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Extensive use of geosynthetics in the rehabilitation of an old industrial waste deposit

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ABSTRACT: Reahabilitation of the surface of bauxite residue deposit nr 3 at Alcoa Poços de Caldas plant involved extensive use of drainage, impermeabilization and reinforcement geosynthetics. The quantities involved were 36,000m² of woven geotextile, 4,000m² of geogrid, 341,000m² of non-woven geotextiles, 140,000m² of drainage geocomposites and 275,000m² of geomembrane. A description as presented of the choice of geosynthetics types, the design criteria used for each layer, construction observations and initial performance evaluation.

1 INTRODUCTION

Bauxite Residue Deposit (BRD) nr.3 of the Poços de Caldas ALCOA aluminium plant has been formed by a valley closure in the early eighties and has operated until 1990. Since then, its surface was left exposed, with occasional use as water storage during rainy periods. Its total surface area is about 25 Ha. The residue is a very soft saturated clayey silt, filling the whole valley and with a maximum depth of about 16 m next to the valley closure dyke. The existing pore fluid is caustic soda, pH 12 to 13.

In accordance with ALCOA standards, a decision was taken to rehabilitate the entire deposit surface. The closure eliminates the need of treatment of rainfall water falling on the area before discarding it to the environment as well as of irrigation water used to supress dust during the dry season.

The final arrangement for the rehabilitation of BRD nr. 3 is shown in Figure 1, consisting of earthfills placed on the residue with the final shape, covered by vegetation, providing superficial inclination for rainfall drainage.

2 DESIGN REQUIREMENTS

The following basic requirements were considered during design studies:

(i) Since the residue was deposited directly on the valley surface, without bottom impermeabilization, it was considered necessary for the rehabilitation to inhibit infiltration into the residue;

(ii) The large settlements expected for the earthfills placed on the very soft residue, required a flexible impermeabilization system (i.e.a geomembrane);

(iii) Natural drainage materials (coarse sand, gravel) are not easily available in the region, and are very expensive. Therefore, the use of synthetic drainage materials becomes very attractive;

(iv) It is of interest both from environmental and economical points of view to recover as much liquor as possible from the residue, which will be expelled during its consolidation;

(v) The final geometry of the earthfills had to be defined considering that after settlement due to residue consolidation, the final surface slopes would be of the order of 0,5 to 1,0%.

