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Case Study - Reinforced Soil Wall with Geogrids at Hillside Using Volcanic Tuff as Filling Material

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ABSTRACT
Traditionally, Honduras´s engineering has used concrete walls (masonry or reinforced concrete) for the construction of landfill works on hillside. Nonetheless, in places where these walls are built very close to the slope, the weight of these structures makes them susceptible to a potential failure due to global stability, so it is not uncommon to observe cracks, subsidence or collapses in walls of this type built to hillside.
Over the last few years there has been an increase in the use of geosynthetics for road projects, which have been accepted by the local engineering community since they not only provide a more stable and secure solution for global stability but also environmentally compatible and, which, in turn, reduces costs and execution times.
This document presents a case study of a project in Honduras of a mechanically stabilized earth wall with geogrids, which was built on a hillside for a widening of the road in one of the most important stretches of the country´s roads.
The objective of this case study is to show the global stability analyzes performed for the reinforced earth wall with geogrids, showing the variations of the safety factor when implementing this type of wall instead of a concrete wall and the safety factor variations when building the retaining structure with the used filling material (volcanic tuff) in comparison to other materials found in the study area.

RESUMEN
Tradicionalmente la ingeniería de Honduras ha utilizado los muros de hormigón (mampostería o concreto reforzado) para la construcción de obras de relleno a media ladera en vías terrestres. Sin embargo, en sitios donde estos muros se construyen muy cercanos al talud, el peso de estas estructuras las vuelve susceptibles a un potencial fallo por estabilidad global, por lo que no es infrecuente observar agrietamientos, hundimientos o colapsos en muros de este tipo construidos a media ladera.
A lo largo de los últimos años se ha observado un crecimiento en el uso de geosintéticos para proyectos viales, los cuales han ido siendo aceptados por el gremio ingenieril ya que no solamente brindan una solución más estable y segura para la estabilidad global sino también ambientalmente compatible y, que, a su vez, reduce los costos y tiempos de ejecución.
Este documento presenta un caso de estudio de un proyecto en Honduras de muro de tierra mecánicamente estabilizada con geomallas, el cual fue construido a media ladera para un ensanchamiento de la vía en una de los tramos carreteros más importantes del país.
El objetivo de este caso de estudio es mostrar los análisis de estabilidad global realizados para el muro de tierra reforzada con geomallas, mostrando las variaciones del factor de seguridad al implementar esta tipología de muro en lugar de un muro de hormigón y las variaciones de seguridad al construir la obra de contención con el material de relleno finalmente utilizado (toba volcánica) en comparación a otros materiales encontrados en la zona de estudio.

1. INTRODUCTION

Mechanically stabilized earth walls (MSE) are containment structures that over the last few years have gained considerable popularity due to their various benefits, both constructive, environmental and economic. There are several types of reinforced earth wall that vary according to the type of material used to reinforce the fill and the front facade system used. In Honduras, the most widely used is the so-called Sierra system, which consists of the use of uniaxial high density polypropylene (HDPE) geogrids together with a basket-type facade of electro-welded mesh. Constructively, this system presents execution times that adapt to the demands of the project, being able to work in extended hours resulting in high construction yields. Economically they are very competitive structures since they use as filling material borrow pits of various granulometries and close to the construction zone. In turn, low-cost materials are used to form the facade of the wall such as non-woven geotextile or electro-welded mesh. They are structures that have the versatility to adapt to various topographic conditions, are environmentally compatible and built to high quality standards, have an extended lifespan.

2. CASE STUDY

This document deals with the construction of a mechanically stabilized earth wall (MSE) 13.5 m high with an electro-welded mesh facade for the widening of a section of one of the most important land roads in Honduras. The road in question is located on the CA -11 highway in western Honduras and is a very important commercial highway in the country since it connects Honduras with Guatemala.

