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Importance of seismic loading on Reinforced Earth walls

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ABSTRACT: The purpose of utilizing reinforced earth walls instead of rigid retaining systems is to make, more economical and safe structures under the exposed loads and settlements experienced during the service life, especially in regions having high seismic activity. Looking at the basics of the system, reinforced earth walls are soil structures, formed as a result of the composite system consisting of concrete, steel and soil elements. Therefore they are more flexible and as a result of this property, reinforced soil retaining walls can accommodate large differential settlements and reduce earthquake response on the structural system. For a case study of reinforced earth walls, structural analysis are carried out with the widely accepted commercial program PLAXIS on a major intersection project of Istanbul. In this article with the numerical analysis performed, the expected displacements of the reinforced earth wall in static condition and under the expected seismic loading are determined. In addition, also a comparison of the numerical analysis with the limit state design is performed. Based on the results of structural analysis study it is seen that, reinforced earth wall is a beneficial structural solution as a retaining structure especially when it is constructed on soft foundation soil and in seismically active regions.

1 INTRODUCTION

The main principle of the mechanically stabilized earth (MSE) walls is to form a composite earth wall, combining the backfill soil with the retaining wall by means of friction. Improving the mechanical properties of soil by adding materials like straw, wooden beams, metal other materials was used through out the history of mankind. In 1963, Henry Vidal proposed detailed design procedures for the mechanically stabilized earth walls, thereafter the idea is widely accepted as a major invention in the civil engineering area and the utilization of the system grew rapidly as the system is both economical, fast in terms of application and more resistant to the engineeringly problematic cases like settlements on soft soils and seismicity, compared to the classical retaining wall systems.

A typical schematic view can be inspected at Figure 1. The reinforcements lied through the man-made backfill soil, these reinforcements work by friction and uses the friction force againist the lateral earth pressure component on the panels. Therefore the "strips" enable the use lower section width for the panel system (as low as 14cm), compared to the classical retaining wall sections (varying from 30cm to 200cm’s).

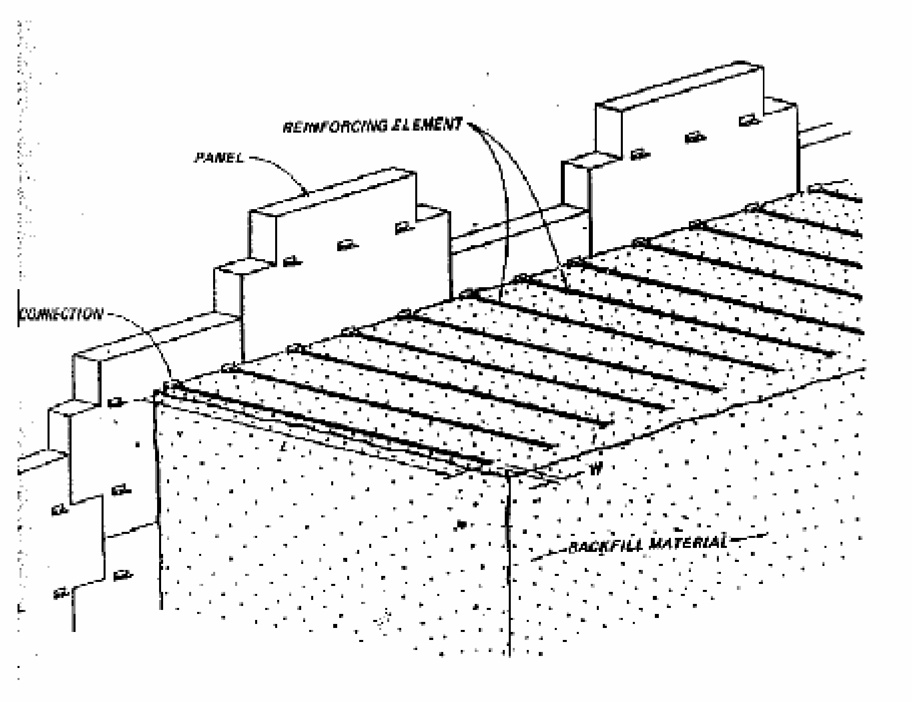

Figure 1. Schematic view of mechanically stabilized earth (MSE) wall

The backfill is man-made in the reinforced earth structures, therefore it is usually prefered for the embankments in the roads, railroads, the connection roads to the overpass bridges and for the abutment system of the bridges.
Reinforced earth system is applied in a controlled procedure of placing the panels, placing the backfill and compacting, then lying the strips and backfilling cycle. Unlike the anchorages that are used in the support of the deep excavations, strip section used in the MSE walls is designed in a flat rectangular shape, having the dimensions of 40mm × 4mm in general for the steel strip case, this is entirely the result of the difference in the placing conditions of the anchorages and strips. The rectangular shape is more able to form a sufficent friction and it is also enhanced by a ribbed strips using passive resistance of the soil in addition to the friction. The longitudinal section of a strip is shown on Figure 2.