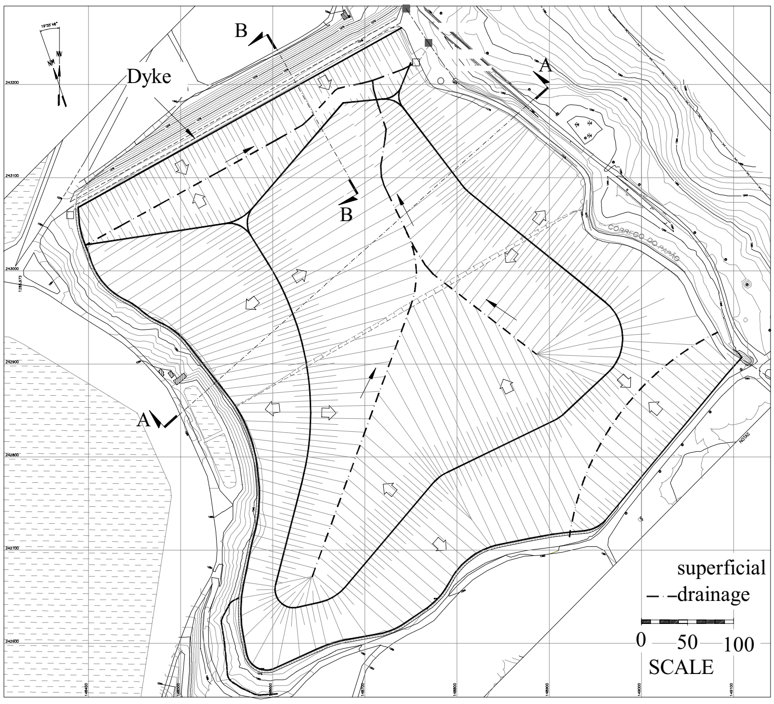

Figure 1 – Final Arrangement of BRD#3 Rehabilitation

Table 1. Geosynthetics Used in BRD#3 Rehabilitation

Geosynthetic Type	Main Characteristics	Quantity
Woven Geotextile	Polypropylene, tensile strength (NBR 12824): LD: 55kN/m TD: 35 kN/m	36,000 m²
Biaxial Geogrid	PVA, tensile strength (ASTM D-4595): 70kN/m	4,000 m²
Non-woven Geotextile	Needle punched, polypropylene, mass per unit width 400 gr/m², transmissivity (ASTM D-4716) ≥ 8x10^{-6} m²/s under 30 kPa, i = 0.1	341,000 m²
Drainage Geocomposite	Polyethylene geonet, between 2 heat bonded polypropylene geotextiles, flow per unit length (ASTM D-4716) > 5 x 10^{-5} m²/s under 30 kPa, i = 0.1	140,000 m²
Geomembrane	PVC, 0.8 mm thickness, tensile strength (ASTM D-822) ≥ 10 kN/m, seam strear strength (ASTM D-3083) ≥ 10 kN/m	275,000 m²
Geopipe	Polyethylene, flexible, slotted, corrugated	16,500 m

These requirements, together with construction constraints and planning, were then incorporated in the final design.

3 ADOPTED SOLUTION

The environmental rehabilitation of the BRD # 3 consisted of the following layers, from bottom to surface:
- a drainage layer on the residue surface to collect and direct to the industrial plant the liquor ascending from the residue due to the load to be placed; this layer is formed by alternating strips of drainage geocomposite and non-woven geotextile; Additionally, along the valley closure dyke, where softer areas of residue were found, a reinforcement was required under the drainage layer;
- a compensating fill layer, with variable height in order to maintain a sloping ground after settlement of the residue;
- an impermeabilization layer formed by a compacted soil layer and a 0,8 mm thick PVC geomembrane;
- a drainage layer to collect infiltrating rainfall water placed over the geomembrane; this layer is also formed by alternating strips of drainage geocomposite and non-woven geotextile;
- a final conformation soil layer, covered by an organic layer and vegetation.

Figures 2 present typical sections illustrating the adopted solution.

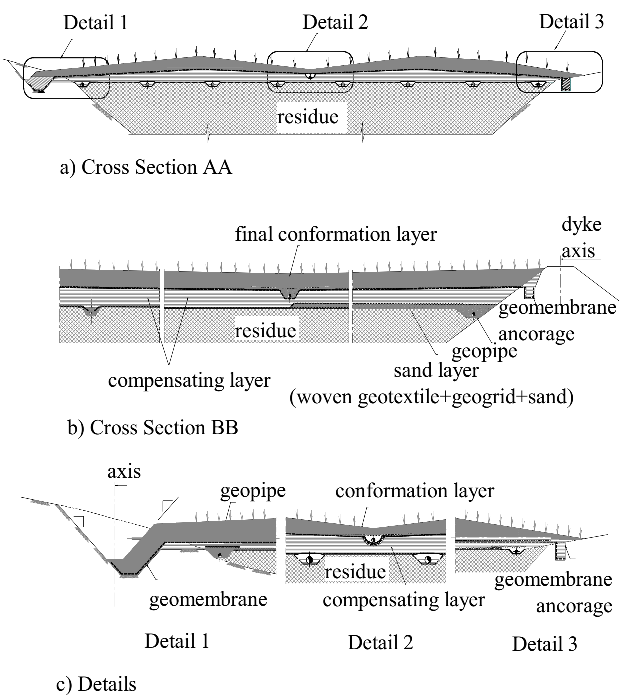

Figure 2 – Typical Cross Sections and Details

Table 1 presents the description and total quantities of the geosynthetics used.

4 DRAINAGE LAYER ON RESIDUE SURFACE

The drainage layer to collect the liquor from the residue is formed by strips of drainage geocomposite and geotextile. The geocomposite has a polyethylene net between two heat-bonded polypropylene geotextiles. The geotextile strip is a needle punched non-woven polypropylene fabric.

The choice of polypropylene geotextiles was due to the contact with caustic soda in the residue in the lower layer. During the bidding process, the same supplier was chosen for both drainage layers due to unit price reduction considering the increased area to be supplied.

In the initial stages of design of the drainage layers, only drainage geocomposites were considered due to its high in-plane flow capacity. However, its high unit price (around US$ 5.00/m²) and the need to reduce total rehabilitation cost, led to the solution of replacing part of the geocomposite by a non-woven geotextile in alternating strips.

The strip widths were defined considering:
- Liquor inflow computed as indicated by Koerner (1998) and assuming a safety factor of 2.0.
- Maximum hydraulic head of 0.5 m in the geotextile and drainage geocomposite;
- Overall reduction factor of 5.0, applied to MARV values of transmissivity and flow per unit width of the geotextile and geocomposite respectively, defined for a vertical pressure of 30 kPa.

