External stability of geogrid reinforced-soil segmental bridge abutments under seismic excitation

Attar, I. H. & Fakharian, K.
Dept. of Civil & Env. Eng., Amirkabir Univ. of Technology, Tehran 15875, Iran, E-mail: kfakhari@aut.ac.ir

Keywords: reinforced soil, Geogrid, segmental bridge abutment, seismic analysis, external stability, bed-soil

ABSTRACT: Usually there are four modes of external instability for retaining wall systems. Because of the flexibility and large contact area at the base, usually overturning, sliding, and bearing capacity do not occur in reinforced walls. Instead, the rotational mode of external instability, especially under seismic excitations, may occur. In most of the numerical models, however, the effect of bed-soil, that may cause rotational mode of external instability is not considered and instead, a rigid-bed is assumed in the model.
This paper presents the results of a finite difference analysis on two segmental bridge abutments, reinforced by geogrid, subjected to seismic loads, and with the main focus on effect of bed-soil condition, that may cause external instability. Rigid condition was assumed for the bed-soil (soil underlying the reinforced abutment) in the 1st model, whereas the Masing nonlinear hysteretic unload-reload model, as the real soil condition was considered for bed soil of the 2nd abutment. This nonlinear model is also used for reinforced and retaining soils in both abutments analyses.
The results show a substantial difference between the two bed-soil conditions. Using actual properties for bed-soil caused higher absorption of seismic energy and large deformations rather than using rigid properties. If the excitation is large enough, external instability is inevitable, therefore the seismic deformations of abutment front face and strip footing increase. Finally, a solution is proposed for preventing of external instability.

1 INTRODUCTION

The reinforced soil bridge abutment is an alternative for the traditional abutment in an area that soil has low strength due to small vertical stress of this kind of abutments. Although bed-soil resistance may not be a problem in static condition it might cause external instability in seismic condition (Fakharian and Attar, 2006).

Some studies are conducted in recent years on static performance of reinforced systems under vertical loading (e.g. Bathurst et al., 2003). The first full-scale geogrid reinforced-soil bridge abutment with segmental wall was constructed and monitored in 1999 near Denver, Colorado (Abu-Hejleh et al., 2000). The monitoring results indicated adequate performance under static condition and traffic loads. A numerical model was developed by Fakharian & Mojtahedi (2002) to perform parametric studies for optimum design under static condition. Dynamic numerical models have also been developed for finding adequate seismic model (Fakharian and Attar, 2005), effect of deck load (Fakharian and Attar, 2006), and effect of reinforcement characteristics (Attar and Fakharian, 2006).

It is obvious that the exact real condition with all the details cannot be considered in numerical modeling and usually, some preliminary analysis should be made for verification purposes to determine the effect of various parameters. In seismic analysis of reinforced systems, the usual assumptions are elasto-perfectly plastic behavior for soil, no slip permission for reinforcing element, zero cohesion for the soil mass, and one of the most important of all is modeling bed-soil as a rigid bed instead of real condition. The main objective of this paper is to consider the effect of adequate modeling of such factors in the numerical analysis, in particular the effect of bed-soil characteristics.

2 DYNAMIC NUMERICAL MODELING

The Founders/Meadows bridge abutment constructed and completely instrumented in Denver is used for numerical modeling (Fig. 1). The numerical model generated by FLAC is shown in Fig. 2 with slight changes compared to the prototype, such as changing the facing height from 5.9m to 6.0m.

The initial condition for the seismic analysis is the static stability of the system, which is maintaining the initial stresses while resetting all the deformations. The grid is the same throughout static and seismic analysis, but the boundary conditions and stress-strain relations are different.

The soil model is nonlinear elastic with M-C (Mohr-Coulomb) failure criterion under static condition, but softening effects after failure are also considered in this study. In the dynamic analysis, a hysteretic nonlinear behavior applying Masing rule in unload/reload process is used.

The reinforcing elements are modeled by elasto-perfectly plastic cable elements with no compressive strength, available in FLAC. The injection layer option around cable elements was used as the interface to simulate the frictional behavior of soil-geogrid. The thickness of this layer was assumed zero and friction angle and cohesion were considered 0.75×Φ and zero, respectively. Considering the assigned perimeter around the cable element (in our case equivalent to 2m which is the unit thickness of the wall in plane strain condition and doubled for above and below the geogrid effect) and the confining stress (determined by program), the slip limit or failure criterion is established. Bathurst and Cai (1994) showed that the geogrid modulus does not vary with loading rate for practical purposes. Therefore, an elasto-perfectly plastic assumption in seismic loading has sufficient accuracy for geogrids.

