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Behaviour of an upstream stack formed with geotextile wrapped dikes

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ABSTRACT: In order to increase storage capacity of Residue Disposal Area 2 at Alumar plant an upstream stacking system was devised consisting of small contention dikes built on top of the existing residue and forming a slope. The initial upstream dike was 1m high, formed by refractory bricks wrapped by a geotextile. Subsequent dikes 40cm high were built using three geotextile tubes wrapped and tied together by non-woven geotextiles. Overall slopes were initially 5H:1V, flattening after 5m high to 10H:1V. Residue discharge was done from the crest of the slope and water drainage done by buried horizontal and vertical perforated geotubes and, subsequently, by decants in the center of the stack. Overall behavior of the stack was highly satisfactory, with no records of instabilities, reduced horizontal displacements of the initial dikes and limited overflow occurrences. The use of small dikes enabled a continuous operation of the stacking system since construction of dikes could be done simultaneously with residue discharge, in opposite sides. The stacking and the RDA have recently undergone complete rehabilitation.

1 INTRODUCTION

Alumar refinery produces approximately 1.3 million tones of alumina per year, generating about 960,000 tons of residue. This residue is disposed in areas formed by conventional compacted soil dikes, having storage capacities of 4.0 to 5.0 million cubic meters. The Bauxite Residue Disposal Areas (RDAs) are fully lined due to the high causticity of the residue (pH=13) and the presence of high metal concentrations.

The implementation of each of these areas cause a significant environmental impact due to the extensive areas to be cleared and use of natural construction materials obtained in borrow areas. The possibility of extending the storage capacity of the RDAs is therefore of great interest, particularly without increasing their footprints. Reduced footprints also reduce the overall risk of future contamination.

The present paper describes the technique of Upstream Stacking which has been employed on top of RDA 2 at Alumar plant for additional residue storage, including data about its behaviour until complete rehabilitation.

2 DISPOSAL SYSTEM

The Alumar RDAs are formed by perimeter dikes built of compacted local soil, having their base and internal slopes lined with a single composed liner formed by a 0.8mm PVC geomembrane and a 50cm thick compacted clay layer. A base drainage system is placed on top of the geomembrane for reduction of hydraulic head on the impermeabilization system and for collection of the caustic liquor.

The residue is pumped from the Alumar refinery to the RDAs, located about 6 km away, at solids content (in weight) of about 15%. The recirculated liquor from the RDAs is used for pumping.

In the conventional disposal system, inside the contention dikes, the maximum residue elevation is about 1.0m below the crest of the dikes, corresponding to a typical average residue thickness of about 15m.

RDA 2 at Alumar has operated conventionally from 1990 to 1997, with a total storage capacity of 4.0 million cubic meters. Its surface area (about 32 Ha) was left exposed until 2000. In order to increase RDA 2 storage capacity without increasing the footprint, an upstream stacking system was devised consisting of small contention dikes built on top of the existing residue surface and forming a slope.

3 BASIC ASSUMPTIONS

The following basic requirements for the upstream stack were considered during design studies:

(i) the perimeter dikes would be of small height (0.30 to 0.50m), in order to facilitate construction on the residue;

(ii) use of the same residue discharge system and conditions (solids content, flow);

(iii) other residues from the plant should preferably be used for dikes construction;

(iv) final stack geometry should guarantee the stability of the slopes and of the external dike due to the surcharge;

(v) install an overflow system with a discharge capacity sufficient to handle the flow of water from the residue plus that due to a rainfall with a 100 year return period without risk of overtopping over the slope dikes;

(vi) construction of the first upstream dike at a minimum of 25m away from the external contention dikes.

The studies to support the design decisions considering the above assumptions involved hydrological analyses for definition of rainfall characteristics, hydraulic flow analyses for spillway and decant definitions and geotechnical investigations for settlement and stability studies of the stack.

