Use of geosynthetics for the elevation of a mining dam construction in Brazil

Utilisation de géosynthétiques sur l'élévation d'une construction de barrage d'exploitation au Brésil

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ABSTRACT
This paper describes aspects related to the elevation process of a mining dam, named Capão da Serra, located in the city of Nova Lima/MG in Brazil. The main objective of Capão da Serra Dam is the mining sediments retention and effluent clarification from the exploration of Tamanduá Mine. The project was developed for the third and last phase of the dam elevation, with an height increase equal to 8.0 m. Since the beginning of its operation, the hydraulic system of the dam was composed by a tulip-shape spillway, complemented by a security earth spillway located on one of the sides of the dam. However, long-term efficiency of the hydraulic system was not clear, due to uncertainties regarding the expected hydraulic head at the final elevation of the dam. Since this was the last phase of the dam elevation, aspects concerning the run-off system were also taken into account with the objective of defining the most efficient, secure and long-last hydraulic system for that specific site conditions. The new spillway, placed directly over the dam earth mass, was designed to support a runoff flow equivalent to a 10,000 year return period rainfall and a high velocity free-surface flow. Geosynthetics were applied to develop primary and secondary functions concerning erosion control, soil reinforcement, drainage and filtration. Several innovations were proposed and applied during this work, concerning geosynthetics installation plan. The geometric project had to be well established to avoid perturbations on the hydraulic flow at the interface between reservoir and spillway. The geosynthetics characteristics attended all needs of this project, including durability, flexibility, easy handling and compatibility to conventional construction materials.

RÉSUMÉ
Cet article décrit des aspects liés au processus d'élévation d'un barrage d'exploitation, appelé 'Capão da Serra', situé dans la ville de Nova Lima, municipalité dans l'état du Minas Gerais au Brésil. L'objectif principal du barrage 'Capão da Serra' est la conservation des sédiments issus d'exploitation et la clarification de l'effluent de l'exploration de la mine de Tamanduá. Le projet a été développé pour la troisième et dernière phase de l'élévation du barrage, avec une augmentation verticale de 8 m. Depuis le commencement de son opération, le système hydraulique du barrage s'est composé par un déversoir de type tulipe, complété par un déversoir de sécurité situé au droit du barrage. Cependant, l'efficacité à long terme du système hydraulique n'était pas évidente due aux incertitudes concernant la charge hydraulique prévue pour l'élévation finale du barrage. Puisque c'était la dernière phase de l'élévation du barrage, des aspects liés au système d'écoulement ont été également pris en considération avec le but de définir le système hydraulique le plus efficace, assuré et durable. Le nouveau déversoir, placé directement au-dessus de la masse de terre du barrage, a été conçu pour supporter un écoulement correspondant à des précipitations dont la période de retour est de 10000 ans, ainsi que pour supporter un écoulement à surface libre sous la condition de vitesse élevée. Des géosynthétiques ont été appliqués pour développer des fonctions primaires et secondaires liées au contrôle d'érosion, au renforcement du sol, au drainage et à la filtration. Plusieurs innovations ont été proposées et appliquées durant ce travail en ce qui concerne le plan de mis en oeuvre des géosynthétiques. Le projet géométrique a dû être bien établi pour éviter des perturbations dans l'écoulement hydraulique à l'interface entre le réservoir et le déversoir. Les caractéristiques des géosynthétiques ont entièrement répondu aux besoins de ce projet, y compris la durabilité, la flexibilité, la facilité de manipulation et la compatibilité avec les matériaux de construction conventionnels.

Keywords :Geosynthetics, Geogrids, Geotextiles, Geocells, Dams

1 INTRODUCTION

This paper presents aspects related to the use of geosynthetics in the downstream face covering of the Capão da Serra Dam spillway, constructed in 2003, located in the city of Nova Lima/MG. The main objective of Capão da Serra Dam is the retention of mining sediments and effluent clarification from the exploitation of Tamanduá mine.

The project was developed for the third and last phase of the dam elevation, previewing an increase of 8.0 meters. Aspects concerning the run-off system were put in discussion with the objective of defining the most efficient, secure and long-last hydraulic system for that specific site conditions. Specific studies were developed considering several aspects in order to obtain the best cost-benefit solution. The results showed that the best alternative was attended by the use of geosynthetics.