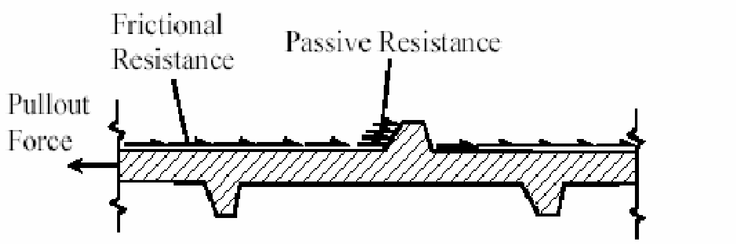

Figure 2. Longitudinal section of a strip and working principle

2 PAST PERFORMANCE OF MSE WALLS UNDER SEISMIC LOADING

The advantage of the mechanically stabilized earth wall compared to the classical structure is its flexibility. The strip system in the MSE walls works with friction formed by the initial deformation during the construction, the wall stabilizes itself in an equilibrium position where the deformations are enough to form the necessary friction force. When the dynamic earthquake loading arises, the system deforms more to accomplish the higher friction forces required. These forces are carried by the strips and the concrete panels which are also designed for the higher level of loading caused by the earthquake.
In the case of settlements on the soft foundation soil, reinforced concrete retaining wall systems show signs like visible cracks due to the rigidness of the system where as MSE walls proved to be more resistant to the ground movements especially differential settlements. Therefore the combination of facing, reinforcement and granular backfill has performed successfully, in an ever-increasing number of retaining walls including bridge abutments and other structures, for over three decades (Anderson, 2004)
In the limit state design, all the elements of the system are tested againist the highest possible stresses at the same time whereas, the finite element approach brought the performance issue into the design so that the engineer can inspect the expected amount of stresses and displacements on each element of the system. The engineer therefore can perform very sofhisticated analysis like testing the whole system's sensitivity to the some critical elements he may choose. These elements may be the soil profile and/or the structural elements like the strips and concrete panels.
The different performances of MSE walls are tested in the real earthquakes throughout the world. The results showed that the inextensible strips like steel, have shown a better performance than the extensible counterparts like polymers and geotextiles under seismic conditions. Some publications does not suggest the purely frictional strips like geotextiles in the regions having an earthquake risk of a>0.19g (FWHA-SA-96-071, pg130).
The MSE walls tested under the various earthquakes throughout the world since the past three decades. One case study is performed after the August 17, 1999 Kocaeli Earthquake (Mw=7.4) that struck northwestern Turkey, on the Arifiye Overpass Bridge approach embankment MSE walls. Although the magnitude of the earthquake was greater then the value used for design the MSE walls demonstrated a good performance showing only minor cracks. Performance of Reinforced Earth structures under major earthquakes has been remarkably well in the past in spite of the fact that whether specifically designed for earthquakes or not. (TAI Internal Report, 1984), (RECO-Manography M12, 1994), (Boyd, 1995), (Mitchell et al, 2000), (Segrestin, 2000), (Sankey & Segrestin, 2001), (Martin et al, 2007).
As an addition to what have been said, it must be mentioned that, to be able to have the stronger material as the seismicity of the area are increased, the amount of strips (the used number and length of strips used per m2 of wall) will be increased accordingly placed in the reinforced earth structure.

3 CASE STUDY ALTUNİZADE INTERSECTION REINFORCED EARTH WALLS

In Altunizade Intersection, the connection of the Motorway coming from the Bosphorous Bridge that connects the Europe and Asia sides of İstanbul, to Üsküdar district is rehabilitated. The overpass and underpass structures offered a transpassing to and out of the district for the purpose of undisturbed traffic on the main motorway (D-100). The project included a viaduct and an underpass constructed by the utilization of cantilever bored piles. All the approach ramps of these structures were constructed as MSE walls.
Reinforced Earth™ system is preferred for both high resistance to earthquakes in a seismically very active region, and economy. The construction methodology was also more adventageous, as it will not disturb the current traffic by closing a lane for the foundation excavation and scafolding compared to the classical retaining wall system application method.

