Numerical Analysis of Reinforced Earth Abutments – A Case Study

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ABSTRACT

Reinforced earth soil structures have been applied to many projects worldwide during last 35 years. Economic feasibility, fast construction and high resistance to earthquakes due to the flexibility of reinforced earth are the main reasons for the preference of reinforced earth instead of the conventional retaining structures.

The purpose of utilizing reinforced soil abutment walls instead of classical reinforced concrete structures is to make more economical and safe structures under the exposed loads and settlements experienced during the service life, especially in regions having high seismicity**.** Since they are more soil like structures, reinforced soil retaining walls can accommodate differential settlements and reduce earthquake response on the structural system. In order to exhibit the benefits of reinforced earth abutment walls, structural analysis are carried out with different commercial programs FLAC, and PLAXIS. For the considered case study of DDY-8 Railway Overpass Project in the content of "Bozüyük Mekece Improvement Project 2nd Part" their results are compared and critically evaluated.

In flexible reinforced earth structures the deflection of the reinforced earth panels under the heavily concentrated loading of beam seats sometimes become the main concern of the clients. FLAC and PLAXIS are especially chosen, since they use different numerical methods, finite difference and finite elements respectively. Therefore they both have the ability to estimate the displacement values of the reinforced earth abutment structure. Classical limit state design is used to verify the results by limit state analysis.

Structural analysis results of the model study indicate that reinforced soil wall is a very beneficial structural solution as retaining structures of river banks, bridge abutments and retaining walls especially when incorporated with soft foundations and high seismicity.

Keywords: Abutments, reinforced earth, numerical analysis

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1. INTRODUCTION

The idea of adding different materials to soil for extra strength is not new and researchers have provided valuable documentation of the use of straw, wooden beams, metal and other materials to improve the engineering properties of the soil-reinforcement system in the past. In 1963, the French engineer, Henri Vidal introduced rational design procedures for incorporating tension reinforcing elements into soil to produce a desirable composite material applicable for important engineering structures. It soon became obvious that when compared to conventional retaining walls, reinforced soil structures could offer many advantages, including speed and relative ease of construction, flexibility of the resulting structure, and economy (Whitcomb and Bell, 1979). Besides, like reinforced concrete, the beneficial effects of adding materials to soil depend on the combination of the tensile strength of the reinforcing material and the shear bond with the surrounding soil (Lee, 1973).

2. REINFORCED EARTH ABUTMENTS

Although more than 400.000m^2 Reinforced Earth structures have been completed in Turkey, there is still a doubt about the performance of the reinforced earth abutments. This is because of the highly concentrated load of the beam seat placed right above the reinforced earth wall. More than a thousand reinforced earth abutment structure have been completed all over the world. (Anderson, 2004).

2.1. Basic Principles of Reinforced Earth

As explained by McKittrick in 1978, "The basic mechanics of Reinforced Earth were well understood Vidal and were explained in detail in his early publications. A simplification of these basic mechanics can be illustrated by Figure 1. As shown in Figure 1a, an axial load on a sample of granular material will result in lateral expansion in dense materials. Because of dilation, the lateral strain is more than one-half the axial strain. However, if inextensible horizontal reinforcing elements are placed within the soil mass, as shown in Figure 1b, these reinforcements will prevent lateral strain because of friction between the reinforcing elements and the soil, and the behavior will be as if a lateral restraining force or load had been imposed on the element. This equivalent lateral load on the soil element is equal to the earth pressure at rest ($K_0\sigma_v$). Each element of the soil mass is acted upon by a lateral stress equal ($K_0\sigma_v$). Therefore, as the vertical stresses increase, the horizontal restraining stresses or lateral forces also increase in direct proportion." Reinforced Earth is, therefore, a composite material, combining the compressive and shear strength of compacted granular fill with the tensile strength of horizontal, inextensible reinforcements.

In practical terms, the larger the surcharge put atop of a Reinforced Earth structure, the stronger the material becomes. Thus, understanding Reinforced Earth's basic mechanics and its resulting inherent strength and flexibility, and with the addition of a facing system, this composite material was well suited for use as bridge abutments and other heavily loaded structures. The combination of facing, reinforcement and granular backfill has performed successfully, in an ever-increasing number of abutments and other structures, for over three decades (Anderson, 2004).