2 PROJECT CHARACTERISTICS

2.1 *Capão da Serra Dam*

The project expansion included the increase of Capão da Serra dam from the elevation 975.00 m to 983.00 m, operating with a minimal water level at the elevation 980.00 m and a maximum water level at 981.78 m. Figure 1 presents a plan view of the project.

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Since the beginning of its operation, Capão da Serra dam was structured by a hydraulic system composed by a tulip-shape spillway complemented by a security earth spillway located on the right side of the dam, placed over natural soil.

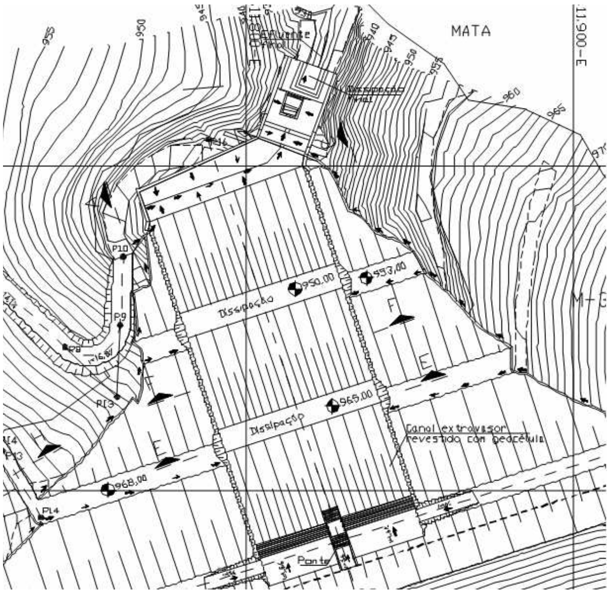

Figure 1. Plan view of Capão da Serra Dam Spillway Project.

The downstream slope had two intermediate berms in the levels 968.0 m and 953.0 m. In the central region of the dam, it was implemented a surface spillway, 50 m wide, over the geogrid reinforced backfill. The spillway was constructed with a platform in the top region, 8.8 m long and 1.6% steep, between the levels 981.25 m and 981.11 m, and the downstream slope right after that.

The berms between each slope, 7.5 m long, presented important functions in the energy dissipation through the generation of hydraulic steps. In order to cause the complete hydraulic dissipation in the most critical situation, it was designed two dissipation basins in series. Figure 2 shows some details of the geosynthetics disposition in the project.

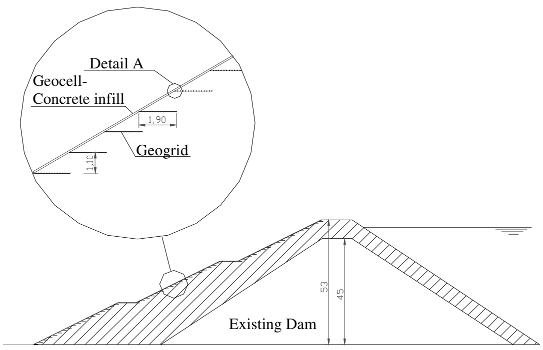

Figure 2. Cross section of the Dam.

2.2 *Hydraulic aspects*

Hydrologic studies verified that the hydraulic structures of Capão da Serra Dam had to be enhanced. The new spillway was designed to support a runoff flow equivalent to a 10,000 year return period rainfall. Its structure was placed directly over the earth mass and develops a high velocity free-surface flow, whose characteristics are shown in Table 1.

Table 1. Flow characteristics

Maximum Flow	126 m³/s
Maximum Flow velocity	13 m/s
Return Period	10000 years

3 GEOSYNTHETICS

Geosynthetics were applied to develop primary and secondary functions concerning erosion control, soil reinforcement, drainage and filtration. The tables 2, 3 and 4 present the characteristics of the geocells, geogrids and geotextiles, respectively.

