Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Case history: PVA geogrid reinforced wall for a residue deposit facility

Paes Jr., G.
Alcoa Alumínio do Brasil, Poços de Caldas, Brasil

Costa Filho, L.M.
LPS Consultoria e Engenharia, Rio de Janeiro, Brasil

Pacheco, E.
LPS Consultoria e Engenharia, Rio de Janeiro, Brasil

Silva, A.E.F.
Huesker Ltda, São José dos Campos, Brasil

Keywords: reinforced wall, geogrids, PVA, stiffness, chemical resistance

ABSTRACT: In order to reduce the environmental impact and the soil movement volumes on the construction of a Residue Deposit Area (RDA 7) at Alcoa Poços de Caldas plant, a solution was adopted concerning to a 5 m high reinforced fill with steep external face on top of the earth dike, 1700 m long. Due to the high pH of the deposit material (NaOH contaminated sludge), a special chemical resistant geogrid was required. High tenacity PVA yarn geogrids were selected for the project and rigid quality control procedures for delivering and installation follow-ups were adopted. After 4 years of the end of construction, negligible displacements of the wall face were measured on two different instrumented control sections.

1 INTRODUCTION

At the Poços de Caldas ALCOA aluminum plant in Minas Gerais state, Brazil, the recent bauxite Residue Disposal Areas (RDAs) have been built using perimeter compacted earth fills with internal slopes 2.5H:1V and external slopes 2H:1V with berms every 10 m height. The construction material for the dikes was obtained by excavation in the internal part of the deposit area and the geometric dimensions of each RDA were defined targeting a balance between cut and fill volumes. The internal slopes and the bottom of the deposit have a single sealing system consisted of a 0.8 mm thick PVC geomembrane over a 50 cm thick compacted clay layer. The residue is a very soft silty-clay, discharged as slurry at low solids content and having caustic soda (pH 12 to 13) as fluid. During filling a standing body of caustic fluid exists over the residue.

The area occupied by the plant RDAs is very hilly, with elevation differences of the order of 40–50 m to the adjacent valley bottoms. All recent RDAs have been built on top of the hills, with the dikes external slopes sited on the inclined natural terrain.

During design studies for the construction of the RDA 7, the available location implied in excessively long earth fills, extending over natural slopes and getting very near the floodplain of the adjacent creeks. Also, some protected ciliary bushes could be affected. Therefore, due to the excessive volume of earth fills and to reduce the environmental impact, a solution was studied involving a reinforced soil wall for the upper part of the perimeter dikes.

2 BASIC ASSUMPTIONS

The following basic requirements for the reinforced soil wall were considered during design studies for the RDA 7:

(I) The storage capacity of the reservoir (about 1.5×10^6 m^3) had to be kept, compared to the solution without reinforced wall;
(II) As an additional guarantee, the reinforcement had to be made from a caustic resistant polymer. Due to that, HDPE, PVA or PP geogrids or geotextiles could be used in a first view;
(III) A maximum 5.0 m high reinforced soil wall was considered as reasonable, due to the fact that there was no previous experience of this type of solution, particularly using the locally available clayey-silt residual soil. For the same reasons an external slope 5V:1H was selected for the reinforced soil.

3 SELECTION OF REINFORCEMENT

A preliminary design of the reinforced wall was developed considering the assumptions above in order to select the type and arrangement of the reinforcement. Both geogrids and woven/nonwoven geotextiles available in the Brazilian market were considered for use as reinforcement.

The commonly used geogrids are made of polyester, and were therefore not suitable. Alternative geogrids available are those made of PVA or HDPE. The PVA geogrid has higher stiffness and lower reduction factor (about 2.0) to be applied to the MARV nominal strength. Nonwoven PP geotextiles have higher deformability and require higher reduction factors (about 4.0 to 5.0), which would lead to a larger number of reinforcement layers in this case. This smaller vertical spacement offset the lower cost per unit area of the nonwoven geotextile. The available woven geotextile is made of PP and also requires high reduction factors particularly due to creep effects.

Several reinforcement arrangements were considered for the wall, including variations on separation and nominal strength. A PVA geogrid was selected, despite its apparent higher unit price, due to:

- higher stiffness, with consequent smaller wall deformations and displacements;
- greater anchorage resistance;
- the standard woven geotextile (50 kN/m) requires a small vertical spacing, whereas the PVA geogrid enables vertical spacings of 40 to 60 cm, with less construction constraints.

Additional studies led to an optimization in the geogrid characteristics, with the selection of PVA geogrids of 55 and 35 kN/m nominal strength in different heights of the wall. FORTRAC MP PVA geogrids manufactured by Huesker were used. Figure 1. presents the isochronous curves of the used PVA geogrid.