As a summary of what have been said, it must be mentioned that, to be able to have the stronger material as the surcharge is increased, one must increase the used amount of strips (the total length of strips used per 1m^2 of wall) that will be placed in the reinforced earth structure.

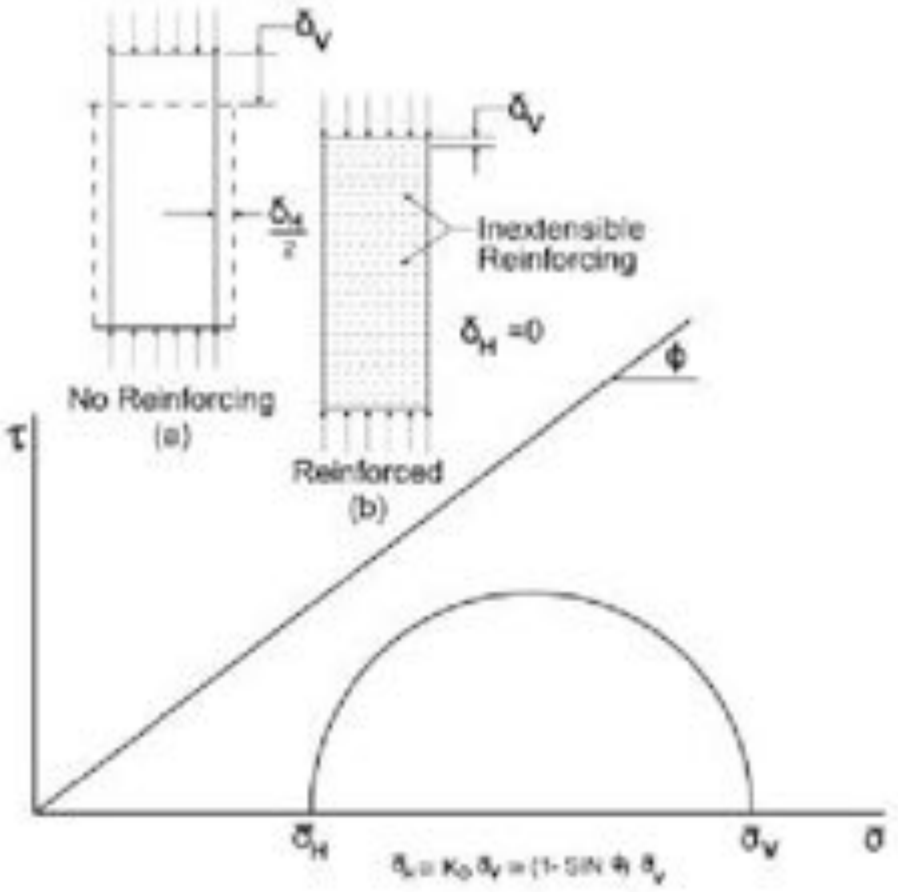

Figure 1. (Kittrick, 1978).

3. CASE STUDY: DDY-8 BRIDGE ABUTMENT STRUCTURE

In the content of the Bozüyük Mekece Highway Improvement Project Section 2, DDY-8 Railway Overpass Bridge Abutment Walls were bid by Reinforced Earth Company Turkey. In the discussion that was arranged between the client, consultant and Reinforced Earth Company, Project Manager Mr Kuroda, required the displacements to be estimated in order to approve the design solution with reinforced earth.

The classical preliminary designs prepared by the Reinforced Earth Company were not able to estimate the displacements in the abutment system because the designs were using "Limit State" methods. Which is briefly using the limits of the materials in design but it does not take into account the strains formed by stresses. Therefore a new method to calculate the displacements is needed.

In order to reply the request with satisfactory report, it is decided that a numerical analysis of the reinforced abutment system will be appropriate. Numerical analysis methods are capable of calculating the displacements in any part of the defined system. This is done by the finite difference software FLAC first and then the more popular geotechnical finite element program PLAXIS. These programs are chosen because of their wide usage in geotechnical areas. As will be explained, the designed reinforced earth abutment with limit state method is checked by the numerical analysis in this case study.

