

Experiences of mine closure cover with geosynthetics in Peru

Rainer Lagos^{1*}, Gustavo Fierro²

¹Tecnología de Materiales S.A, Perú

² Tecnología de Materiales S.A, Perú

Abstract. Peru is internationally recognized as one of the countries with significant mining reserves. According to the Department of Energy and Mines (MINEM), as of December 2021, a total of 672 mining concession holders were registered and declared in the Monthly Statistical Declaration (ESTAMIN). Likewise, 44 mining concessions are in the closure stage (progressive, post-closure and final). In addition, Peru has 7956 Mining Environmental Liabilities (MEL) as of 2020, according to the inventory approved by the Department of Energy and Mines, which need to be remediated as they constitute a permanent and potential risk to the health of the population, the surrounding ecosystem and property. As part of the closure of these MEL and closure of some mining components, the use of geosynthetics has increased in Peru, and we speak specifically of the closure cover in slopes, platforms, sidewalks and others, which has become relevant as an alternative solution for soils selected as part of a traditional closure, the objective of this work is to present a series of experiences of the application of geosynthetics in mine closure covers, which intervene in the physical, geochemical and hydrological stability. It is worth mentioning that geosynthetics have been applied in Peru for more than 30 years in mining projects.

1 Introduction

Geosynthetics in Peru are being used as part of the solutions in the closure coverings of MEL and mining component closures, these materials are an alternative to a traditional closure, since geosynthetics can replace soil coverings, such as granular fill for drainage and low permeability soils for waterproofing, also, there are some geosynthetics of reinforcement and cellular confinement that improve the stability of the coverage in slopes, in order to have a better long-term performance. This paper will show some closure cover systems and their installation process of geosynthetics used in some mine waste closure projects in Peru.

* rlagos@tdm.com.pe

2 Case history N°1- Closing of waste rock dump Excélsior

2.1 Background

The Excélsior Closure Plan is the largest environmental liability in the history of Peru, located in Cerro de Pasco, with 69 hectares and 55 million tons of mining waste accumulated from 1956 to 2000. Figure 1 shows the initial stage of the closure of the Excélsior mine.



Fig. 1. Initial stage before closing.

2.2 Geosynthetic closure coverings

2.2.1 Types of coverage

The design of the vegetation cover, as well as the selection of the species, responded to the characteristics and properties of the soils.

Type I Cover

This type of cover was installed on the slope of the dump, in order to fulfil the function of waterproofing the clearing, the slopes were 2H:1V.

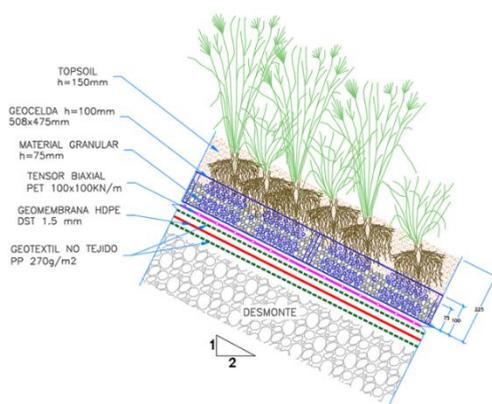


Fig. 2. Type I cover.

Granular material (0.075m thick): It had the function of filter and drainage of the waters that could cross the topsoil by means of a catchment system, the waters were derived from the waterproofed waste water tank.

Topsoil or topsoil (0.15m thick): Its function was to support the native grass species planted for revegetation.

Geomembrane: This geosynthetic made of 1.5mm double textured HDPE (high density polyethylene) was used to encapsulate the reservoir and contain the flow. Based on PNN (net neutralization potential) analyses, this reservoir had a potential to generate acid drainage, making it necessary to reduce the infiltration levels of non-contact water with the acid-generating material. The geomembrane used follows an international standard specification GM13 of the GSI (Geosynthetics Institute) that guarantees good mechanical performance, due to its high resistance to chemical and biological degradation, as well as its high resistance to UV rays.

Nonwoven geotextile: This material made of PP (polypropylene) with a grammage of 270g/m² was placed under and over the geomembrane for puncture protection purposes. The profiled slopes could present puncture zones that could damage the geomembrane during the process of installing the geosynthetics and filling the cover materials.