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Figure 3. Altunizade Intersection

The analysis of the wall is performed by the VALDEZ program which is specifically prepared for the design of Reinforced Earth™ walls. VALDEZ program uses the limit state design procedures. The design is based on the limits of the materials used and the loads under the most critical conditions (pseudostatic earthquakeload). The VALDEZ program makes the necessary checks of external stability accepting the wall as a whole mass, and internal stability by evaluating the lateral earth pressure on each panel of the system and placing appropriate number of strips accordingly.

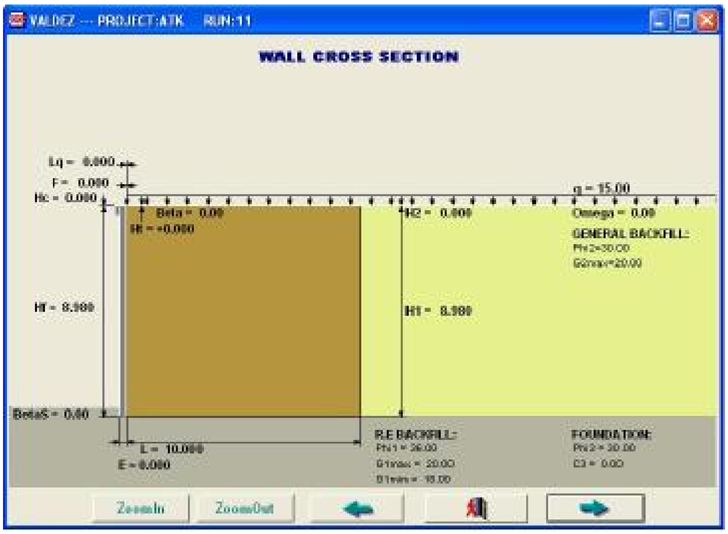


Figure 4. VALDEZ output

VALDEZ program is widely used in commercial area for its fast and easy applicability on the different cases. Although limit state approach is the fastest method to calculate the exact quantity and length of reinforcing strips required for the retaining wall in accordance to the design codes and standarts, the finite element method is more “real”, as its approach is displacement (performance) based. The method divides the entire system into small elements including the panels, strips, subsoil, reinforced earth backfill and existing or general backfill. Then it calculates the displacements caused by the loads and other effects that is imposed on the system. In a composite system formed by the combination of soil and structural elements like Reinforced Earth™ wall, the performance based approach gives more comprehensive results, also the finite element approach enables engineer to understand the sensitivity of the system to the various effects and how much of the allowable limits are actually expected to be used for each element. For the finite element analysis, widely accepted commercial program PLAXIS is utilized. PLAXIS is specifically prepared for the structure and subsoil, it includes initially defined soil models.

For the demonstration purpose, the finite element analysis performed on the same cross-section described in Figure 4 is presented on this paper. In other words a control analysis is performed on the limit state design in order to compare the results more efficiently. The used parameters for the definition of elements on finite elements are given in Table 1 and Table 2. The parameters were determined according to the values given in literature (Kulhawy and Mayne, 1990) based on the results of soil investigations.

Table 1. The soil parameters used in numerical modeling

Soil Type	∅	c (kPa)	E (MPa)	υ
Subsoil	30	-	50	0.3
General Backfill	30	-	50	0.3
Reinforced Earth Fill	36	-	60	0.35

Table 2. The parameters used for the structural elements

Structural Elements	E (GPa)	Cross Sectional Area (m^2)	Moment of Inertia (m^4)
Facing Panels	32.7	0.14	$4.86x10^{-4}$
Steel Strips	210	$2x10^{-4}$	-

The analysis have been performed by stages. Each fill stage, (placement of panels, placing the strips and reinforced earth fill) has been modelled separately.