The adopted strip width were 4.0 m for the geocomposite and 8.0 m for the geotextile, facilitating the use of standard factory furnished widths. Figure 3 shows the adopted arrangement. The panels were installed directly over the residue, parallel to the dyke access; except next to it, where they were installed in the transversal direction. Considering the probable hydraulic head in the drainage system associated with residue settlements, and to enhance the liquor collection and drainage 8 trenches were excavated in the residue in the upstream-downstream direction. The trenches were lined with polypropylene non-woven geotextile, filled with sand and with a flexible polyethylene slotted pipe in the bottom (see Figure 4). The eight pipes converge to a single collecting tube, which leads to a sump in the deposit abutment. The tube entrance in the sump is at an elevation below the minimum predicted for the residue surface after settlement. At the sump, the overall liquor flow can be measured before pumping it to the plant.

Along a 40 m wide zone next to the closure dyke, where more difficult construction conditions were expected due to softer residue, a sand drainage layer was designed wrapped by a woven polypropylene geotextile (see Figure 2). This layer, besides its grater drainage capacity, provide adequate support for trucks and spreading tractors. The woven geotextile had its minimum MARV nominal strength defined as 35 kN/m, for a global reduction factor of 2.0, in agreement with the procedure proposed by Palmeira (1999). In a limited stretch of very soft residue, the use of an isotropic PVA geogrid was necessary on the woven geotextile, with a minimum nominal strength of 55 kN/m.

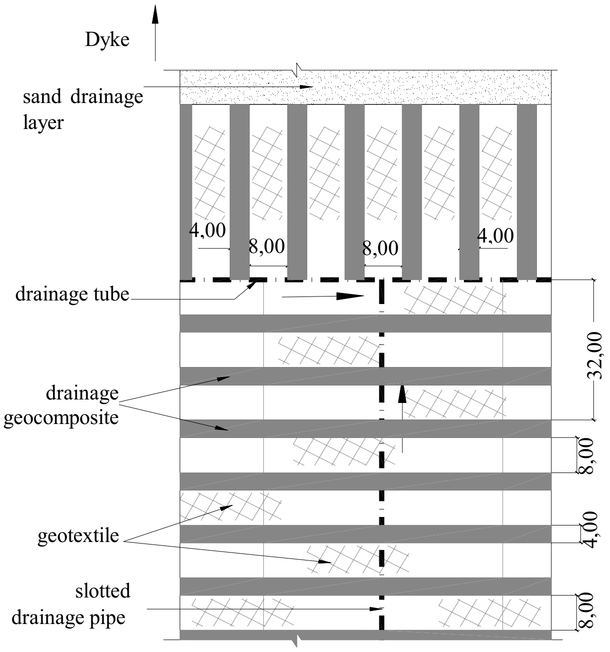

Figure 3 – Geosynthetics Modulation – Drainage Layer on Residue

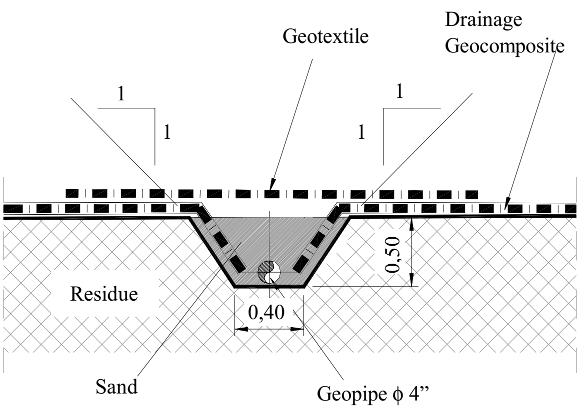

Figure 4 – Detail of Drainage Trench

5 IMPERMEABILIZATION AND INFILTRATION COLLECTION LAYER

Over the final compacted layer of the compensation fill, a 0.8 mm thick PVC geomembrane was installed.

A very flexible geomembrane was required to accommodate the settlements, both total and differential in localised soft areas, and to facilitate the installation of the drainage ditches for the geopipes in the upper drainage layer. The very thigh construction schedule, with several activities occurring at the same time on the site, also required the use of factory fabricated large panels (around 1000m²) with a minimum of field seams. All these reasons led to the choice of PVC geomembranes.

The drainage layer to collect infiltration water from rainfall was placed on the geomembrane and is formed by strips of drainage geocomposite and geotextile, similar to those used in the drainage layer over the residue. The strips widths were 4.0 m for the geocomposite and 8.0 m for the geotextile. The field arrangement of the strips was variable, in order to follow the maximum slopes of the earth fills, indicated in Figure 1.

