implementing the project. The present study illustrates the design details and insights of expansion of a lined slurry pond dyke height from existing average height of 10 m to 12 m. The perimeter of the dyke is approximately 1600 running meters. Out of this, space for outward (d/s) expansion of the dyke height was available for 1200 m, the rest of the dyke portion where its toe is situated at property boundary and hence there is no possibility of increasing the dyke height in outward fashion. This scenario imposed a unique challenge in terms of the design and planning for the construction activities including material transport.

In view of the above constraints, it is proposed to expand the 400 m stretch of the dyke in inward (u/s) fashion. This demands a need for enhancing the strength of the underlying sludge so as to withstand the loads from the proposed expansion. For this purpose, special construction techniques were deployed to enhance the strength of the underlying sludge. Prior to the expansion of the dyke in inward fashion, the sludge subgrade was strengthened by using slag which in turn is reinforced with a geogrid layer. On top of the stabilized slag an aggregate layer reinforced with a geocell was placed to form a firm foundation for expansion of the dyke height. This enabled the construction of dyke of 2 m above the sludge slurry. To control the lateral spreading of the deposited sludge upon loading, a vinyl sheet pile of height 4.5 m was installed. The sheet pile was installed parallel to the proposed dyke section at 1 m from its toe line. The inner dyke was lined with GCL and HDPE geomembrane which were connected with the respective liners at the intersections of the outer dyke and thus ensuring the integrity of the lining system. The body of the dyke was also further strengthened by introducing geogrid reinforcement layers to ensure the long-term performance of the dyke.

Keywords: HDPE geomembrane, GCL, geocell, geogrid, Vinyl sheet pile, geotextile, slope stability

1 BACKGROUND

A slurry pond was constructed at Hindustan Zinc Factory, Debari with a depth of 3 m to store Jarosite waste during the period 2000 to 2003. The side slopes of both inner and outer slopes are 1V:2H with a top bund width of 3 m. It was lined with a HDPE geomembrane of 1.5 mm thickness and protected by a geotextile layer. This landfill complied with the regulations of Central Pollution Control Board, CPCB (2001). The components of modern landfills and their construction aspects are described by Gartung (1996), Cancelli and Cazuffi (1994). The initial design and construction of the landfill followed the recommendations given in these publications. The factory was disposing their liquid Jarosite waste into this secure land fill (SLF). As the landfill was filled to its capacity, expansion of the capacity became necessary on two occasions. The height was raised to 11 m and later to 16 m in the year 2016. An aerial picture of the overall site is shown in Figure 1.

The first stage expansion of the slurry pond at Hindustan Zinc factor was carried out in 2010-11 with steeper slopes 1V:1.5 H slope of the dyke with reinforcement geosynthetics and a lining system comprising of HDPE geomembrane and geotextile. The site was operated as per the original design. However, as the capacity was about to be exhausted by 2016, management took a decision to check the feasibility of expanding it by another 2.0 m height. The various components of the slurry storage facility includes disposal system, system to pump out excess water from the slurry pond, pipe corridor for distribution of slurry at various points, dyke design.

Figure 1. Overall view of the landfill site

The technical feasibility of expanding the height and to ensure the sustainability and stability of the structure, the following techniques were adopted.

1. Reinforcement of the structure by using geosynthetic reinforcement layers across the height of the structure to enhance the stability.
2. Turfing on the outer slope for preventing erosion of the soil from the dyke section.
3. Extending the geosynthetic lining consisting of GCL, HDPE geomembrane on the inner embankment to the top of the proposed structure.
4. This pond is being used for disposal of Jarosite slurry. The leachate water is collected through the infiltration well and perforated pipelines, finally into a lined leachate pit and transferred to ETP for further treatment and reuse.
5. Pumping system on South-east corner to evacuate the excess water accumulated at SE corner.
6. Kerb wall and chute drains along the slope at an intermittent distance to remove the slope water thereby reducing the erosion of slope soil.

The maximum height of the existing embankment is 14 m and minimum height is 6 m. It was decided to increase the height of these embankments to 16.0 m and 8.0 m, respectively. The side slope is 1V:2H on the inner side of the slurry disposal pond and 1V:1.5H on the outside slope.

2 DESIGN FUNDAMENTALS OF JAROSITE POND-III EXPANSION

The main component of designing the expansion of the Jarosite pond-III by 2 m from the existing height is to carry out a slope stability analysis of expanded section throughout the periphery. In its first expansion of dyke from 558.4 m to 561.4 m, the height was increased by 3.0 m. The method adopted for expansion was done as below:

- Downstream expansion for 1200 m length (space available d/s side)
- Upstream expansion for 400 m length (space not available on d/s side)

As there was no space on a 400 m stretch on the outer slope on part of Northern and Eastern dykes, the only way to increase the height was to make a dyke of 400 m on the inner side of the slurry pond while the pond is in operation.