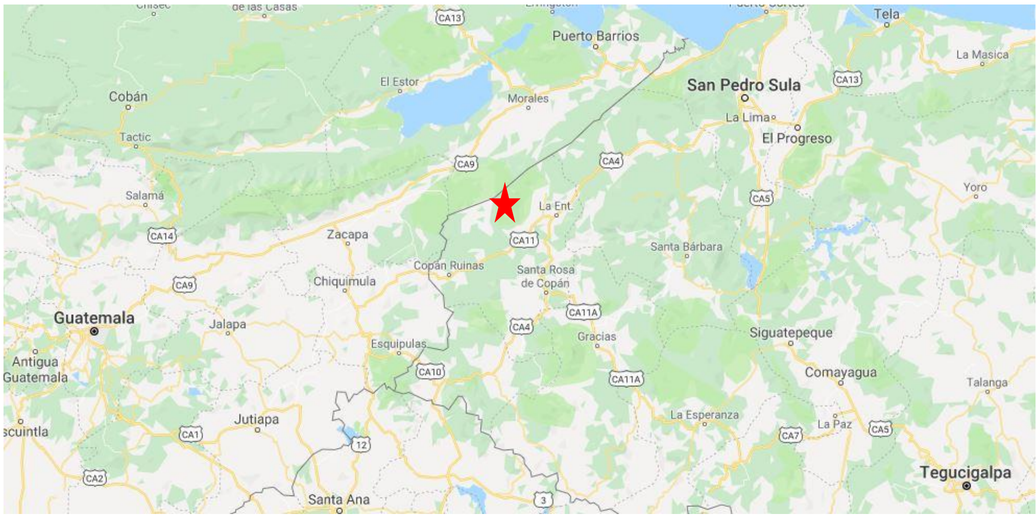

Figure 1. Geographic location of the study area (Image taken from Google Maps)

This road section was built in the 70's where demographic, economic and commercial conditions were low in Honduras, so it was built with basic engineering standards such as a rolling surface with a double surface treatment and two lanes for circulation. Nowadays, where commercial relations have multiplied and where all types of heavy-duty vehicles are circulating, a re-adaptation of the existing geometry of the road section in question is necessary, so the national authorities opted for improvement of the radius of curve of the section to improve the comfort and safety of the users.

2.1. Site Conditions

The study area is located within the stations of the project 23 + 740 - 23 + 860. It resides on a mountainous topography, has a tropical rainy climate and an average height of 877 meters above sea level. The geology of the site presents intercalations of tuffs, shales and ingimbrites. It has a difference of elevation of 6 m from the highest point and the lowest point, so in the area it drains a lot of surface runoff when it rains. This runoff has managed to infiltrate the different strata of the soil causing a weakening of the mass of soil that has induced movements on the pavement. The solution to this condition that was applied at the time of the construction of this section was the installation of small diameter pvc pipe perforated and wrapped in geotextile on a gravel bed as an evacuation mechanism for this runoff, now underground.
The road section was built at hillside, on what appeared to be a deposit of an old, unconsolidated landslide. Land exploration work was carried out with 6 m deep open pits prior to the execution of the wall on an already excavated platform 4 m high, excavating a fractured, loose and saturated material of the same characteristics as the material of the cutting slope, which indicated the presence of a material with few geotechnical characteristics. Unfortunately, the study area lacked a relevant geotechnical exploration that faithfully characterized the terrain, so the information on the open pits was an added value to the project execution.

2.2. Containment System

The retaining wall system used is formed by a facade of electro-welded mesh baskets wrapped by a non-woven geotextile and a triaxial geogrid, and anchored to the uniaxial geogrid by a steel rod, which work together to resist differential seats and large external loads. These walls have the flexibility to vary the angle of inclination of the facade, generally using an angle of 70 ° inclination. In turn, they work with any type of filler material since the geogrids used as reinforcement are chemically inert.

The system starts from the placement of a draining filter at the base of the wall. To do this, a drainage system is used using a 6”diameter perforated pvc pipe wrapped in a non-woven geotextile and which is connected to a runoff collection system with geodren on the retained soil. Depending on the saturation conditions of the foundation floor, a layer of crushed gravel at least 50 cm thick is placed in the first basket of the wall.

The reinforcement used is with uniaxial geogrids (HDPE) which resist large stress loads in one direction. In turn, its open opening allows a good interaction with the filling material, allowing the interlocking between particles to be achieved, achieving a high performance of the structural filling. In Honduras, this system is commonly used for landslide stabilization, widening roads or stirrups in bridges.