4 ADOPTED SOLUTION

The upstream stack was conceived with the following arrangement:

- Construction of dikes parallel to the external contention dikes of RDA 2, leaving a safety distance of 25m between the stack foot and the external dikes, except in the northwestern corner were a basin for flood storage was left to accommodate the extreme rainfall flows before discharging to RDA 3 through a surface spillway;
- Initial dike about 1.0m high formed by used refractory bricks (residue) from Alumar smelter, wrapped by nonwoven 300gr/m^2 polypropylene (PP) geotextiles. The construction of the initial dikes is shown in Figure 1 and its initial operation in Figure 2;
- Subsequent small dikes about 40cm high, built using 3 geotextile tubes 25cm in diameter, wrapped and tied together by nonwoven PP geotextile. The 1.5m long geotextile tubes were filled with used plastic cups and bottles and transported to the site by hand. Figure 3 presents the assembly of these dikes with the geotextile tubes. Bags filled with residue sand were also occasionally used for dike construction;
- Overall slopes, defined by slope stability calculations based on the initial geotechnical investigations, were initially 5H:1V. Subsequent site investigations, when the stack was 3.5m high, required their flattening to 10H:1V after 5.0m height, maintaining the factor of safety of 1,5.
- A maximum height of 6.5m was attained by the stack on top of the existing residue, while according to the stability studies 8 to 9m high could be reached, due to operational restrictions of the plant associated with excess water in its balance;
- Residue discharge, by wet technique at the current average solids content of 15%, is done inwards from the dikes crests using flexible polyethylene tubes 10 cm in diameter;
- Drainage of water was initially provided by perimeter drainage 20m wide along the base of the stack near the initial dike, discharging to the peripheric channel by flexible polyethylene tubes under it, complemented by a mesh of vertical perforated flexible polyethylene tubes wrapped with nonwoven 200 gr/m^2 PP geotextile, spaced every 20m. Subsequently, drainage was done by decants formed by circular Armco tubes 2.6m in diameter, installed in the centre of the area and discharging to the perimeter channel by 4 buried flexible polyethylene geotubes 30cm diameter each.

A typical cross-section of the upstream stack is shown in Figure 5.

Figure 1. Construction of initial dike

Figure 2. Operation of initial dike

Figure 3. Assembly of dikes using geotextile tubes

Figure 4. General view of drainage tubes and decants.

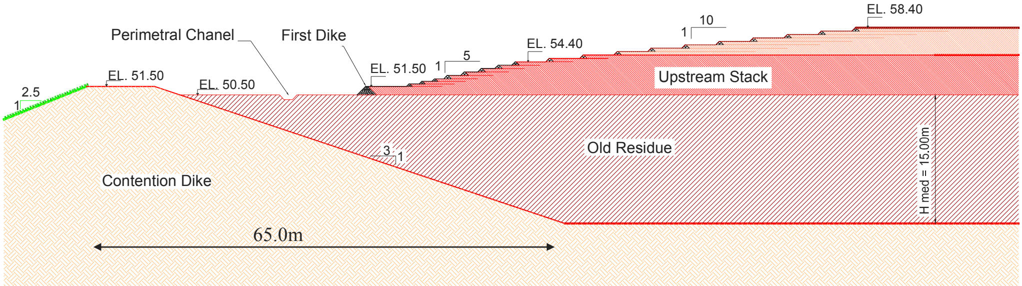

Figure 5. Typical cross-section of upstream stacking

5 UPSTREAM OPERATION

Residue discharge for filling of the first dike took place between May and September 2000. Subsequently, residue discharge was done simultaneously to the construction of the small dikes 0.40m high. The formation of the stack was done until February 2004, with interruptions during the rainy season. The operation had to be stopped in order to rehabilitate the area in the second semester of 2004.

In general, the operation occurred without major problems. In a few occasions localized displacements of the geotextile tubes occurred due to water flow underneath the dike and only in a few instances very limited overflow occurred over the stack crest, without any risk to the slope integrity. The simultaneous residue discharge and construction of new contention dikes on opposite sides of the stack was done successfully, considering the size of the stack area.

The internal drainage system operated well. With free water, the perimeter dikes provide free drainage, but as soon as the residue touched the geotextile, its efficiency was greatly reduced due to impregnation by the residue fines. The same occurred with the vertical drainage geotubes but they remained operational, with limited flows being observed even after complete buried in residue.

