Design experiences of MSE structures under complex conditions in a highway project

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Abstract. The design and construction of Mechanically Stabilized Walls (MSE) have had a great boom in Guatemala in recent years. Central America's largest private infrastructure road project has required the construction of more than 30,000 m^2 of MSE structures under extreme seismic, topographical, and hydrological conditions. Considering that Guatemala has been a country with very high seismicity and the project being on a good percentage of slopes on the margins of a river, made both the design and construction of the project face great challenges. The project consists of tier walls, walls with upper slopes, walls supported on extremely steep slopes and walls with heights that can reach more than 20 meters. Many of these structures have critical hydraulic and global stability conditions. There are three case studies of walls, that by their complexity deserve to be considered for further study and from which there are many lessons for the future use of mechanically stabilized structures in the face of complex conditions.

1 Introduction

Guatemala is in the Pacific "Ring of Fire", at the junction of three main tectonic plates, which makes it a country with a high seismic hazard, steep topography and unique hydrology. These special conditions make the MSE structures the ideal retaining wall system to be considered in challenging infrastructure projects. During the last decade, the first totally private road project in the country "Via Alterna del Sur" or VAS, was developed at the south of Guatemala City. The project consisted of three sections that together add up to a total of 31 kilometers in length and 30,000 square meters of installed MSE retaining walls. More than eight million cubic meters of soil were cut and more than three million cubic meters of fill were placed.

Within the MSE walls designed and construction, there are several structures that due to their geometrical and topography complexity have some special technical interest. These three case studies provide an overview of some special design considerations that involve compound, global stability and/or rapid drop-down analysis. The FHWA-NHI-00-043 (ASD), FHWA NHI-10-024/25 (LRFD), AASHTO Standard Specifications for Highway

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Bridges (2012), as well as the Guatemalan Association of Structural and Seismic Engineering AGIES design guidelines, were used for the design and construction of these walls.

2 MSE WALL System

The Mechanically Stabilized Earth Wall (MSE) structures used on this project consists of Segmental Retaining Walls (SRW) and Wrap Around walls incorporating HDPE geogrids as reinforcement. These geogrids are highly oriented and resist deformation when subjected to high tensile loads for a long period of time. In addition, these geogrids present long-term durability due to the ability to resists chemical and/or biological degradation. These conditions make them ideal for MSE applications.

3 Seismicity

Earthquakes are relatively frequent in Guatemala. The country lies in a major fault zone known as the Motagua and Chixoy-Polochic fault complex, which cuts across Guatemala and forms the tectonic boundary between the Caribbean plate and the North American plate. In addition, along Guatemala's western coastline, the Cocos plate pushes against the Caribbean plate, forming a subduction zone known as the Middle America Trench located approximately 50 km off Guatemala's Pacific coast. This subduction zone led to the formation of the Central America Volcanic Arc and is an important source of offshore earthquakes. Both major tectonic processes have generated deformations within the Caribbean plate and produced secondary fault zones, like the Mixco, Jalpatagua, and Santa Catarina Pinula faults.

According to the Structural and Seismic Engineering AGIES macro-seismicity map, for the city of Guatemala where the project site is located, a peak acceleration (PGA) of 0.44g is recommended. This high seismic condition was the one that controls most of the MSE designs on this project.

4 Soils and load conditions

Three soil zones are normally required for the design of MSE structures. The reinforced soil zone represents the fill soil mass that is reinforced by geogrid. The retained soil zone represents the fill or native soils behind the MSE mass and the foundation soils that represents the native soils that support the MSE mass.

The following effective stress parameters, moist unit weight (γ), effective friction angle (φ'), and effective cohesion (c') were used during the design of the case studies included in this document.

Table 1. Summary of soil parameters

Soil Zone	Description	Moist Unit Weight, γ,	Effective Friction Angle, ϕ'	Effective Cohesion, c',
		(kN/m^3)	(°)	(kPa)
Reinforced Zone (Above water table)	Volcanic ash	14	34	0
Reinforced Zone (Below water table)	AASHTO 57 Stone	22	36	0
Retained Zone	Volcanic ash	14	34	0
Foundation Zone 1 (Case Study 3)	Volcanic ash	13	36	35
Foundation Zone 2 (Case Studies 1 and 2)	Alluvial	13	33	11

Regarding the design loads, a regular traffic load of 12 kPa and an additional dead load of 3.5 kPa corresponding to the pavement structure were considered in the design of these MSE structures.