2.3. Reinforced Fill

The filler material used (Figure 2) was a tuff, taken from a borrow pit located 12 km away from the construction zone. Its geotechnical parameters are shown below in Table 1:

Table 1. Geotechnical parameters of the filling material used

	Borrow pit 12+700 (used)	Borrow pit Sierra (optional)
% Passing	Value	
4.75 mm	100	100
#40	68.9	21.6
#200	35.6	15.6
Maximum particle size (mm)	102	102
Plasticity Index (PI)	NP	9
Friction angle (°)	34	35.3
Specific weight (KN/m^3)	14	21

Various material banks with better geotechnical characteristics were evaluated but had the disadvantage of being too far from the construction zone or presenting poor borrow material.

Figure 2. Borrow pit 12+700 (volcanic tuff)

2.4. MSE Wall Design

For the design of the wall the following types of analysis were performed:

- Analysis of external and internal stability: Using the Tensar Soil program which applies the DEMO 82 methodology (FHWA 1997) and assesses the behavior of the wall against sliding, loading capacity and turning (external stability) and internal sliding of geogrids (internal stability), which takes into account factors such as tension, pullout and pullout and breaking connections.

- Global stability analysis: For this purpose, the Tensar Slope limit equilibrium analysis program is used, which uses the simplified Bishop methodology to calculate the wall safety factor.

Since Honduras is a country with moderate seismic potential, both analysis situations were carried out using a horizontal seismic coefficient of 0.30 for dynamic analysis. In turn, the static analysis was performed.

The geometry of the wall was designed using the ratio of width and height of the wall, L / H> 0.70, and this value can be lowered to a ratio of 0.6. The dimensions of width and height were 9.50 m and 13.5 m, respectively. Figure 3 shows the designed cross section:

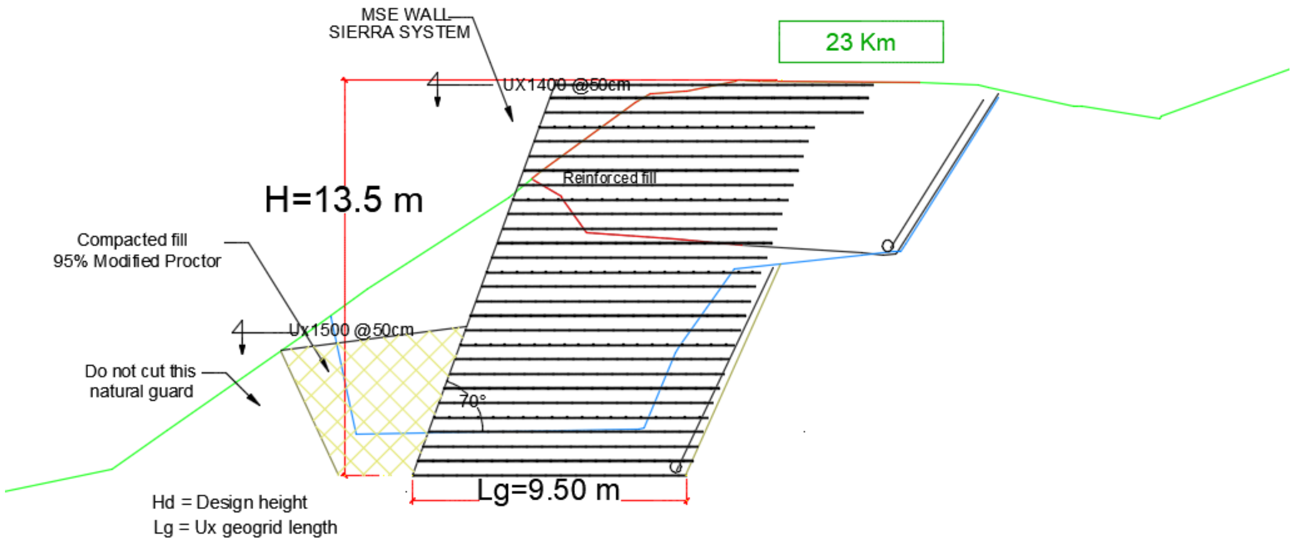

Figure 3. Cross section of the MSE Wall

The design parameters for reinforced padding, retained soil and foundation floor are shown below:

- Reinforced filling: cohesion 0, friction angle of 34 ° and specific weight of 14 KN/m^3
- Retained soil: cohesion 5 KN/m^2, friction angle of 28 ° and specific gravity of 18.5 KN/m^3
- Foundation soil: cohesion 15 KN/m^2, friction angle of 24.6 ° and specific gravity of 18.5 KN/m^3
- Live load (traffic load): 12 KN/m^2
- Dead load (concrete pavement): 3.6 KN/m^2
- Minimum FS for static analysis of 1.3 and for the dynamic case of 1.1