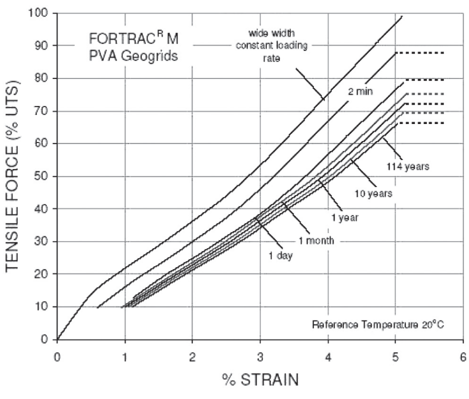

Figure 1. Isochronous curves of the selected PVA geogrids (TRI 2002).

4 ADOPTED SOLUTION

The general arrangement of the perimeter dikes with the reinforced wall is shown in Figure 2, from which it can be noticed the extension that the external fill slopes would require if this solution were not adopted.

An optimal design led to the specification of panels of geogrids with nominal strength of 55 kN/m on the 6 bottom layers and layers of geogrids with nominal

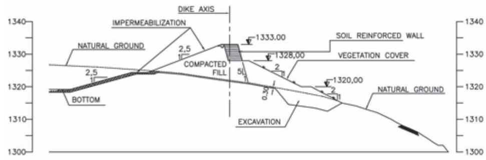

Figure 2. Typical cross section of the upper dike.

strength of 35 kN/m on the 3 upper ones. Figure 3 shows the cross-section of the wall. The external face protection consisted of bags of organic soil with seeds, wrapped by the geogrids, and an erosion control mattress covering the whole face. The total length of the wall is 1710 m, with constant height.

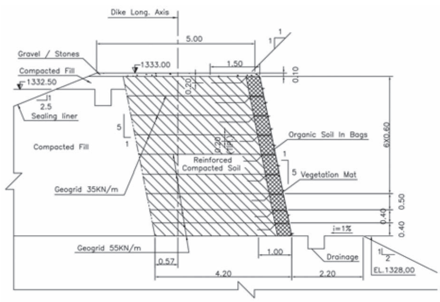

Figure 3. Typical cross section of the reinforced fill.

5 DESIGN STUDIES

The soil used for the construction of the reinforced wall is a residual soil derived from nefelinic sienite, consisting of a silty-clay with the following geotechnical average characteristics:

- Percentage < # 200: 47.2%.
- LL = 60%; PI = 27%.
- Natural water content: 36.5%.
- Maximum dry unit weight: 14.1 kN/m^3.
- Optimum water content: 31.5%.
- Effective strength parameters: $c' = 5$ kPa, $\phi' = 29°$.

Overall dimensions of the reinforced wall were defined by external stability analyses (overturning, base sliding, foundation bearing capacity and global stability) with fairly satisfactory results compared to conventional minimum requirements (ABINT 2004).

Internal stability analyses were performed to define vertical spacing and anchorage lengths of the geogrids. A value of $tg\delta' = 0.8\ tg\phi'$ was used for anchorage studies, as suggested by ABINT (2004), with a target minimum factor of safety of 1.5. An overall reduction factor of 2.0 was applied to the geogrids MARV tensile strength.

The following loading conditions were used for design studies:

(a) Uniform surcharge of 10 kPa on the entire upper platform;

(b) Concentrated surcharges due to vehicles, 60 kN per wheel, with 3 axles;
(c) Surcharge due to rolling tampers and hand-held compactors, with their associated pressure diagrams;

Surcharges on situations (a) and (b) are not applied simultaneously. In fact, construction surcharge on situation (c) greatly exceeds the loading due to the previous surcharges.

6 CONSTRUCTION OF THE WALL

The wall was built in two construction seasons (dry periods of 2001 and 2002) due to large earthmoving volumes of the perimeter dikes and the relatively short dry period in the region.

The following construction sequence was employed for each layer of wall construction:

(I) Machine leveling of the previous layer;
(II) Spreading of the geogrid, cutting of 5.70 m length to include the face anchorage length. Staples were used to fix the geogrids to assure good positioning. Roll width was 3.7 m and a 10 cm overlaps were used for adjacent panels;
(III) Installation of the bags, and wrapping back of the geogrids, fixing them with staples;
(IV) Spreading and compaction of the strip of soil, about 1.5 m wide, adjacent to the bags, by hand tampers in layers of about 13 cm of thickness. Compaction trials with rollers produced large displacements of the bags;
(V) Careful spreading and compaction of the remaining soil layer, including the total dike width, using Dynapac CA-25 vibratory rollers, and a layer thickness of 20/25 cm.