The infiltration flow was estimated considering the capping soil as saturated and with a permeability equal to 5.0 x 10^{-6} cm/s, obtained from tests carried out on samples of compacted earthfill. This flow calculation is probably conservative, and, for this reason, no factor of safety was used in the design of the drainage system.

However, the reduced transmissivity of the geotextile, associated to an overall flow reduction factor (clogging, etc) of 5, required the use of geopipes intercepting the drainage layer to reduce its length and provide adequate flow capacity for the system, without allowing excessive dampness of the vegetation layer.

The solution used also had to take into account the large settlements (of the order of 1.5 m) of the rehabilitation fill due to the residue consolidation for the calculations of the final declivities, which are of the order of 0.5 to 1.0%, aggravated by the long extensions of drainage, therefore reducing the total flow capacity of the drainage layers (geocomposite and geotextile).

It was therefore found necessary to install flexible slotted polyethylene geopipes in ditches disposed obliquely to the drainage strips every 25 m approximately, as shown in Figure 5. The water collected in the geopipes is discharged in peripheric open ditches.

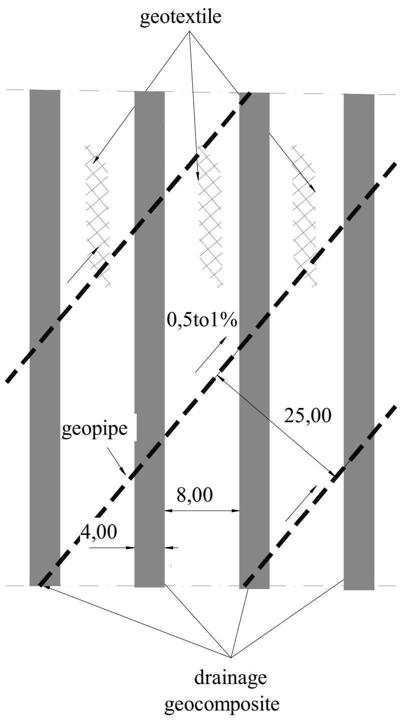

Figure 5 – Geosynthetics Modulation of Infiltration Collection Layer

6 CONSTRUCTION AND INSTALLATION OBSERVATIONS

The works were performed in two stages, in the dry seasons (april to november) of 2000 and 2001, advancing from downstream to upstream.

The following main observations can be mentioned:

- Despite the existing woven geotextile and drainage layer next to the closing dyke and the geogrid reinforcement, some settlements and upheavals were observed in the residue, requiring careful spreading, eventually manual, of the sand layer and soil fill.
- In the remaining area on the residue, a few settlements were observed under the geotextile or drainage geocomposite during initial spreading of soil.

- The double seams between the geotextile and geocomposite strips were made with the lower geotextile of the geocomposite, with the seamed stretch folded over the geocomposite, in order to guarantee flow continuity.
- Covering of geotextile and geocomposite panels in both levels was generally done no later than 48 hours after their placement and seaming, reducing therefore the risk of their displacement by wind or excessive exposure to solar radiation and dust.
- All geomembrane panels were thermally welded and tested using compressed air. The entire geomembrane surface was spark-test tested.
- The QC/QA system included:
  - Presentation of proof test results of specific properties of geotextiles, geocomposites and geomembranes before bidding, carried out by independent laboratory;
  - Accompanying the arrival of every material to the site, the supplier had to provide test results for each lot;
  - Execution of destructive tests in the field seams of geotextiles/geocomposites and of geomembranes.

7 INITIAL PERFORMANCE

Immediately after the installation of the collection liquor drainage system, it started to operate continuously, but with variable flows as function of the construction schedule.

To the present moment (march 2002), the drainage system operates satisfactorily, having been recovered about 25,000 m^3 of residue liquor, with variable flows between 3.0 and 6.0 m^3/h.

Associated to liquor recovery, settlements of the order of 0.2 to 0.6 m were observed until this moment, still well bellow the final estimated values.

Finally, the drainage layer over the geomembrane is operating well, with discharges from the buried drainage pipes after rain periods and with vegetation well consolidated in the whole area surface.

8 CONCLUSIONS

The intensive use of drainage, impermeabilization and reinforcement geosynthetics for rehabilitation of the BRD#3 was a determining factor for the fulfilment of the cost and time schedule proposals.

The problems encountered during construction were of small magnitude, practically restricted the initial stages of geosynthetics and fill placement on the very soft residue.

The rehabilitation behaviour until the present moment is fairly satisfactorily.

9 ACNOWLEDGEMENTS

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