The jarosite pond was in operation and slurry is being continuously discharged, at a flow rate of 80 m3/hr, into the pond from the North dyke towards the South dyke. Also, as the ground slope is from West to East side, the slurry while flowing from North towards South direction slurry also was flowing towards the wall of the Eastern dyke, as shown in Fig. 2.

The other important aspect was to join the existing lining system comprising of joining of existing HDPE geomembrane to the new HDPE geomembrane. However, there were a few problems which made the project extremely challenging to design and implement.

The third challenge was to design a lining system which can connect the final lining system which will be inside the slurry pond to the existing lining system which will be outside of the inner dyke.

Figure 2. Pictorial view of the Jarosite pond-III

2.1 *A measure to mitigate space non-availability for expansion of Jarosite pond*

As sufficient space was not available on the outer side of the embankment, a slightly steeper slope of 1:1.5 was erected with geosynthetic reinforcement layers. This geosynthetic was placed across the slope width at various depth intervals to increase its stability. This was successfully executed and in the year 2010. Over the past four to five years, there was no distress in the embankment, probably due to the introduction of geosynthetic reinforcement layers and a relatively large factor of safety. As the maximum height for which it was designed was 14 m on the Eastern side, it is convincing that, we can adopt similar technology for expanding on North, South and West sides where the maximum height that will be attained is less than 14 m. However, as the overall structure's height is increasing by 2 m, additional reinforcement with uniaxial geogrid in combination with high strength geotextile is introduced in the new construction, Figure 3 and 4.

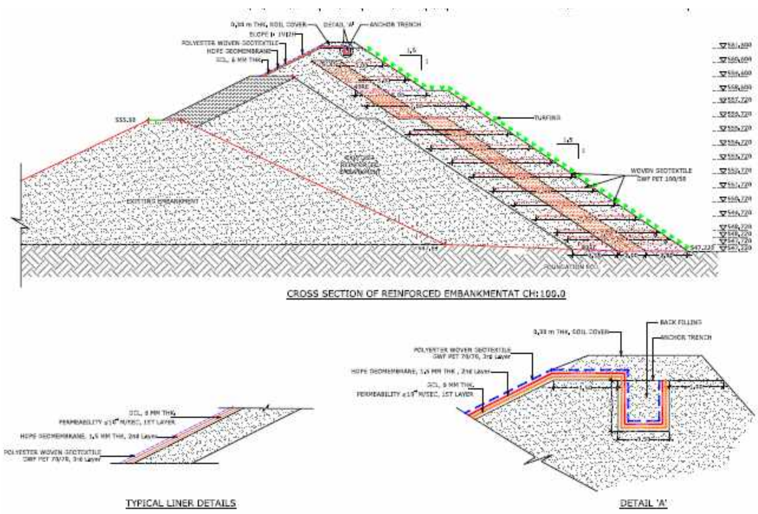

Figure 3. Schematic view of embankment height rising with HDPE liner extension

2.2 *Outer slope stability analysis and construction*

As the height of the dyke is expanded from 8-16m with slope of 1:1.5, it was estimated through engineering calculations that the slope will be unstable unless reinforced. For this reason, stability analysis performed in 2010 was taken as baseline information. Based on this, woven polyester geotextile and uniaxial geogrids were proposed as a reinforcement material for constructing the embankment. This eliminated the formation of slip circle failure. The reinforced embankment was designed using the GEO5 and RESSA computer programs to achieve a factor of safety 1.5. For global slope stability check, Bishop's slip circle method was used to find the factor of safety. The designs are carried out for both static and seismic conditions.

Following are the design parameters:

Soil Properties: Based on the soil investigation report, the following soil properties are considered for design.

Embankment Soil

Unit weight :	γ	=	21 kN/m^3
Angle of internal friction :	ϕ'	=	22 °
Cohesion of soil :	c'	=	25 kPa
Saturated unit weight :	γ_{sat}	=	21 kN/m^3

Foundation Soil

Unit weight :	γ	=	20 kN/m^3
Angle of internal friction :	ϕ'	=	19 °
Cohesion of soil :	c'	=	30 kPa
Saturated unit weight :	γ_{sat}	=	20 N/m^3.