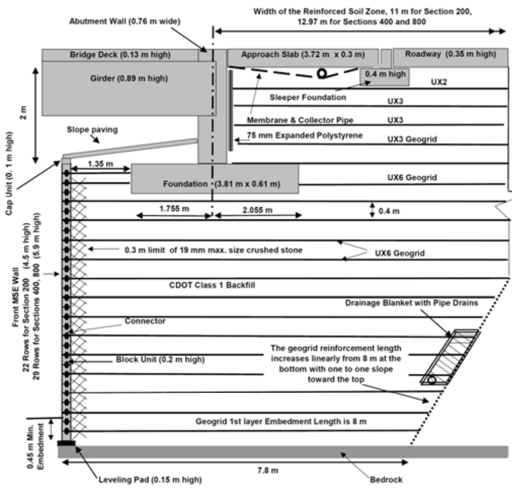


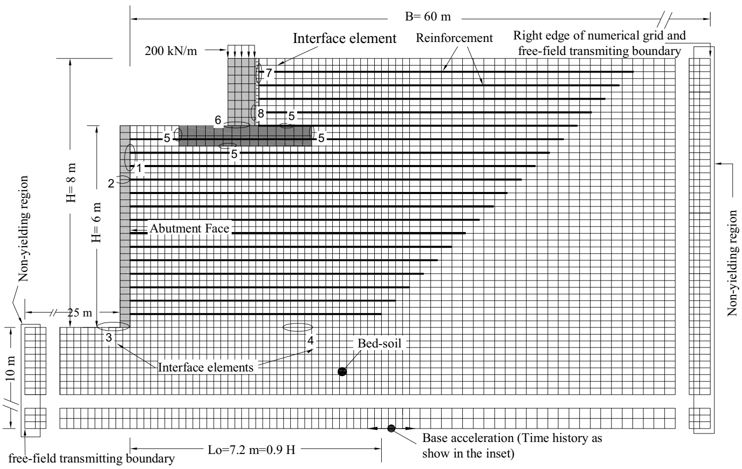
Figure 1. Veiw of the instrumented Founders/Meadow segmental bridge abutment near Denver, USA (Abu-Hejleh et al., 2000)

The interface element of FLAC was used to model the friction between difference contact surfaces of soil-soil, soil-concrete and concrete-concrete, as stated in the former sections and demonstration in Fig. 2.

A variable-amplitude harmonic motion (Fig. 2) is used for dynamic excitation, and is expressed as:

$$\ddot{u}(t) = k/2 \times \sqrt{\beta \, e^{-\alpha t} t^{\xi}} \, \sin(2\pi f \, t)$$

where: α = 5.5, β = 55, ζ = 12 are constant coefficient; f = frequency; and t = time; k = Peak amplitude of the input acceleration assumed as 0.5g, and the frequency, f = 3 Hz. t is time and varies between 0 and 6 seconds.



Interface Elements

1: Face/Soil	2: Block/Block	3: Face/ Bed-Soil	4: Reinforced Soil/Bed-Soil
5: Bridge Footing/Soil	6: Abutment Wall/Bridge Footing	7: Polystyrene/Soil	8: Abutment Wall/Polystyrene

Figure 2. Numerical grid, interface elements, and boundary conditions for the seismic analysis of segmental bridge abutment.

The case of fully instrumented Founders/Meadows segmental bridge abutment by Abu-Hejleh et al. (2001) was used for static verification of numerical modeling and the results of the 1/6 scale shaking table tests on a reinforced wall presented by Bathurst et al. (2002) were used for seismic verification of the numerical model. Analysis results have shown good agreement with instrumentation results.

More information on model verification, grid, boundary condition, loading, soil model, reinforcement model and other details can be found in Attar (2004) and Fakharian and Attar (2007).

3 ANALYSIS RESULTS

External stability of reinforced bridge a butments is usually controlled by vertical displacement and rotation of the abutment foundation and horizontal displacement of front face. These displacement components are evaluated and compared for both model types as explained below.

When a rigid bed condition is assumed, the bed-soil region has no displacement, but reinforced soil region may slip along the bed. Strength of the bed-soil at real condition is considered relatively low ($c = 20$ kN/m^2, $\Phi = 30°$).

3.1 *Horizontal displacement of abutment facing*

One of the important advantages of reinforced soil structures during seismic response is their flexibility, and therefore, more horizontal displacement, compared to less flexible conventional concrete structures. They may undergo considerable deformations without causing any failure. Therefore, it is necessary to control their serviceability. Figure 3 presents the normalized horizontal deformation of the abutment facing due to static and seismic loading for two conditions of the bed-soil. The figure shows that when the bed-soil is not strong enough, the external instability at seismic condition occurs.