The results of the analysis described above are shown in Figures 4 and 5, below:

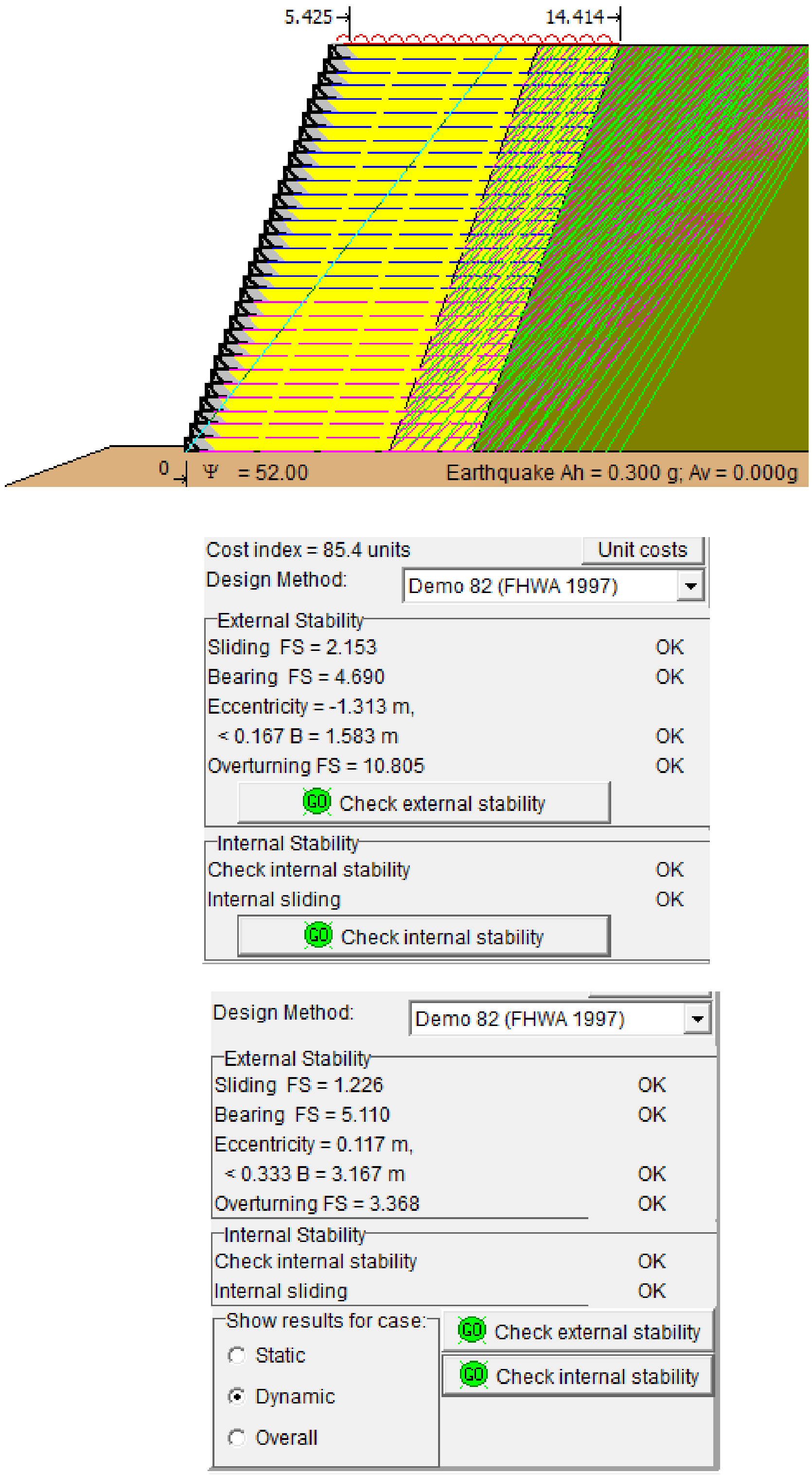

Figure 4. Analysis of external and internal stability static and dynamic scenarios