The soil parameters used in numerical modelling is given in Table 1. The parameters were determined in accord to the values given in literature (Kulhawn and Mayne, 1990).

Table 1.

Soil Type	ϕ	c (kPa)	E (MPa)	ν
Occasionally blocky silty sandy gravel	30	-	100	0.3
Middle stiff, occasionally gravelly, silty sand	30	-	80	0.3
Middle stiff, occasionally blocky rare gravelly, silty sand	30	-	50	0.3
Reinforced Earth Fill	36	-	60	0.35

The parameters used for the structural elements in the analysis are summarized in Table 2.

Table 2.

Structural Elements	E (GPa)	Cross Sectional Area (m^2)	Moment of Inertia (m^4)
Facing Panels	32.7	0.18	4.86e-4
Steel Strips	210	2e-4	-

In numerical analysis the design coming from the limit state analysis is used. So instead of making a secondary design, a control analysis of the limit state is performed.

3.1. FLAC Analysis Results

Results of the analysis performed can be seen in the Figure 2 and Figure 3. In these analysis by taking into account the borehole datas given, the subsoil is numerically modelled, after that the structural elements -the precast panels and steel strips- are modelled. Finally the pseudo staticaly calculated, equivalent seismic forces are applied to the system.

The displacements formed as a results of this loadings are calculated. In the graphs given, the calculated displacements in the x and y direction is presented. For the static case the maximum displacements occur as, δ_x=1,25 cm, δ_y= 4.50 cm. These displacements form especially at the construction stage as elastic deformations. After the equivalent seismic load is applied, displacements change to δ_x=1,75 cm ve δ_y= 4.50 cm.

To sum up, the additional displacements that are expected to occur for the seismic conditions are, $\Delta\delta_x$=0,50 cm $\Delta\delta_y$= 0.00.

Considering the subsoil conditions the settlements are expected to be 4.50cm as said before the additonal equivalent seismic loading did not cause a change in this values. As a result the wall stays in the applicable engineering limits.

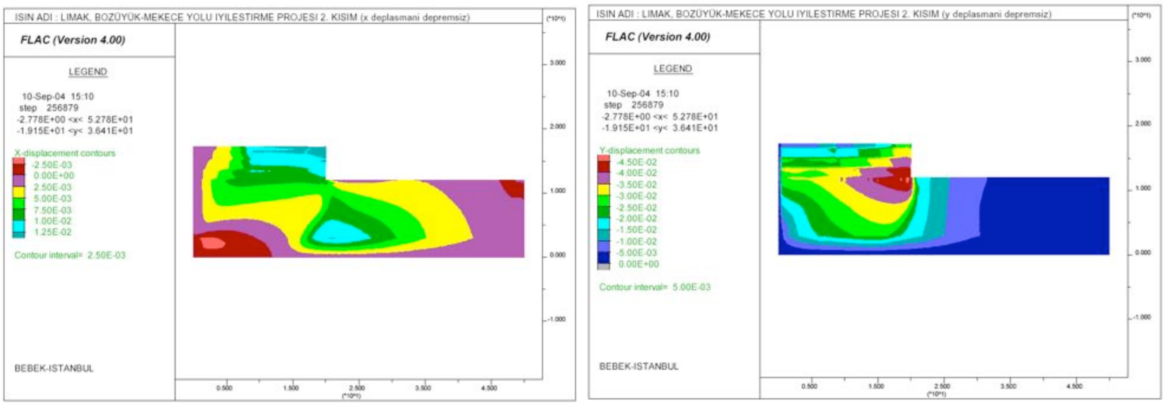

Figure 2. (FLAC Analysis Results Static Condition).