Geocell: The geocell, made of HDPE (high density polyethylene), followed the GSI GS15 standard specification, with dimensions of 100mm in height and 508x475mm in opening. The purpose of the geocell was to improve the short- and long-term stability conditions of the cover on the 2H:1V slope. This cover was made up of 75mm of granular material for drainage of precipitation infiltration and 150mm of topsoil for vegetative growth with native species. The geocell contributes in generating a macrocorrugation along the slope, the geocell walls increase the stability influence of the cover beyond 100mm thickness, which made it unnecessary to confine the cover in its total height. The geocell type considerations were a function of slope steepness, geotechnical parametric of the cover material and final total thickness of the closure cover.

Biaxial tensor: This tensor made of high-strength PET (polyester) was used to support the geocell filled with cover material on the slope. It was anchored in trenches built on each slope sidewalk, in which the entire set of geosynthetics was anchored, i.e., the geomembrane, geotextile and tensor. PET is a material that shows low deformation over time when subjected to a constant load, making it an ideal material for a structure whose closure life is projected to be hundreds of years.

Type II Cover

This type of cover was installed on the surface of the platforms and sidewalks of the reservoir.

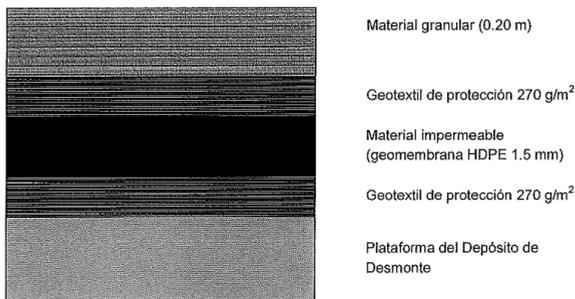


Fig. 3. Type II cover.

Type III Cover

This type of cover was installed on the surface that limits the slope of the Excélsior dump and the Quiulacochoa tailings storage, it fulfilled the function of waterproofing and stabilizing the tailings surface.

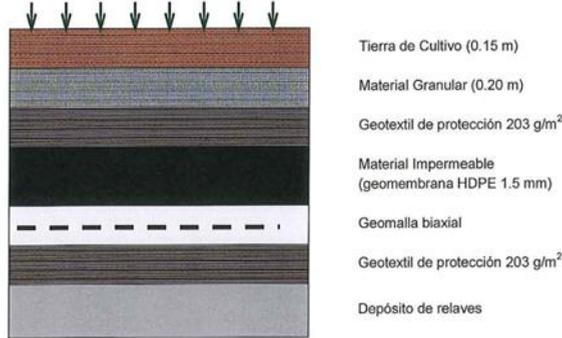


Fig. 4. Type III cover.

Type IV Cover

This type of cover was installed on the natural ground surface or on fill with borrow material, at the foot of the waste dump.

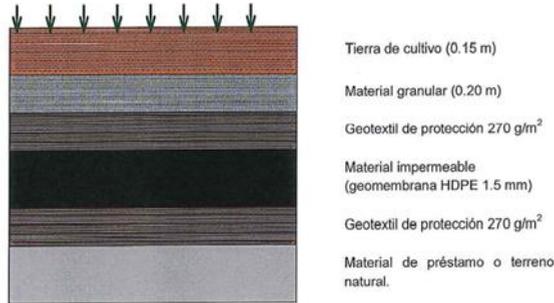


Fig. 5. Type IV cover.

Type V Cover

This type of cover was installed over the water pools located on the dump platform.



Fig. 6. Type V cover.

Type VI Cover

This type of covering was installed on the surface designed for sloped accesses.

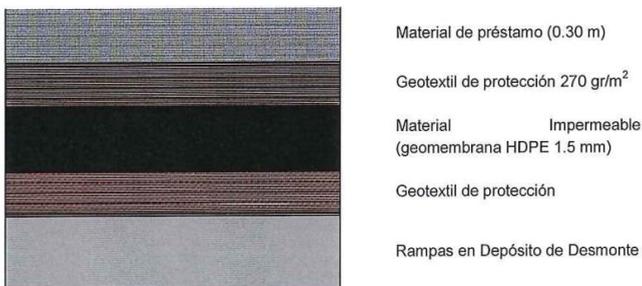


Fig. 7. Type VI cover.

2.3 Coverage Installation Procedure.

Once the slopes of the reservoir were shaped and profiled to achieve physical stability, the geotextile and geomembrane were installed.



Fig. 8: Geomembrane and geotextile installation.

Once the placement of the geotextile over the geomembrane was completed, the biaxial tensor anchored in a trench was progressively placed on the sidewalk in the planned areas. The geocell was then installed on the slope. They provided backfill stability and facilitated gravel placement for large areas and long slope sections.