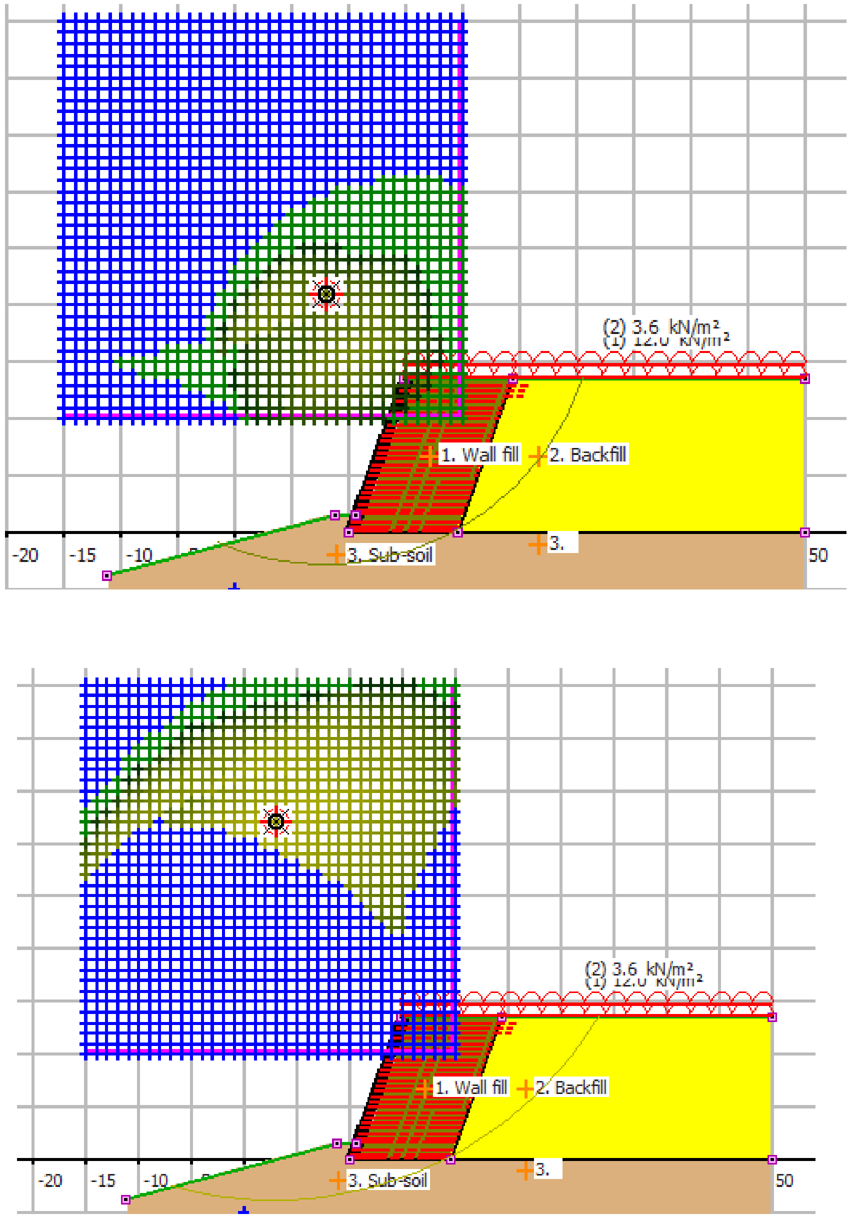

Figure 5. Global stability analysis of static (minimum FS 1,430 > 1.3, OK) and dynamic scenarios (minimum FS of 1,102 > 1.1, OK).

Now, using the Sierra Bank and varying the values of friction angle (35.3 °) and specific weight ($21 \mathrm{KN/m^3}$), the following results are obtained as follows in Figure 6:

