Design and construction of a stabilization work for a landslide using reinforced soil slope with geocells face

Eriksson Jamanca, Tecnología de Materiales S.A., Lima, Perú.

ABSTRACT

The present document consists in the application of reinforced soil slope with geocells face (RSS-GF) for the construction of a stabilization work a landslide. The using geocells face allows the vegetation that is required completions in the environmental recovery of mining works. It is an environmental civil application based on physical stability concepts that was developed during the design stage, during the construction stage and concluded at the operation stage.

In this way, this work includes a referential framework in which the context, the environment and the background for the design of reinforced soil slopes and the environmental recovery of sectors intervened by the mining industry.

The methodology used to carry out the design was the analysis of physical-environmental stability and even economic and functional, to support the advantages of the solution of reinforced soil slope with geocells face with respect to conventional solutions of earthworks, works of armed concrete or gabions inclusive. The functionality and durability of the solution proposal were also analyzed, including integration of revegetation and drainage to ensure the integrity of the application.

The results of the design and construction allowed demonstrating the functionality, stability and innovation of the use of geocells and geogrids in the recovery of civil-environmental works for the mining industry. Once again, the use of geosynthetics demonstrates its credibility in its use for the development of civil projects.

RESUMEN

El presente trabajo consiste en la aplicación de un talud de suelo reforzado con fachada de geoceldas para el trabajo de estabilización de un deslizamiento de masa de suelo. Dicha cara a largo plazo permitirá la vegetación que se requiere en la recuperación ambiental de las obras mineras. El presente caso es una aplicación civil-ambiental basada en conceptos de estabilidad física que se desarrolló durante la etapa de diseño, construcción y concluyó en la etapa de operación.

De esta manera, este trabajo incluye un marco referencial en el que se observa el contexto, el medio ambiente y los conceptos de diseño de taludes de suelo reforzados y la recuperación ambiental de sectores intervenidos por la industria minera, ambos en la etapa de diseño.

La metodología utilizada para llevar a cabo el diseño fue el análisis de la estabilidad físico-ambiental e incluso económica y funcional, para respaldar las ventajas de la solución de talud de suelo reforzado con fachada de geoceldas con respecto a las soluciones convencionales de movimiento de tierras, obras de concreto armado o gaviones incluso. También se analizaron la funcionalidad y la durabilidad de la propuesta de solución, incluida la integración de revegetación y drenaje para garantizar la integridad de la aplicación.

Los resultados del diseño y construcción permitieron demostrar la funcionalidad, estabilidad e innovación del uso de geoceldas y geomallas en la recuperación de obras civiles y ambientales para la industria minera. Una vez más, el uso de geosintéticos demuestra su credibilidad en su uso para el desarrollo de proyectos civiles.

1. INTRODUCTION

1.1 Site

The site of the project is located at relative coordinates 305 223E and 8 820 743N in Oyon District, Lima department, around altitude between 3400 to 3600 m.a.s.l. It far away 241km to Lima center approximately. Figure 1 shows the location.

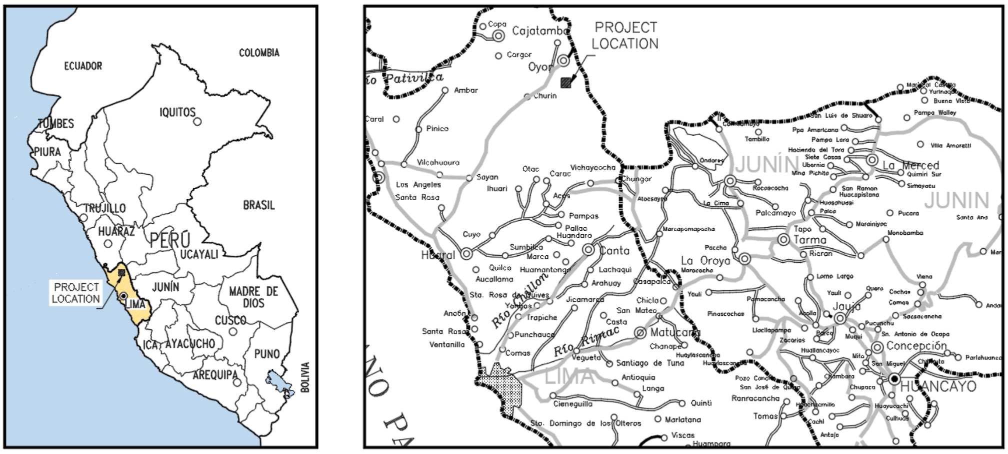

Figure 1. General project location (left), specific site the project (right)

1.2 Description

The sector of the project is characterized by complex topography such us very steep irregular slopes, four geological contacts are well defined and varying hydrological conditions. The conceptualization of the problem must consider different technical aspects from the point of view of the geotechnical conditions, environment, cost, cut-fill balance and time schedule to get the best alternative solution. After checking different options, the final solution was the combination of the cut-fill soil, more innovation geosynthetics technologies. This solution included cut part of instability soil mass and the construction a reinforced slope soil with geocells face (RSS-GF) as a retain mechanical earth system. The RSS-GF have the following characteristics; total length of 85m, height of 4.8m, 408m2 of geocells face, slope of 1V:0.63 H (58°) with an intermediate berm, which was used to construction a water channel.