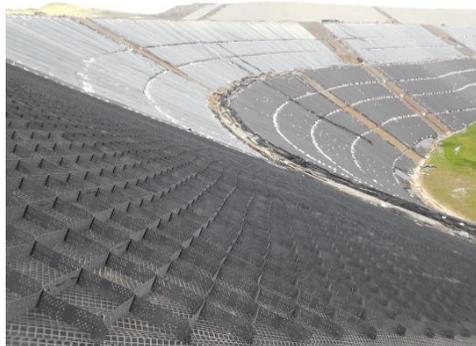


Fig. 9: Geocell and geogrid installation.

Next, the granular material was placed for drainage purposes of the flow through the topsoil (see Figure 10), which discharged into perforated pipes placed transversally to the slope, and these into concrete collector boxes. Finally, topsoil was placed on top of the gravel for vegetation purposes with native species.



Fig. 10: Topsoil placement and revegetation.

3 Case history N°2- Closure of Mining Environmental Liability of the Former Esquilache Mining Unit

3.1 Background

The former Esquilache Mining Unit is located in the town of San Antonio de Esquilache, in the district of San Antonio, province and region of Puno. The 135 Mining Environmental Liabilities (MEL) of the former "San Antonio de Esquilache" unit include a total of 170 components, which include mine mouths, chimneys, shafts, trenches, mine waste, tailings, among others.

3.2 Geosynthetic closure coverings

The purpose of the cover and subsequent revegetation is to permanently replace the vegetation cover on bare soils or soils degraded by environmental liabilities, providing protection against erosion and preventing the generation of acid drainage by isolating the materials. The coverage used in the mine stripping was based on the quality of the materials stored, since all were ARD (acid rock drainage) generators.

3.2.1 Types of coverage

The design of the vegetation cover, as well as the selection of the species, responded to the characteristics and properties of the soils.

Type I: cover for acid generating material with revegetation.

This type of cover is used for mine waste that generates acidity. The design criterion used is that less than 5% of the annual precipitation reaches the acidity-generating material.

Topsoil or topsoil (0.20m thick): With the function of supporting the planted species, the thickness established was that necessary for the growth of the native grass species to be used for vegetation.

Granular material, crushed stone (0.20m thick): It has the function of filtering and draining water that could pass through the topsoil or by means of a catchment system.

Protective non-woven geotextile: The use of the geotextile was to avoid direct contact of the upper granular substrate with the geomembrane, avoiding possible cracks and cuts in the geomembrane that would prevent its function of waterproofing the slope of the mine waste rock.

Geomembrane: It was a HDPE material with a thickness of 1.5mm, whose function is to ensure the waterproofing of the mine waste slopes, because according to the analysis of the PNN (net neutralization potential), these wastes have a potential to generate acid drainage.

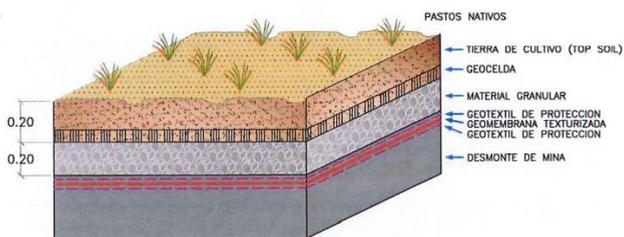


Fig. 11: Type I cover.

Type III: cover for material that does not generate acidity or natural soil.

This type of cover was used for mine clearings and components that do not generate acidity and do not show surrounding vegetation.

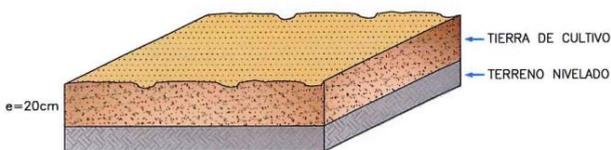


Fig. 12: Type III cover.

Type IV: cover for non-acidity generating material or natural soil. Incorporated a revegetation program.

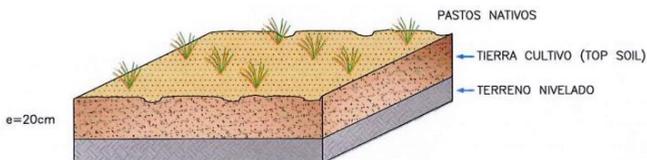


Fig. 13: Type IV cover.