5 Case studies

5.1 Case Study M07-03dr

This stepped wall of 22.20 meters of total height was composed of two-tier walls with 7-degree batter and wrap face. The lower wall was about 13.60 meters tall, and the upper wall was about 8.60 meters. In addition, on top of the upper wall a 1.5H:1V slope with 7.40 meters develops. The entire structure with a total height of 29.6 meters rests on top of a 20 meters high slope with an inclination of 40 degrees. The foundation soils for this structure were compound by soils of volcanic origin with very good mechanical properties. Due to the hydrogeological conditions of the project site, a drainage system with geocomposites was considered for the structure.

Considering that the MSE structure was a tier wall located on top of a steep toe slope, composite and global analysis were necessary to perform. These analyses were performed in addition to the internal and external stability analysis. Due to the presence of the tall slope at the toe of the wall as well as the one in the crown, it was necessary to increase the geogrid lengths within the reinforced fill to about a 30% above the minimum recommended by FHWA to control the overall failure of the MSE structure. The longer geogrids were required at the base of the wall to satisfy the required factor of safety of 1.5 for the static condition and 1.1 for the seismic. In the next figures, the initial geogrid layout obtained from internal/external and compound stability vs the results of global stability requirements are shown.

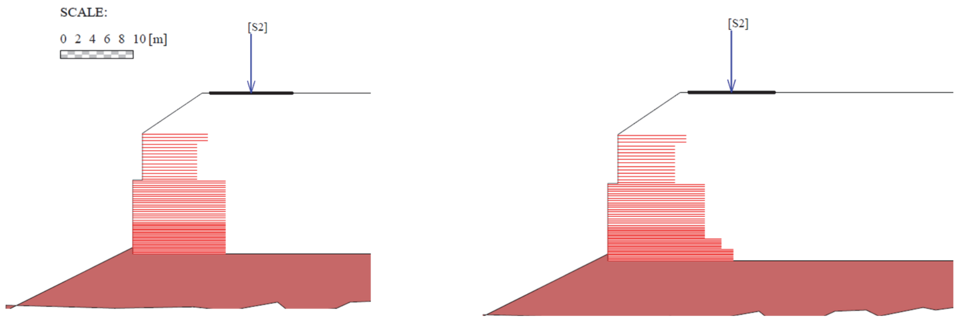

Figure 1(a) and 1(b). Results of Internal/External & Compound Stability Vs Results of Global Stability in terms of geogrid lengths.

5.2 Case Study M07-02-dr

The second MSE structure consists of a 16.8-meter tier wall consisting of a lower wall with a height of 8.80 meters and an upper wall of 8.0 meters. The lower wall rests on a 40 meters high slope formed of very competent volcanic soils. In addition, an extremely tall slope was planned to be built behind the MSE structure. See Figure 2.

Considering the geometrical conditions of the MSE structure, a global stability analysis was performed resulting in a significant increase of the required geogrid lengths to satisfy the target factors of safety under static and seismic conditions. Once the global stability of the entire slope including a very tall backslope on top of the MSE wall was run, the required factors of safety were not met. Based on that, it was necessary to include 100 Ton 40-meter-long active anchors to control the overall stability of the slope.

Based on the experience with the design of this structure, it is very important to remember that a comprehensive global stability analysis needs to be performed when any type of retaining structure in going to be built under critical geometrical conditions.