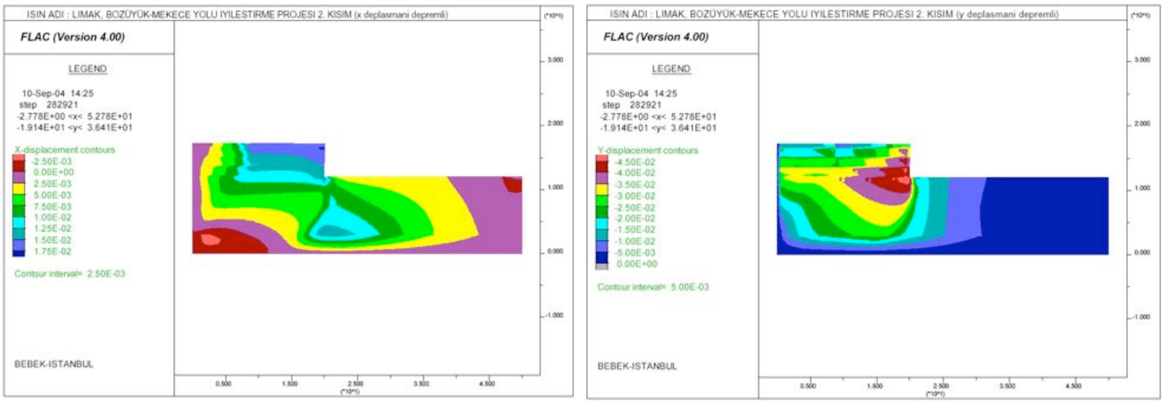

Figure 3. (FLAC Analysis Results Seismic Condition).

3.2. PLAXIS Analysis Results

Like the analysis performed by FLAC, the same structural and soil parameters are used with the PLAXIS software. For the static case the displacements are calculated as, δ_x=1,90 cm δ_y= 4.00 cm in the seismic case the displacements are happened to be, δ_x=3,50 cm δ_y= 5.20. Therefore under the pseudo static earthquake conditions the additional displacements are $\Delta\delta_x$=1,60 cm $\Delta\delta_y$= 1.20. In the Figure 4 and Figure 5 the PLAXIS analysis results can be inspected, the x displacements are given left side of the Figures.

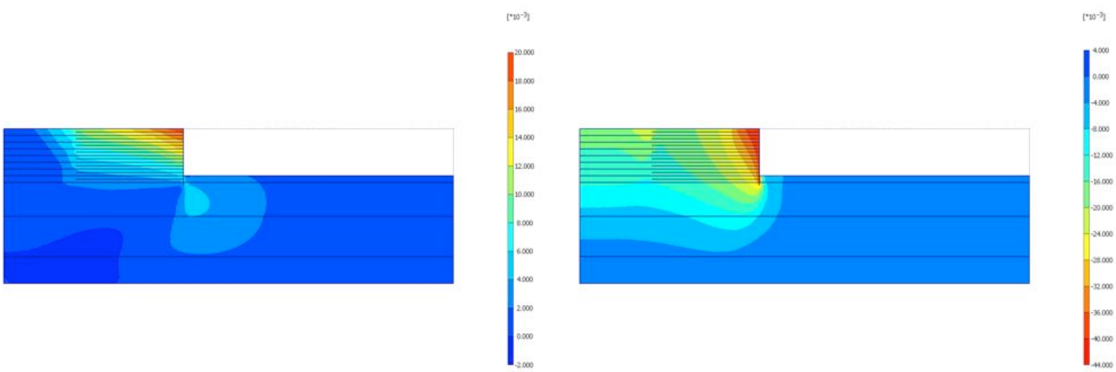

Figure 4. (PLAXIS Analysis Results Static Case).