Figure 2. Overview of the project site (left) and the steep irregular slopes (right)

2. BACKGROUND

2.1 Geological and hydrological conditions

The geology along the sector of the project has four geological layers. First layer was organic soil, its depth was between 0.5meters to 2.0meters. Second layer, which was the most cut soil in the construction stage, was a deposit of alluvial fine soil, its SUCS classification was ML and CL (silt, clay and gravel) and its depth close to 6 meters. The next layer was a deposit of alluvial granular soil type GM and SC according SUCS, it has a medium and high density. Its depth was 8 meters approximately. The final layer was a sandstone rock, this sedimentary rock had a medium resistance and showed alterations that gave very high fractures (RQD 63%). The geotechnical-geological cross section that is shown on figure 3

About hydrological condition, water-bearing strata were known before the beginning of construction. Moreover, it's one of the agents that generate problem in the sector of the project. However, for the solution RSS-GF water drainage blankets were implemented at the back wall and perimeters channels to capture the surface precipitation so that the RSS-GF does not saturate and possibly fail. The geotechnical survey gave the subsurface conditions and typical properties of each geological layers and design parameters used in the analysis. The design parameters were based on independent tests conducted on laboratory (Anddes, 2017). Such us soil classification, direct shear box tests, triaxial shear tests, tests method for density of soil in place by sand-cone and proctor compaction tests. All tests were conducted on soil samples taken from site to obtain the friction angles (Φ), the cohesions (C) and densities (γ). The following table 1 shows the parameters.

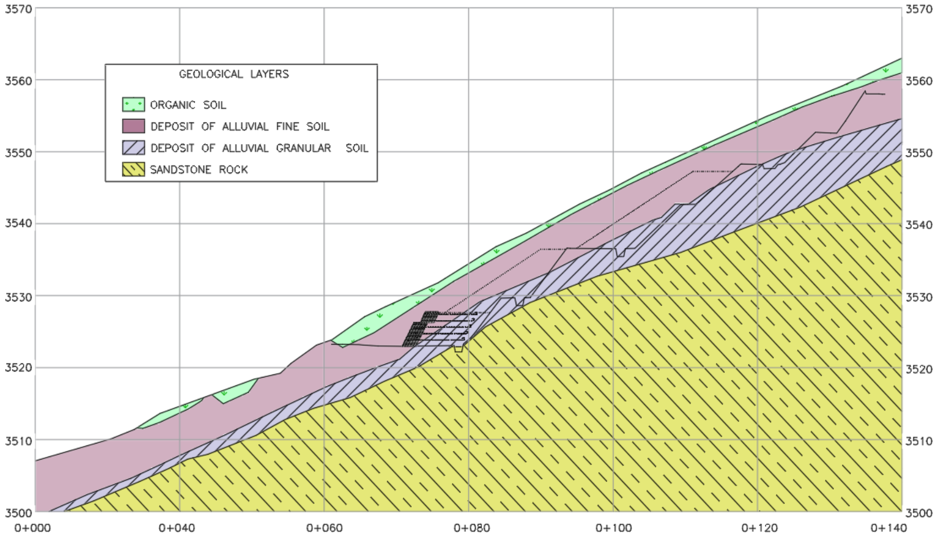

Figure 3. The geotechnical-geological cross section

Table 1. Characteristics of tested soils.

Stratum	Total Unit Weight (kN/m3)	Angle of internal friction (°)	Cohesion (kN/m2)
Organic soil	14.0	10.0	10.0
Deposit of alluvial fine soil	16.5	25.0	15.0
Deposit of alluvial granular soil	17.0	33.0	10.0
Sandstone rock	22.0	30.0	120.0
Structural fill soil[1]	20.0	34.0	20.0

[1]the geocells was fill by this soil also.

2.2 Other considerations

The reinforced soil slope with geocells face (RSS-GF) was constructed using a geocell as a face and type uniaxial geogrid reinforcement. About the geocell material in this case was manufactured from 150mm wide strips of high-density polyethylene ultrasonically welded together to give an open-cell construction having a cell of 416mm long and 374mm width. The concept behind the use of this material in earth works is that when the geocell is expanded and in filled with structural fill soil the cells of the web laterally confine the soil to provide a stable soil-geosynthetic composite. This property allows getting a stable face. Over time, it is expected that exposed cells in the RSS-GF can be vegetated.