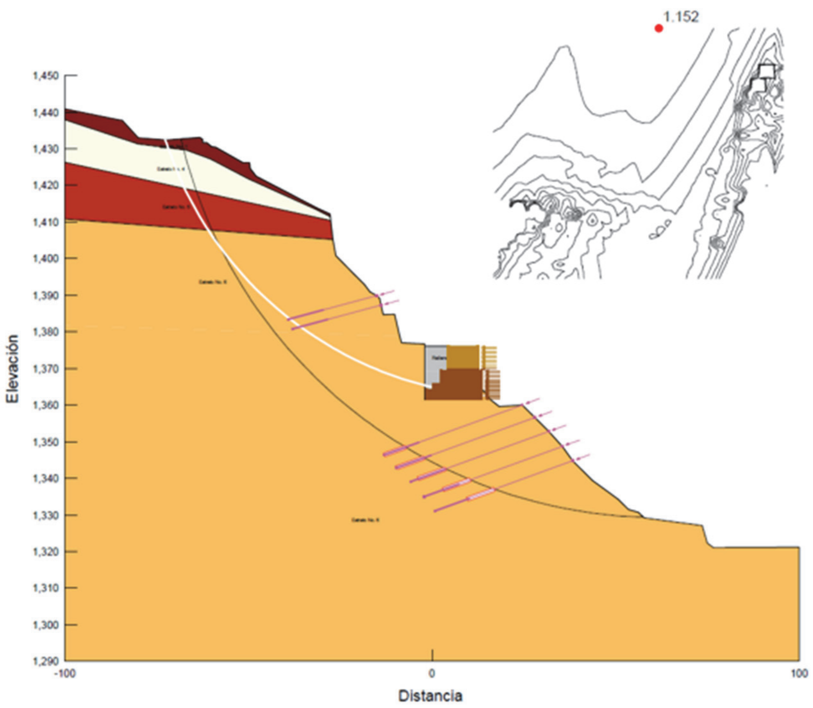

Figure 2. Global analysis of the entire structure for the seismic condition

Figure 3. Panoramic of MSE wall and anchors after construction

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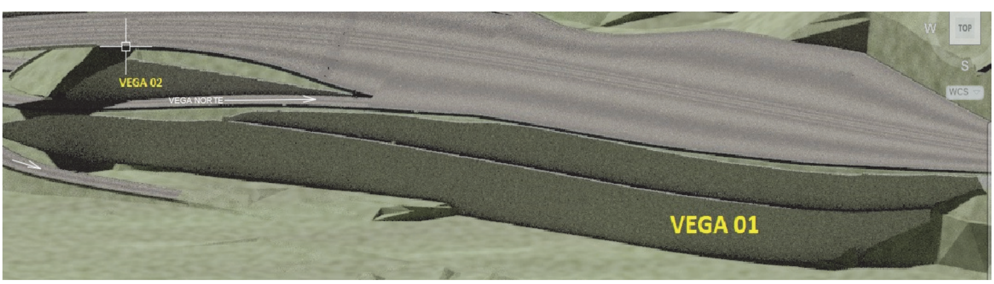
5.3 Case Study Bay for Bridge 15

The third case study consists of a Segmental Retaining Wall (SRW) designed and built in 2 tier sections like the previous ones. The maximum height of the structure was about 20.9m, 13.1m for the inferior wall and 7.8m for the superior wall. The offset of the upper wall on the lower one was just 1.8m, which made the walls behave almost as a single wall. In addition to being a tall MSE structure, the inferior wall was built within the flood zone.

Considering the tier and the flooding conditions, the internal/external stability analysis were complemented with rapid draw down and compound stability analysis. Embedment length for the lower wall had to be increased to about 25% to meet the required factors of safety for the above-mentioned conditions. For this particular MSE wall, the compound stability under the seismic conditions was the one controlling the design. General views of the proposed and constructed walls are shown in Figures 4(a) and (b).



Figures 4 (a) and (b). View of the proposed and constructed MSE wall

6 Conclusions

Numerous MSE structures have been built around the world in the last four decades. This practice has provided cost efficient structures that offer suitable solutions for places with complex topographic and/or hydrological conditions.

The MSE wall system allows to build in places with limited accessibility, like places where other systems would be almost impossible to be considered. Due to the flexibility of the system, MSE walls with complex geometries can be built on heterogeneous soils due the capacity of controlling differential settlements.

A proper design that incorporates compound, rapid drawdown and global stability analysis are required to guarantee the safety and performance of these structures during the entire design life. Some of the conditions that required analysis besides the internal and external stability that should not be neglected are:

- Compound and global stability analyses are essential in walls with complex geometries or when those structures are located on top of slopes.
- Rapid drawdown analysis is prevalent in river flood zones or in any situation where the wall has a susceptibility to flooding events.
- Global stability analysis should be performed in all walls founded on top of soils with critical geotechnical and/or hydrological conditions.

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