3.3 Coverage Installation Procedure.

The first stage in the closure was the shaping and profiling of the slopes to then place the nonwoven geotextile, as shown in Figure 14.



Fig. 14: Geotextile installation.

The double-textured HDPE 1.5mm geomembrane was placed on both the slopes and the platform, as shown in Figure 15.



Fig. 15: Geomembrane installation.

As a fourth layer of geosynthetic, a biaxial polyester tensor was installed on the slopes, with the purpose of joining the geocell and confining the topsoil on the slopes, this benefited the stability of the cover, the tensor was anchored in trenches located on the dump platform.



Fig. 16: Biaxial tensor installation.

The last layer of geosynthetic, the 10 cm high HDPE geocell was installed, which complemented the system with the tensor, the union of both materials was with Nylon ties. Figure 17 shows the placement of geocells on the tensor, which were laterally and longitudinally joined with nylon ties.



Fig. 17: Geocell installation.

4 Case history N°3- Closure of Mining Environmental Liability of the Former Los Negros Mining Unit

4.1 Background

The project is located in the province and district of Hualgayoc, in the Cajamarca region. The components of the Closure Plan for environmental mining liabilities of the former Los Negros Mining Unit consist of 53 environmental liabilities, including mining workings such as mine mouths, chimneys and pique; processing facilities such as leaching plant, crushers, leaching ponds and mining waste dump.

The closure objective was to comply with the physical stability of all the intervened components and structures designed to achieve the stability objectives. These elements include, among others, stockpile areas, in situ closures, retaining walls, plugs, ponds, etc. Characterize and propose adequate technical and environmental measures to maintain the physical stability of the environmental remediation components in the short, medium and long term. In this sense, the physical stability of the components will be designed to withstand extraordinary seismic and hydrological events.

The objective of the geochemical stability was to ensure the chemical stability of the area in the long term by complying with the requirements of Peruvian environmental regulations regarding effluents from mining environmental liabilities facilities. Establish cover to reduce infiltration, so that a minimum amount of seepage can be ensured to meet water quality objectives in the tributaries and the receiving body.

The objective of hydrological stability was to maintain the balance of watersheds and micro-watersheds, maintaining the ecological flow of watercourses that may be affected by mining operations with an adequate water management system.

4.2 Geosynthetic closure coverings

The remediated surfaces in the different components of the project were covered with geosynthetics and revegetated. There were 5 types of coverage:

Cover type 1

Made up of hydroseeding and biodegradable mulch, this type of cover was used in areas where clearing and rocky areas with steep slopes were removed.

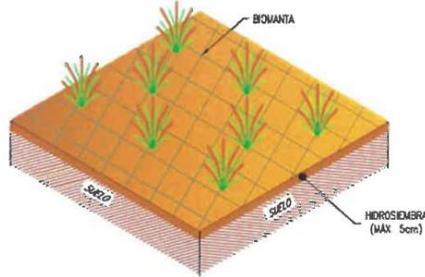


Fig. 18: Topsoil placement and revegetation.

Type II cover

They were used in the closure of the stockpile and on-site closure areas.

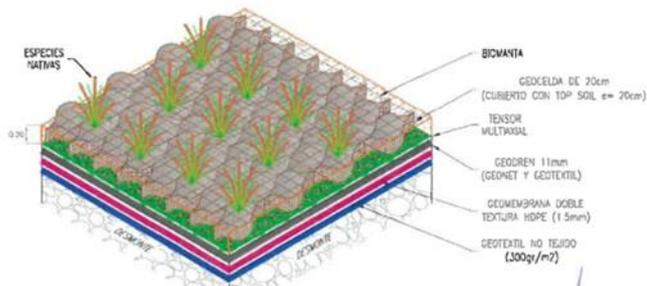


Fig. 19: Type II cover

Type III cover

This type of cover was used on the backfill placed at the manholes entrances.

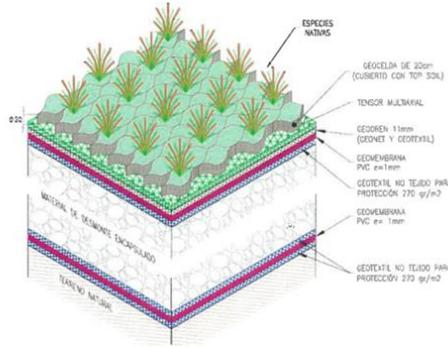


Fig. 20: Type III cover

Type IV cover

This type of cover was used to close the accesses except for the main access. Because the accesses must be maintained for maintenance and monitoring activities, this type of cover was used during the post-closure stage of the project.