In addition, uniaxial geogrids offer global stability of system RSS-GF, this material is made from quality high density polyethylene (HDPE) and carbon black additive, by the process of extrusion of high-quality sheet, accurate punching, and then stretching in one direction to get a major resistance in one direction. The uniaxial geogrid has consistent high-performance properties with optimal creep resistance, aging resistance, and chemical and biological durability. The System RSS-GF were constructed with a higher strength geogrid having a long-term allowable design load of 65 kN/m, this reinforcement was extended completely through the width of the solution to the overall stability

The derivation of allowable long term design strength (according to the FHWA and GRI procedure) for the uniaxial geogrid HDPE used for the design is shows in table 2. The value of 0.58 was used in design for the coefficient of composite geogrid pullout from soil (Ci), and 0.58 for the coefficient of composite geotextile direct shear against soil (Cds). The above parameters were based on independent tests conducted on the uniaxial geogrid HDPE with different soils. Such uniaxial geogrid HDPE have been shown to have better interaction properties with fine grained soils than other type and geotextiles (Elias, V., Christopher, B., Berg, R. 2001).

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Table 2. Long-term allowable design load of HDPE uniaxial geogrid

Property	Units	Values
Ultimate tensile strength (T_{ult})	kN/m	170
Minimum Reduction Factor for Installation Damage (RF_{ID})[1]		1.05
Reduction Factor for Creep for 120-year Design Life (RF_{CR})[1]		2.48
Minimum Reduction Factor for Durability (RF_D)[1]		1.00
Allowable long term design strength (T_{allow})[2]	kN/m	65

[1]Based on independent tests made by manufacturer following the test procedure in ASTM

[2]Reduction factors are used to calculate the geogrid strength available for resisting force in long-term load bearing applications. Allowable Strength (T_{allow}) is determined by reducing the ultimate tensile strength (T_{ult}) by reduction factors for RF_{ID}, RF_{CR} and RF_D per GRI-GG4-05 [$T_{allow} = T_{ult}/(RF_{ID} \cdot RF_{CR} \cdot RF_D)$].

3. REINFORCED SOIL SLOPE WITH GEOCELLS FACE DESIGN

The design of the solution was based as mechanically stabilized earth slope, according to Elias V. et al. (2001). All analyses that were part of the design considered the internal failure such as failure planes crossing only the geogrid-reinforced zone, external failure that is failure planes not crossing any reinforcement and compound stability that included rotational failure following the spencer method. It considers two situations of analysis, static and pseudo-static condition. For the last consideration the seismic acceleration of the project site is 0.24g with a seismic coefficient of 0.5, giving a pseudo static analysis a value of 0.12g. These analyzes were performed using two design computer softwares Slide of Rocscience and ReSSA of ADAMA Engineering. A typical cross section that was used in the stability analysis is shown on figure 4. The results of the slope stability analysis indicate that the design of the solution was optimal; the figure 5 and 6 show the analysis "compound stability" that was the most critical.