Table 2. Geocells characteristics

Description	Geocells made of thermofixed nonwoven strips, 100% polypropylene, attached mechanically by stitching. Height: 10 cm
Primary Functions	Bottom and side revetment of the spillway. Concrete infill
Secondary Functions	Execution auxiliary system, by acting as concrete form and dilation joints
Total Volume	10000 m²

Table 3. Geogrids characteristics

Description	High tenacity polyester geogrids coated with PVC. Tensile Strength (ASTM D 4595) – 35/30 kN/m (MD/CD)
Primary Functions	Enhancement of geotechnical properties of local soil, main component of the dam soil mass
Secondary Functions	Intermediate anchorage system for geocell revetment. Geocells are fixed to geogrids by stapling
Total Volume	8000 m²

Table 4 . Geotextiles characteristics

Description	Polyester nonwoven geotextile. Mass per unit area- 200g/m². Tensile strength (ASTM D 4595) – 10 kN/m
Primary Functions	Promote separation between embankment surface and geocells concrete infill
Secondary Functions	Avoid erosion of embankment surface during geocell installation, due to transit of workers
Total Volume	12,000 m²

4 CONSTRUCTION PHASES

Several innovations were proposed and applied during this work concerning geosynthetics installation plan. Designer, constructor, geosynthetic manufacturer and client defined together all steps towards the most efficient and economic way of executing the work

While large trucks, loaders, scrapers and compactors operated, a careful geogrid installation process took part. The geogrids were placed with a vertical spacing of 1.10 m and total inclusion length of 1.90 m. As the geogrids were going to be used as anchorage system for the geocells, it was necessary a 20 cm geogrid strip overpassing the limits of the compacted embankment. This strip was then cut to form tongues that fitted into the cells to be correctly fixed by a stapling system.

An “extra” embankment, 50 cm wide, was executed and then removed in order to obtain a proper compacted surface. During this removal, special attention was necessary due to the risk of intercepting the geogrids that could cause undesirable damages to its structure (Figure 3).

Nonwoven geotextiles were placed over the whole downstream surface, between each geogrid layer, before the geocells were expanded. In order to employ the desirable velocity to the geocell installation process, it was decided that the geocells panels had to be all joined together before expanded. It was adopted a very simple and efficient way of achieving that objective. Along the spillway, the geocells were joined together by nylon locks (Figure 4). In the cross-direction way to the spillway axis, the panels were joined by passing polypropylene anchor ropes, through overlaid holes placed on the extreme flaps of the geocell panels (Figure 5).

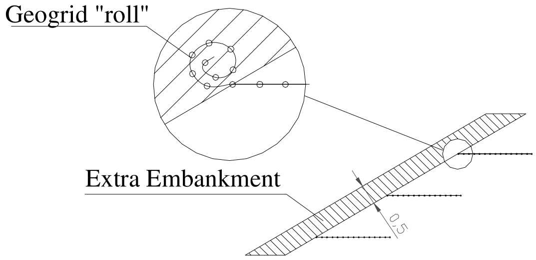

Figure 3. Geogrid installation and placement of extra embankment.

These procedures allowed the transformation of a 15 m² geocell panel into a 2,500 m² panel that was expanded all at once and then aligned and fixed to the geogrids before receiving concrete infill (Figures 6 and 7).

After expansion, the geocells were aligned and fixed to the geogrids by staples. The stapling process took part in order to promote perfect interaction between geocells and geogrid after concrete fill was finished. As the geocells are filled with concrete, small columns are formed within the geogrid voids that guarantee friction forces transfer from the interaction between geocells and concrete infill to the geogrids.

This stapling scheme was carried out to promote a perfect interaction between the geocells and the geogrids after the concrete infilling process. After this, small concrete beams were formed, passing through the geogrid voids, insuring the necessary friction forces, transferred from the geocells filled with concrete to the geogrids. Figure 8 present details of the stapling system between the geosynthetics.

The concrete was launched by a hi-power bombing system (Figure 9) that reached all geocell surface area and promoted its filling in a very rapid and efficient way. The concrete was accumulated inside the upper cells until it dropped down by gravity filling automatically the bottom cells. Surface finishing was done, first of all, by a vibratory rule and then by traditional surface smoothing process (Figure 10).

All the procedures described were successfully applied and led to optimum results, as perfect timing and synchronism were observed. During construction, all the phases could be developed at the same time as shown in Figure 11. Geocells were already filled at the bottom slope while excavation work took place at upper slopes.