The flexible discharge system from the crest formed a sandier beach 5 to 10m wide along all the dikes perimeters, which enabled access to personel 2 to 3 days after discharge was stopped at that point and greatly facilitated construction of the new dike and excavation of the residue to fill bags if required for dike construction or access preparation.

Figure 6 shows a photograph of a general view of the upstream stack of RDA 2 in the final stages of operation.

Figure 6. General view of stack

6 OVERALL GEOTECHNICAL BEHAVIOUR

The geotechnical behaviour of the upstream stacking operation was monitored by:

- 11 settlement plates in the central part of the stack, placed on top of the old deposited residue;
- 17 displacement measurement points on top of the initial dike, registering horizontal and vertical movements;
- Measurement of residue density, shear strength and pore pressures at several depths in the upstream and old residue twice during upstream operation.

The overall behaviour of the stack was very satisfactory, with no records of local instabilities or indications of overall movements of slopes. The settlements measured by the plates under the upstream stack are shown in Figure 7. Vertical movements of the order of 30 to 50cm are observed without a clear tendency for stabilization up to June 2004, while the predicted final settlements during design studies were of the order of 105cm.

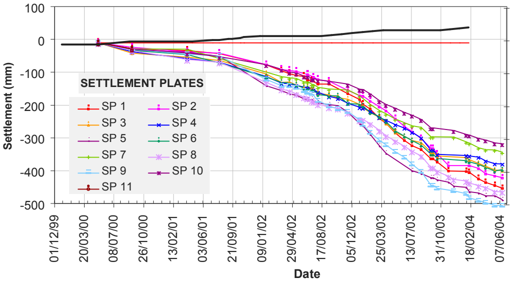

Figure 7 - Settlements of plates under the stack

Vertical movements observed on top of the initial dike varied between 3 and 5cm. Only in an area of softer residue around the flood basin, larger settlements, of the order of 10 to 18 cm, were observed, and these are already stabilized. Typical horizontal movements measured in the same points are shown in Figure 8. All horizontal movements occurred in the direction into the stack and are probably controlled by the stack settlement, with maximum values of the order of 7.5cm. Most of the horizontal movements occurred during the second semester of 2001, coinciding with the second stage of operation of the upstream, immediately after filling of the initial dike.

Measured pore pressures in June 2004, 4 months after end of operation of upstream stacking , show a perched water table about 2m from upstream surface and positive in the old residue. This can be compared with data from the investigations before upstream operation, which indicated negative pore pressures (suctions) in the upper 5.0m of residue (desiccated crust).

A reduction in average undrained shear strength from the 20kPa was noted in the desiccated crust of

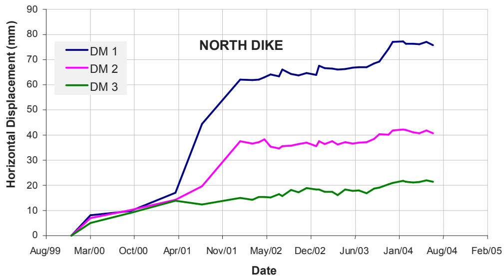

Figure 8. Horizontal movements of initial dike

the old residue after rewetting it with the stacked residue and was taken into account during reevaluation of the stack stability.

7 CONCLUSIONS

The extensive use of geotextile wrapped dikes for upstream stacking of residue on a previously operated RDA proved to be a highly satisfactory solution from the operational, economical and environmental points of view.

At the end of operation, about 1.35 million cubic meters of residue were stored in the upstream stack, which corresponds to more than 30% increase in storage capacity of RDA 2.

The overall behaviour of the stack during dike construction and upstream operation has been very good, with reduced settlements and horizontal displacement and no records of instabilities or excessive movements of the slopes. In particular, the use of geotextile tubes filled with plastic residue and wrapped with non-woven geotextile proved to be a very practical solution for dike construction in small stages, compatible with the required rate of raising of the stack without having to interrupt the residue discharge operation.

The geotechnical studies and continuous evaluation of stack behaviour enabled the formation of the stack in satisfactory safety conditions.

The stacking and RDA 2 have undergone a complete rehabilitation recently and a new similar stacking operation will be started on top of RDA 3, which has finished conventional operation.

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