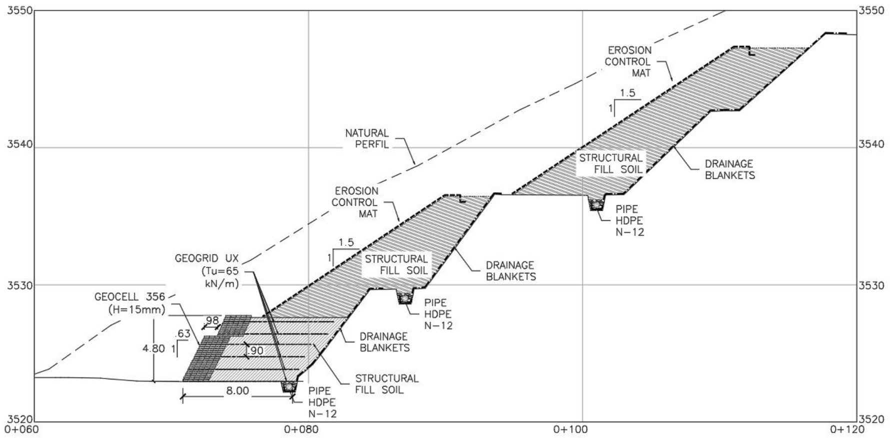

Figure 4. A typical cross section that was used in the MSEW stability analysis

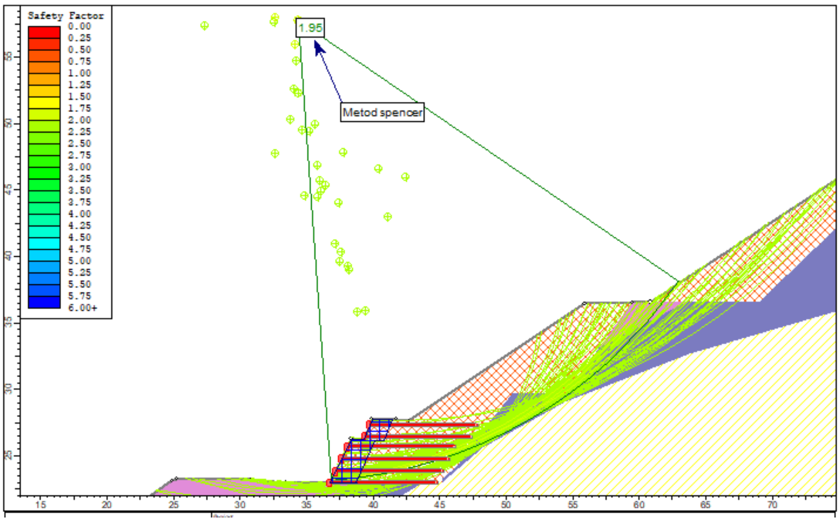

Figure 5. Stability analysis in static condition

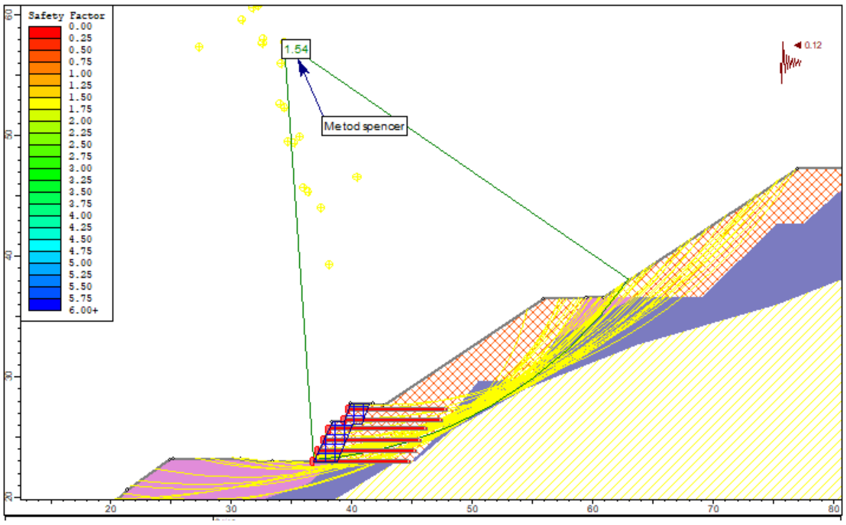

Figure 6. Stability analysis in pseudo-static condition

4. CONSTRUCTION AND EXPERIENCE

The project started in December 2017 and finished in June 2018. The Lowest layer basal reinforcement geogrid was placed directly on the surface of the Deposit of alluvial granular soil that was previously conditioned to start construction work of the RSS-GF.

Each layer of geocell was expanded using steel bars. The corner cells were then infilled to maintain the geocell in an expanded form while the steels bars were removed. The infill comprised the same soil material used for the body RSS-GF and top fill slope. The cells of the geocells were overfilled to a depth of 30mm and then compacted using a double drum vibrating roller. The compaction specification for 95% of modified proctor was easily achieved in the cells using this equipment and the sand infill. In order to maintain the desired face, that shown on the construction drawings. The geogrid material was used to reinforce the RSS-GF, was installed at 0.90m vertical spacing throughout the height of the reinforced soil slope.

The reinforced fill used for the construction of the RSS-GF was a residual soil obtained from a borrow area within the project site that is called structural fill soil. The residual soil was classified as silty sand gradation and was considered appropriate provided good compaction was carried out and good drainage measures were provided. A drainage blanket to intercept groundwater seepage at the rear of the reinforced soil wall was provided. This consisted of granular material wrapped in a nonwoven geotextile filter. At one level within the wall a series of drainage pipes at 10 meters horizontal spacing were installed to drain the water captured in the drainage blanket out through the face of the retaining wall.

Figure 7. Expanded geocells with steel bars and filled with structural fill soil

Figure 8. Laying of reinforcement geogrids

Figure 9. Laying drainage blankets

Figure 10. Front view of the end of the construction

Figure 11. Front view in operation

5. CONCLUSION

All The objective of this paper was to present design, construction and the innovation of the use of geosynthetics of reinforced soil slope with geocells face (RSS-GF). This solution was constructed faster than the traditional solutions such us gabions, concrete walls and other.

The use of geocell functions as confining element, which eliminated the use of wooden or steel formworks as traditionally used.

This solution allows the use of residual soil obtained from a borrow area within the project site that is called structural fill soil. This soil was employed both the face and body of the system.

This project illustrates how geosynthetic materials can be employed in an innovative manner to provide cost-effective solutions to challenging earth embankment or wall problems.

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