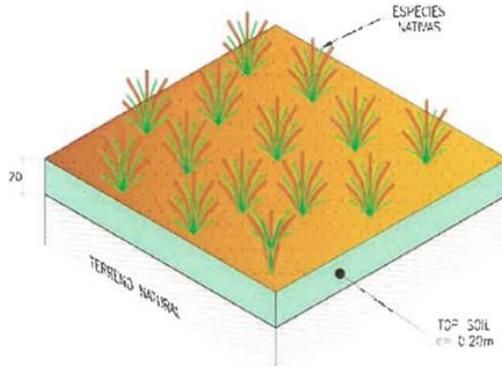


Fig. 21: Type IV cover

Type V cover

This type of cover was used in the closure of the chimney areas.

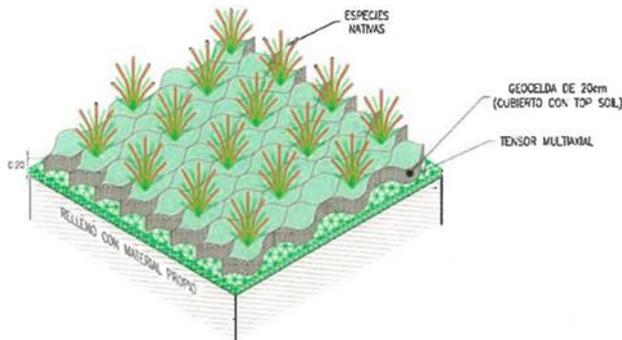


Fig. 22: Type V cover.

4.3 Coverage Installation Procedure.

In the stockpile areas, type 2 cover was used, whose geosynthetics and soil conformation was described above. The photo shows the installation of the geocells on the slope with inclination 2H.1V.



Fig. 23: Stockpile area.

5 Case history N°4- Closure of Mining Environmental Liability of the Former Aladino Mining Unit

5.1 Background

The areas impacted by the environmental liabilities of the former Aladino VI Mining Unit are located in the district of Mañazo, Puno province, Puno region. The 24 environmental mining liabilities of the former Aladino VI unit are grouped into a total of 10 components, which include mine mouths, chimneys, shafts, trenches, mine waste, tailings, among others.

5.2 Coverage system

5.2.1 Waterproofing

The main objective was to limit the percolation of oxygen and water as the prevention method of the acid drainage generating process. As a consequence, the oxidation of sulphides and the generation of effluents was limited, as well as the mobilization of pollutants. These barriers were constructed with geosynthetics that encapsulate the MEL.

5.2.2 Filter layer

The filter layer was formed from natural material, with the objective of minimizing, avoiding and/or diverting the flow of water. This cover fulfilled some premises such as allowing infiltration of precipitation, minimizing or avoiding deep drainage of infiltration water, having the capacity to redirect runoff in circumstances where the intensity of precipitation exceeds the infiltration rate, and allowing gas exchange.

5.2.3 Revegetation

Vegetation played a very important role in the ecosystem because it influenced the water balance, biodiversity or the physical stability of the soil. It is also one of the most effective measures for controlling water and wind erosion to which a soil or material is exposed.

The success of revegetation depends on the reconstruction of the functional root necessary for plant growth, for which it was necessary to meet some conditions such as:

- Availability of material for plant growth.
- Physical and mechanical conditions.
- Chemical conditions.
- Climate

5.3 Description of coverage

Five types of coverages have been established for the closure of the MEL in order to ensure geochemical stability, these are:

Type I Cover: Projected waste dump closure coverage.

Type II Cover: Closure cover for mine waste rock and tailings storage.

Type III Cover: Closure coverage for mine waste rock, mine mouth, tailings storage, mine waste rock, processing plant and infrastructure.

Type IV Cover: Closure cover for mine entry.

Type V Cover: Closure cover for tailings storage.