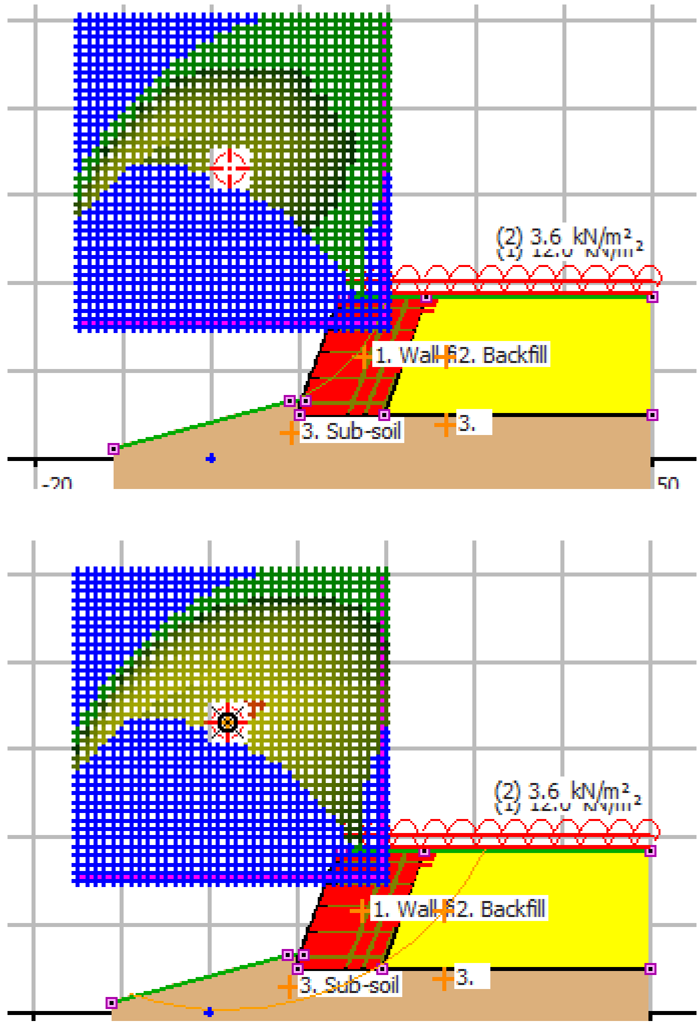

Figure 6. Global stability analysis of static (minimum FS 1,311 > 1.3, OK) and dynamic scenarios (minimum FS of 1,051 < 1.1, failed).

With this results, it can be infer that with a heavier material as concrete (specific weight = 24 $\mathrm{KN/m^3}$), a failure due to global stability might happen if a concrete wall is used.

2.5. Constructive Process

The construction of the wall was done in 3 months. To do this, the first step was improved the conditions of the foundation ground. In this phase, a ground improvement was made by placing 2 layers 50 cm of crushed gravel reinforced with triaxial geogrids with the aim of reducing possible differential seats and thus improving the bearing capacity of the foundation soil.

Once this stage was completed, the 50 cm thick draining filter basket was placed. On top of this layer, the crushed gravel is protected by placing a blanket of non-woven geotextile and the placement of reinforced material baskets vertically spaced every 50 cm begins. The reinforced filling is compacted with a compaction energy of 95% of the Modified Proctor with the maximum density values of 14 $\mathrm{KN/m^3}$ and an optimum humidity of 23.4%. The construction process is shown in Figure 7 below:

Figure 7. Construction process of the MSE wall reinforced with geogrids

3. CONCLUSIONS AND RECOMMENDATIONS

- MSE walls reinforced with geogrids and specifically, using the Sierra system, have good flexibility to be constructed in various adverse topographic situations. They also have reduced execution times that translate into economic savings.
- The friction angle is a very important parameter for the correct interaction between the geogrid and the soil particles of the filler material, where values of friction angle greater than 30° are recommended to ensure that the interlocking between geogrids and filler material occurs.
- The comparison between the filler material used from the 12 + 700 borrow pit and the SIERRA borrow pit produce a significant effect on the calculation of the value of the safety factor) due to the global stability of the mse wall in the dynamic analysis. By not including the natural guard at the foot of the mse wall, we eliminated a counterweight that could possibly reduce the destabilizing forces increased by the heavier specific weight of the SIERRA material (21 KN/m^3) in comparison with the volcanic tuff who has a lighter specific weight (14KN/m^3). Even though the SIERRA material has a better workability for the compaction process, the volcanic tuff represented a better option in factor of safety terms.
- Comparing a conventional concrete wall, who specific weight is greater than the SIERRA material (25 KN/m^3 > 21 KN/m^3), the better solution on this case was the mse wall reinforced with geogrids and using a volcanic tuff as filling material.

4. REFERENCES

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5. ACKNOWLEDGEMENTS

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