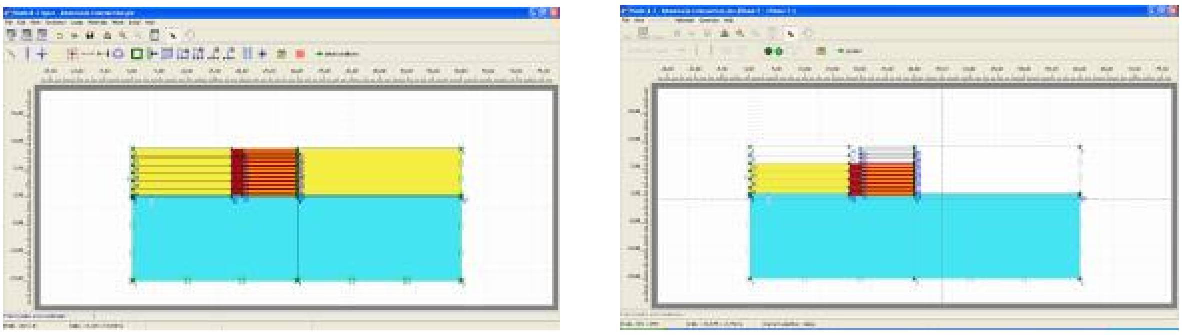
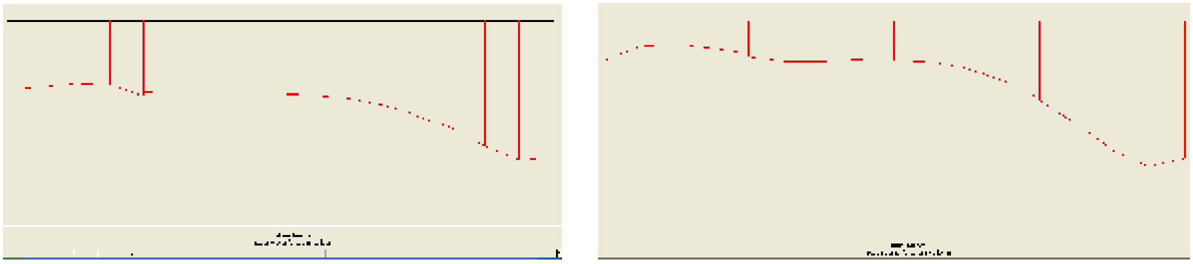


Figure 5. PLAXIS input and a calculation stage

The results of the analysis are presented. The lowermost strip is evaluated as it will carry the max load. On the static case max load per 1m width is given as 125kN whereas the max load increases to 163,5kN. With the limit state design, the assigned number of strips at this depth level is 4strip/1.0m. Therefore the safe capacity of the strips are (4x47,6=190.4kN) are higher than the numerically calculated values.

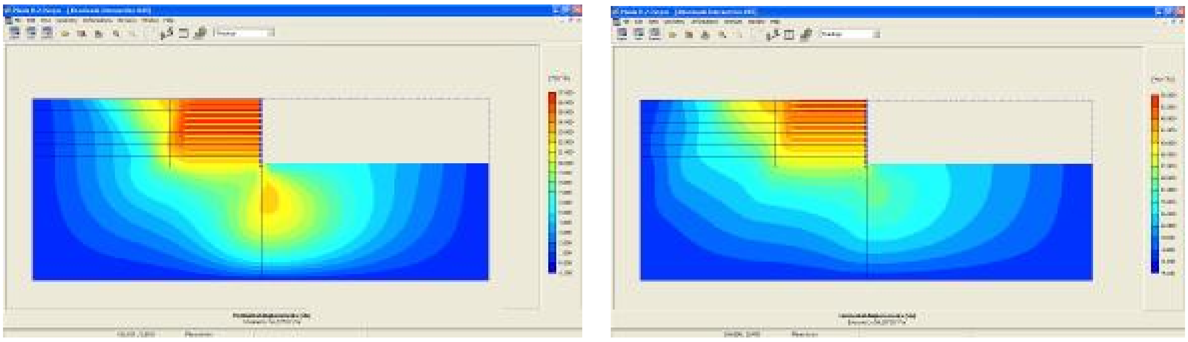


Static Case Seismic Case

Figure 6. PLAXIS results on the lowermost steelstrips on static and seismic cases

Checking the loads on the panels, the max shear and bending moments are neglible. That is the result of the nature of the system as the loads are mainly carried by the strips. Engineeringly speaking one can say, as the stress that the strips can take increases, the MSE wall can resist higher seismic acceleration safely.

The resulting deformations are also presented below. The wall horizontally deforms 1,6cm which will occur during the construction phase and therefore would be avoided. An additional 3,6cm deformation is calculated under the earthquake loading, which is approximately the 0,4% of the total wall height.



Static Case Seismic Case

Figure 7. PLAXIS results: deformation of the entire system

4 CONCLUSIONS

The main aim of the study is to present numerical analysis to reinforced earth systems and estimating the displacements in the abutments under static and earthquake loadings. In order to achieve this aim PLAXIS software is used to control the design carried out by the limit state approach made by the VALDEZ software which is specifically improved for the design MSE walls.
This study serves also for the applicability and comparison of these softwares on the specific Reinforced Earth™ case study. The resulting stresses of the limit state and the finite element proved to be very close.
The results of this analysis clearly have shown that, under seismic load application reinforced earth structures are performing in the acceptable engineering limits in terms of their servicability as long as they are properly designed according to conventional limit state procedures. This is in good agreement with the recent performances of such structures under earthquake loadings, (Segrestin, 2000) (Mitchell et al, 2000), (Martin et al, 2007)

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