Figure 12 shows how important it is the flexibility of the geocells placed on the upper part of the spillway. The geometric project had to be well established to avoid perturbations to the hydraulic flow at the interface between reservoir and spillway. The berms between each slope measures 7.5 m long and develop important function on the dissipation of hydraulic energy.

The hydraulic energy expected for the project run-off flow was extremely high; therefore 2 dissipation basins were still needed to obtain a steady-state flow. At the bottom of the last spillway slope, a horizontal smooth surface basin with 3 m high gabion walls (Figure 14) was built to guarantee total energy dissipation for normally expected flows. In the critical cases of extremely high velocity flows, a second basin placed downstream, made of gabions, dissipated extra hydraulic energy, liberating steady-state flow back to the water course. Figures 13 and 14 show the dam already concluded with side slopes vegetated.

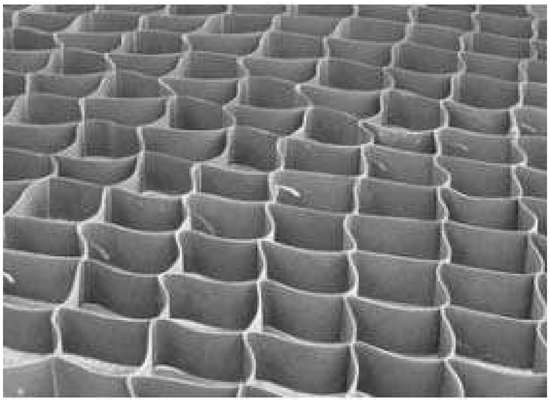

Figure 4. Longitudinal joints.

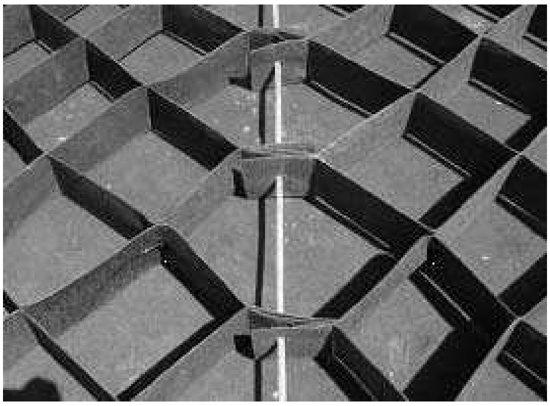

Figure 5. Transversal joints.

Figure 6. Geocell panels ready to be expanded.

Figure 7. Geocells expansion/ Geotextile placed.

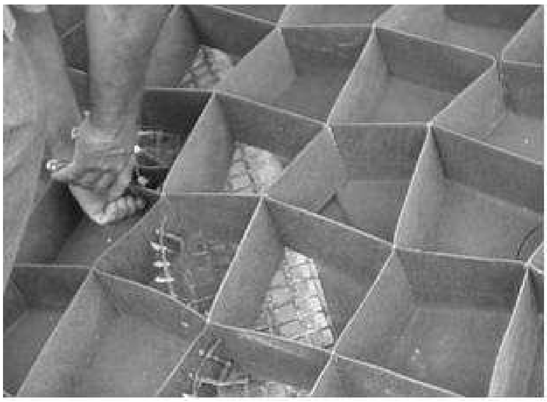

Figure 8. Stapling process.

Figure 9. Concrete pumping system placed.

Figure 10. Vibratory rule being use.

Figure 11. Simultaneous phases of construction.

Figure 12. Detail of the geocells flexibility.

Figure 13. Front view of the spillway after construction.

Figure 14. Final dissipation basin.

5 FINAL CONSIDERATIONS

The Capão da Serra Dam is a very important structure placed in the metropolitan region of Belo Horizonte, capital of Minas Gerais state. Any intervention at this site must be perfectly planned and environment protection activities are indispensable.

An economic analysis was done and resulted that the use of geosynthetics, apart from employing great velocity to all phases of construction, are materials easily measured and so, permits a perfect forecast on the volume needed, during the development of project.

Geosynthetics characteristics attended all needs of this project; durability, flexibility, easy handling and compatibility to conventional building materials and flow characteristics.