Uniaxial geogrids were proposed at bed level and intermediate berm level and woven geotextiles were proposed at various vertical spacings throughout the height of the slope based on the design requirement, as shown in Fig. 4. Figures 5 and 6 show the views before and after the grass turfing on the outer slope for erosion control.

Geogrid reinforcement at base/intersection *Geotextile (High strength) reinforcement at intervals*

Figure 4. Geogrid and geotextile layers installation at the site

Figure 5. Pictorial view of outer slope before turfing

Figure 6. Outer slope after erosion control

2.3 *Inner base & slope stability analysis and construction*

It is also seen that, as the site does not have enough space which will enable us to start the filling up of the soil at North-East corner and going towards South-East corner and raising the height of the dyke, it is decided to construct the dyke for 400 m length from North-East end towards South-East end on inner side the Jarosite pond instead of outer side. This embankment which will be constructed on the inside of the present dyke will be 2 m in height with 1:2 slope on either side and a top width of 4 m. As soon as the length of 400 reaches which is exactly half way of the length of the Eastern dyke, the mouth of the embankment will curve towards the existing dyke. From there onwards till the end of the South-East end, the dyke will be expanded on the outer side.

The steps in the increase of dyke height by 2 m on inside of the North-East corner and towards South-East side are described in the following.

Dewatering was to be done in the beginning which will reduce the level of the sludge surface and consolidate the mass underneath. This will be followed by placing of slag and soil. A separator geotextile is introduced followed by geocell of 150 mm height filled with 20 mm down size aggregates. The geocell layer is further overlain by a 100 mm thick layer of native soil. The embankment will now be constructed on the strengthened surface. The difficulty envisaged was the continuity of the lining which will be now behind the outer embankment of newly constructed embankment. To compensate this difficulty, it is assumed that, HDPE liner on the existing anchor trench will be jointed with a new section of liner having length to cover the run out of the existing embankment, length of the proposed embankment bed and slope and anchor section of the expanded embankment, as shown in Fig. 7.

It is expected that when the consolidation and strengthening will happen on inside of the pond, water/slush may come inside the proposed embankment footprint. Hence to avoid it permanently, a vinyl sheet piling is proposed at a distance of 2 m away from the toe of the inner embankment, as depicted in Fig. 3. It will be inserted 5.5 m which will be less than the height at which the sheet piling will touch the liner. It is also designed that the vinyl sheet piling will be 4.5 m below the soil and 1.0 m above the soil.

The biggest challenge was the stability analysis of the base and slope of the inner dyke. There were many questions going in mind while designing as well as constructing. Designing and construction of the inner dyke on the slurry surface while the flow was in progression was a big challenge. Hence, few design ideas were incorporated from arresting settlement to building a slurry cut off wall.

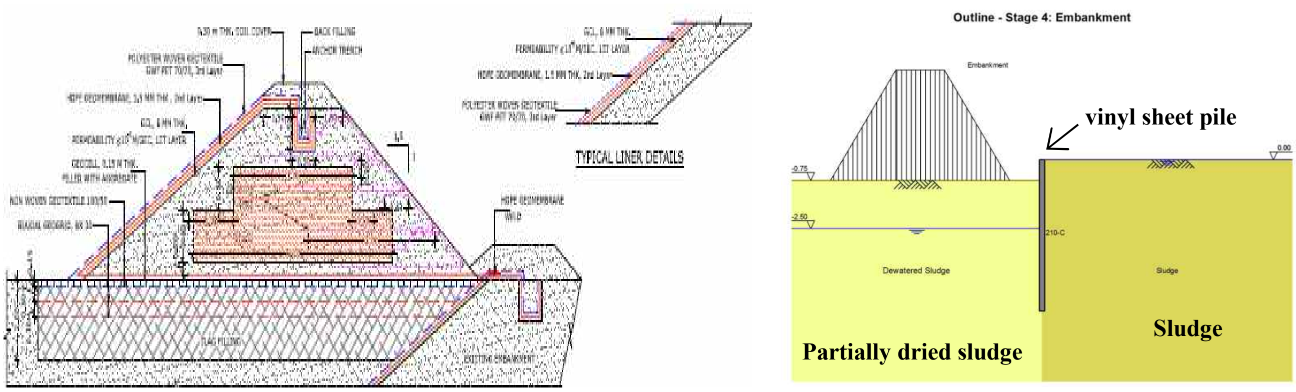

Figure 7. Schematic view of embankment height rising with vinyl sheet piling

Hence, two layers of biaxial geogrids with 30 kN/m tensile strength were proposed with a vertical spacing of 300 mm within the 2 m thick slag fill and a 150 mm thick geocell layer filled with aggregates is proposed over the geogrid reinforced foundation, as illustrated in Fig. 8.