CUADRO DE COBERTURAS		
COBERTURA	COMPONENTES	SOMBREADO
TIPO I	 <p>SEBRADO TIERRA DE CULTIVO (e=0,20 m) MATERIAL GRANULAR (e=0,20 m) ARCILLA (e=0,40 m) GEOTEXTIL, GEOMEMBRANA, GEOTEXTIL.</p>	 D.M.E. PROYECTADO
TIPO II	 <p>SEBRADO TIERRA DE CULTIVO (e=0,20 m) MATERIAL GRANULAR (e=0,20 m) ARCILLA (e=0,20 m)</p>	 DESMONTE DE MINA
TIPO III	 <p>SEBRADO TIERRA DE CULTIVO (e=0,20 m)</p>	 DESMONTE DE MINA
TIPO IV	 <p>RELLENO CON ENROCADO MATERIAL DE PRESTAMO (Ø6" - Ø8")</p>	 LABORES SUBTERRANEAS
TIPO V	 <p>SEBRADO TIERRA DE CULTIVO (e=0,20 m) MATERIAL GRANULAR (e=0,10 m) GEOCELDA (e=0,20 m) GEOMALLA 50 kN/m</p>	
TIPO VI	 <p>SEBRADO TIERRA DE CULTIVO (e=0,20 m) MATERIAL GRANULAR (e=0,20 m)</p>	

Fig. 24: Summary of hedges for the closing of MEL.

A waste dump was built with a height between intermediate benches of 5m and slope inclination of 3H:1V, which was waterproofed with 3 types of cover:

Detail A

Final cover of the waste dump for a 3H:1V slope.

Detail C

Final cover of the starting embankment of the waste dump, for a 2H:1V slope.

Detail 1

Covering of the closing of the waste dump platform and sidewalk.

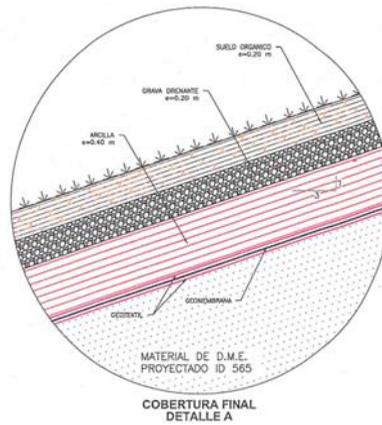


Fig. 25: Detail A: coverage in waste dump.

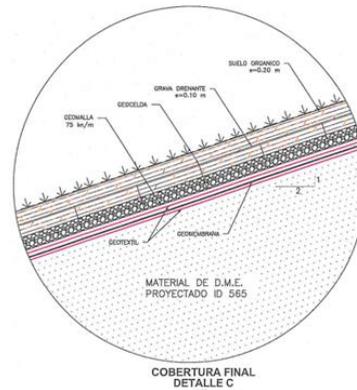


Fig. 26: Detail C: Waste dump slope coverage.

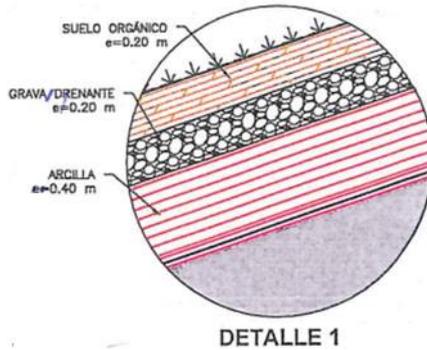


Fig. 27: Detail 1: Waste dump platform coverage.

5.4 Coverage Installation Procedure.

Figure 28 shows a panoramic view of the projected waste dump, where the type A cover, mentioned above, was placed.



Fig. 28: Compacted clay backfills in projected waste dump.

Figure 29 shows the placement of the PET geogrid in the anchor trench, as well as the granular backfill for subsequent compaction. It should be mentioned that the geogrid and geocell helped to improve the long-term stability of the organic soil on the slope, thus guaranteeing the vegetative growth of native species



Fig. 29: Anchor trench for PET biaxial geogrid in the projected waste dump.

Figure 30 shows the geocells installed on slope with slope inclination 2H:1V, considering the type C coverage mentioned above.



Fig. 30: Placement of geocell on slope in projected waste dump.

6 Conclusions

Geosynthetic closure covers have proven to be a technically and economically viable alternative to traditional closures that involve much more earth movement such as low permeability soil and granular fill for drainage purposes. The application of geosynthetics on slopes such as geocells and tensors have contributed to improve the long-term stability of the cover, creating the necessary conditions to confine the fill for the vegetative growth of species in the area, as well as increasing the performance of the placement of the closure fill such as topsoil and crushed stone. Several types of closure cover have been described that were applied in MEL closure, some of which incorporated waterproofing geosynthetics such as geomembrane to encapsulate potential mine waste to generate acid drainage, which is harmful to the environment, accompanied by a non-woven geotextile to prevent puncturing of the geotextile.

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