Strict topographic and compaction control were used throughout wall construction. At least one sample was collected daily or for each 500 m^3 compacted layers to check compaction conditions. In order to reduce risks of geogrid damage during construction some procedures were employed:

(I) Trial tests were performed with the equipment in an experimental fill prior to wall construction using the same procedures to actual construction, with openings of several inspection pits;
(II) The soil was brought to the site in the correct moisture content for compaction;
(III) Use of light bulldozers (CAT D4), with lower pressures, with specially trained operators, to spread the soil layers;
(IV) Fixing the geogrids to the soil surface by staples after stretching them;
(V) Opening of random inspection pits through the soil layer to check the geogrid integrity. This was particularly frequent in the bottom compacted layers.

Due to the large number of subsequent operations during construction of the RDA, of which the reinforced wall was one of the most critical ones, careful planning had to be emphasized throughout the works. It included adjustments in construction procedures to maintain productivity of the services and the overall schedule. In the first construction season productivity was of the order of 115 m^3 of reinforced fill per day. After adjustments, the use of two independent crews, and with more experience, productivities of the order of 260 m^3/day were reached throughout the second construction season, with peaks of 300 m^3/day being attained.

7 QUALITY CONTROL AND QUALITY ASSURANCE OF THE GEOGRIDS

QC and QA procedures were employed during geogrid manufacture and installation, including:

(I) Independent laboratory testing certificates of the proposed geogrids during bidding, including short and long term strength and stiffness;
(II) Test results of resistance of the proposed geogrid after immersion in NaOH caustic liquor with pH = 13;
(III) Each lot produced and delivered included its quality control test results of short term tensile strength. Tables 1 and 2 present a summary of the mean values from the those QC reports;
(IV) Careful spreading and stretching, with careful control of length and overlap. These control procedures enabled an evaluation of losses due to roll cuttings, overlaps and installation

Table 1. Summary of mean values for quality control of the 35 kN/m geogrid delivered to the job site.

Property	Nominal Required Value	Lot 20095-1	Lot 20251-2
Tensile Strength (kN/m)	≥ 35	37.4	37.4
Strain (%)	≤ 5.0	4.5	4.5
Stiffness Modulus at max. strength (kN/m)	≥ 700	831	831

Table 2. Summary of mean values for quality control of the 55 kN/m geogrid delivered to the job site.

Property	Nominal Required Value	Lot 21094-1	Lot 21094-2	Lot 21197-1
Tensile Strength (kN/m)	≥ 55	58.1	60.2	60.5
Strain (%)	≤ 5.0	4.8	5.0	5.0
Stiffness Modulus at max. strength (kN/m)	≥ 1100	1210	1204	1210

damages/errors of respectively 1.5, 1.7 and 4.2% of the total geogrid delivered quantities. The total of 7.4% of losses compares well to the predicted value of 7%.

8 BEHAVIOR OF THE REINFORCED SOIL WALL

During construction of the wall, very small movements were observed. Maximum horizontal displacements at the end of construction in two instrumented control sections were in the order of 25 to 50 mm at a height of about 2.0 m, representing a maximum of 1.25% of horizontal average strain (Becker 2005). The only visible movements were related to the external protection bags during adjacent soil compaction.

A surcharge load test using a loaded heavy lorry on the two measuring sections did not cause any movement, probably because of the construction compaction equipment previously applied stresses, higher than of those induced by the lorry surcharge.

Overall behavior along the entire length of the wall in the 4 years after construction has been very good, with no signs of distress or displacements.

The small movements observed during construction and the negligible ones after that are related to the high stiffness of the geogrids associated with the low deformability fill soil used, as well as to the strict quality control procedures applied during geogrid manufacture and job construction.

9 CONCLUSIONS

The use of the reinforced soil wall solution for the upper 5.0 m of RDA 7 provided a highly satisfactory solution for the occupation of a difficult hilly terrain with significant reduction in earthmoving volume and environmental impact.

The overall behavior of the wall during construction and along the following 4 years of operation has been very good, and this is considered to be related, among others, to the quality control procedures that have been applied during construction.

The success of the solution led to the implementation of a similar 7.0 m high wall in the design of future RDA 8.

Figure 4 presents a picture of the job during construction, showing installed geogrid panels. Figure 5 presents the RDA 7 under operation.

Figure 4. Job construction (geogrid in detail).

Figure 5. RDA 7 under operation.

ACKNOWLEDGEMENTS

The authors are grateful to ALCOA Alumínio S.A. for the authorization to publish the information about construction of RDA 7.

REFERENCES

TRI (2002) "Creep and Creep Rupture Behavior of Fortrac M (PVA) Geogrids (Huesker internal report)", USA.

ABINT (2004) "Brazilian Manual of Geosynthetics", ed. J.C. Vertematti/E. Blucher (in Portuguese).

Becker, L. (2005) Ph.D. thesis, Catholic University of Rio de Janeiro (in preparation).