(a) (b)

Figure 8. Application of geocells for strengthening of inner base

However, while the dilemma as whether to construct the slurry cut off wall through sheet pile followed by building the dyke or strengthening the underlying slurry surface followed by construction of slurry cut off wall posed a big obstacle. Finally, it was decided to strengthen the slurry surface by construction of hard standing which would allow the machine to operate.

Initially, the slag which was dumped posed a severe obstacle for the machines as well as the transport vehicles (as shown in Fig. 5a) and at one point of time, this looked impossible to construct. Hence, again design and drawing was checked to validate the original design concept would work eventually. The construction was slowed deliberately to allow the slag to settle and strengthen the underlying strata slowly and once it was felt that the bearing capacity has been mobilized, geogrid, separation geotextile and geocell was laid (as shown in Fig. 5b). After the geocell was filled up, it was observed that, heavy earth moving machines and transport vehicles could move and confirmed that the necessary strength has been achieved. After this dyke construction began, as illustrated in Fig. 9.

Figure 9. Construction of embankment on geocell strengthened inner base & sheet piling

2.4 *Installation of liner system*

As per the design, a clay liner, geomembrane, and woven geotextile layer were proposed as liner system on inner slopes of the expanded embankment. As difficulties were experienced in compaction of clay on the inner slopes of the embankment, it is proposed to lay geosynthetic clay liner with equivalent permeability criteria of $< 10^{-9}$ m/sec.

The liner system on the outer dyke was fairly straight forward as the existing lining system was to be joined with the new liners, as shown in Fig. 10. To do that, the soil fill on the old liner was removed, the old liner was cleaned up and the new liner was joined and tested.

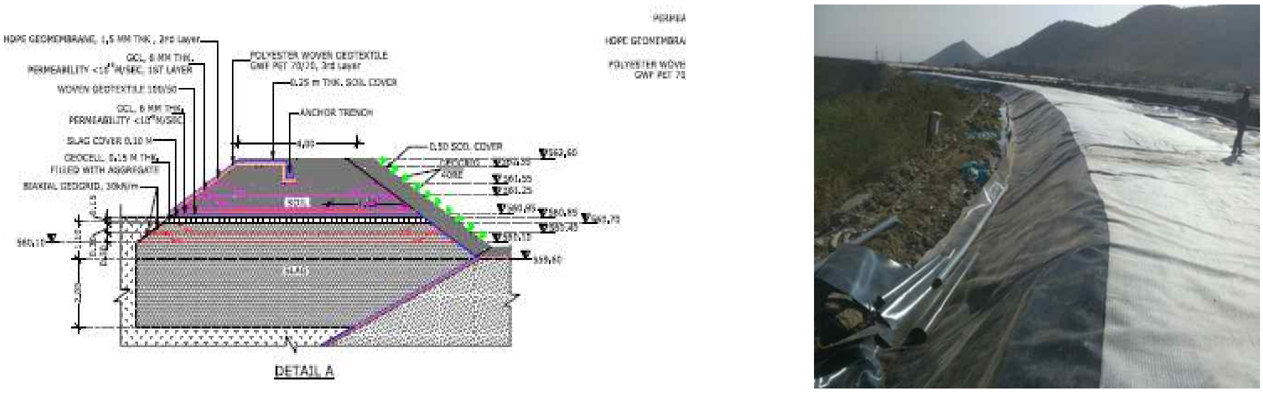

Figure 10. 10 HDPE lining on outside raised portion of the dyke

The difficulty came on the junction of inner dyke with outer dyke as the location of the inner liner of the outer dyke, outer liner of the inner dyke and the existing liner had to be joined in such a way so that, no open surface remains and the junction was welded properly. Extrusion welding was done at these points and further tested with water to cross check.

Another difficulty was to connect the old liner which was outside of the inner dyke slope toe line. As this liner must be welded and continually moved on the bed of the dyke and laid over the slope and the anchor trench.

As per original scheme, the HDPE geomembrane was to be protected against the UV rays and hence, a geotextile was laid over it, as shown in Fig. 11.

Figure 11. HDPE liner covered with geotextile protection layer

3 CONCLUSIONS

It can be broadly concluded that, with proper knowledge and understanding of various geosynthetic materials, its properties and it applications, space as well as engineering limitations can be overcome. The described case study is a worthwhile demonstrated project wherein, space, materials, operating parameters still allowed us to expand the dyke while the dyke was in operating condition. The authors are keen on demonstrating the modern geosynthetic materials in large projects with engineering, space and operating limitations.

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