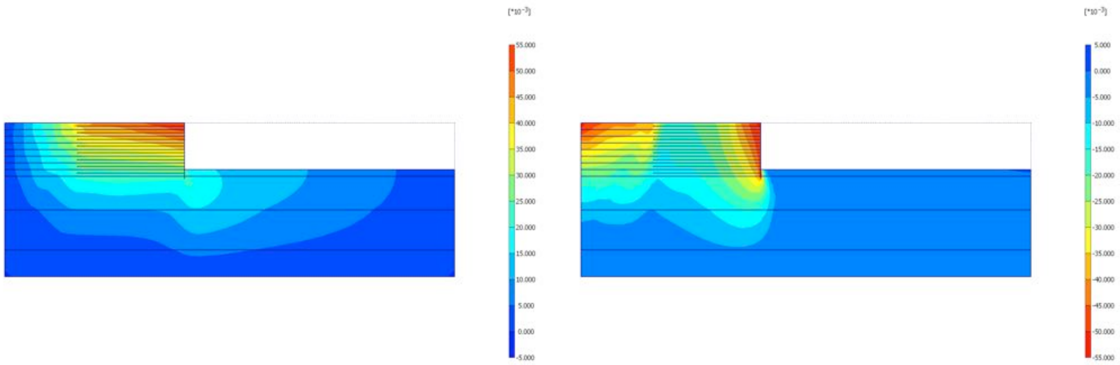

Figure 5. (PLAXIS Analysis Results Seismic Case).

3.3. Stresses on the Strips

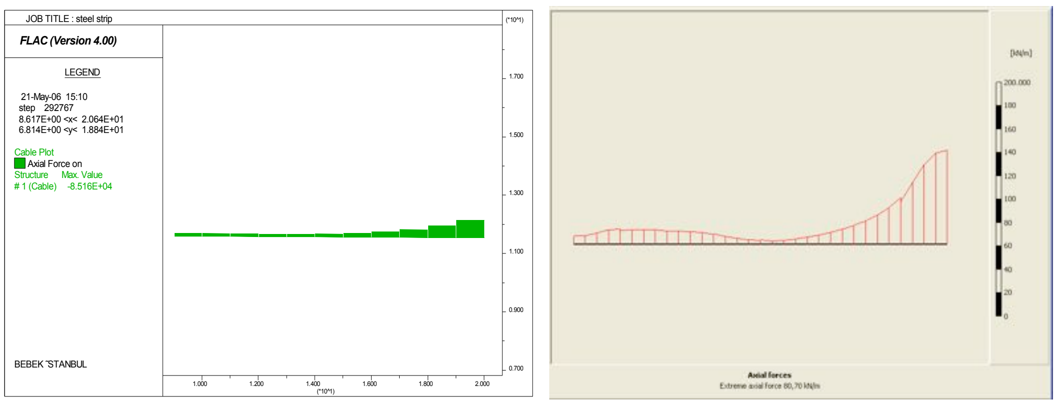

Figure 6. (FLAC and PLAXIS Stresses at the Lowermost Strips, Seismic Condition).

As seen in Figure 6, the calculated stresses for the lowermost strips for the 1m width of wall are given. FLAC calculates the total force needed to carry by strips as 85 kN, where as PLAXIS calculates the same value as 80.7 kN. It must be emphasized that, the calculated number of strips per 1m width of the reinforced earth wall by limit state design is 2, which means that, with the material safety factors applied, the lowermost strips has a capacity of 2x47.6=95.2 kN.

4. CONCLUSION

The main aim of the study is to present an evaluation of theory of soil reinforcement, reinforced soil retaining walls with strip reinforcements, their applications, design methods, components, behaviour under seismic loads. In addition introducing numerical analysis to reinforced earth systems and estimating the displacements formed in the abutments.

In order to achieve this aim two different softwares are used. FLAC and PLAXIS are both popular in the current geotechnical design software market and this study serves also for the applicability and comparison of these softwares on the specific Reinforced Earth abutments case.

The steel strip applications are approximately same in both programs and an equivalent sheet is idealized in both programs. FLAC requires detailed friction properties where as

PLAXIS requires only EA value of the strip. This may lead to an error of checks in pull-out resistance. In the calculations this kind of an error has not been encountered.

The estimations of the displacements are very close except for the x displacement values in earthquakes. The earthquake definitions are not the same in both programs. In FLAC applying the hand calculated pseudo static stresses are introduced where as in PLAXIS ground acceleration could be introduced to the reinforced abutment structure.

Being capable of all the upper stated advantages numerical methods are only approximate methods, their precision changes even by the mesh size selected. And the compile times are still very long for practical design use.

The reinforced earth abutments are being applied all over the world safely. The analysis clearly showed that under a relatively high and concentrated load and under seismic load application reinforced earth abutments are performing in the applicable engineering limits.

Figure 7. (DDY-8 Railway Overpass Bridge Abutment Structure, 2006).

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