3.2 *Vertical displacement of the bridge footing*

It is also necessary to control the vertical displacement and rotation of the abutment foundation. This foundation is in fact a strip footing carrying the deck load to the reinforced soil, as shown in Figs. 2 & 4. Figure 4 shows the normalized displacement profile of the abutment bottom at the end of static analysis and seismic loading for two conditions of the bed-soil. It is observed that the rotation and displacement of the bridge footing is negligible at static condition and also at seismic condition, when the bed-soil is assumed rigid.

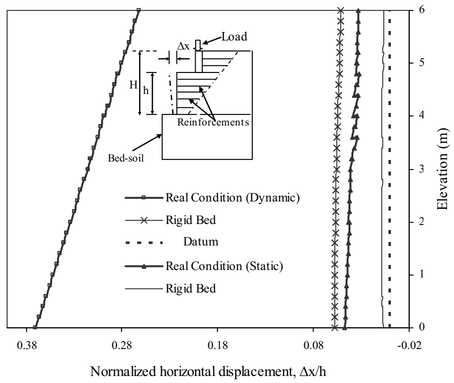


Figure 3. Profile of abutment facing at end of static analysis and seismic excitation for two the bed-soil conditions.

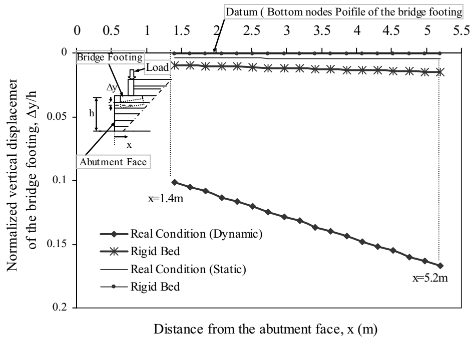


Figure 4. Profile of abutment footing at end of static analysis and Seismic excitation for two Bed-soil conditions.

4 MEASURES AGAINST EXTERNAL INSTABILITY

The results show that for seismically active zones with relatively low strength soils, external instability is inevitable.

Two alternatives are presently under study by the authors. One is the ground improvement techniques such as soil removal and replacement, soil mixing, soil compaction, etc., to increase the strength parameters and to reduce the deformation characteristics of the bed soil.

The other solution is to replace upper parts of the low strength bed-soil by reinforced-soil (which is in fact another improvement method). In other words, the reinforced-soil region of bridge abutment can be extended into the bed soil. A preliminary comparison results are presented in Figs. 5a & b. The figures a & b present the grid deformation of the system before and after reinforcement improvement, respectively. Figure 5a shows that system with no improvement is not stable against seismic excitation, whereas, the same excitation does not fail the system when the bed-soil is improved (Fig. 5b).

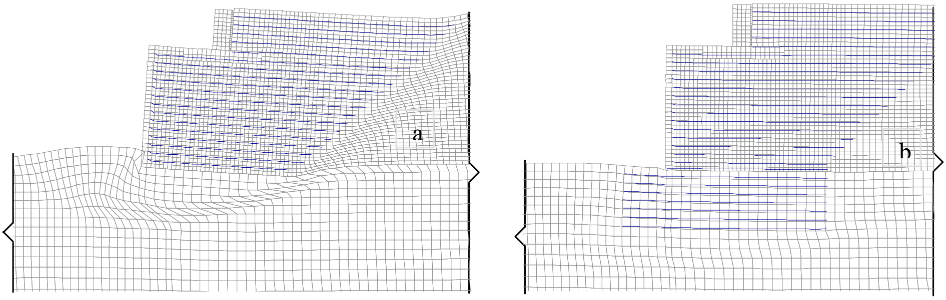


Figure 5. Seismic behavior of the reinforced soil bridge abutment: a) original Bed-Soil, b) improved Bed-Soil with reinforcement extension

5 SUMMARY AND CONCLUSIONS

Comparative analysis results for a segmental bridge abutment using the 2-D finite difference program $FLAC_{4.00}$ is presented. The numerical model has been verified by two well-instrumented reinforced systems, one of which was the Founders/Meadows segmental bridge abutment under static loads, and the second was the shaking table 1/6 scale physical model of a reinforced soil wall.

The results of comparison between two modeling types of bed-soil under static and seismic conditions were presented including a rigid bed-soil type model, and a nonlinear hysteretic hardening-softening model.

The main objective of the paper was to study the effect of bed-soil type model on external stability of the system in static and seismic conditions. When a Rigid bed condition is assumed the bed-soil region has no displacement but reinforced soil region may slip along the bed. Strength of the bed-soil at real condition is considered relatively low.

The main conclusions obtained from the results of this numerical study are as follows:

- There are no remarkable differences between two model types under static condition whereas, differences under seismic condition are considerable.

- Under seismic condition, when the bed-soil strength is relatively low, the main issue is lack of external stability, such as the general rotation of the system.

- A method was presented for preventing the external instability through extending of reinforced-soil region of bridge abutment into the bed soil which shows to be promising for improvement against the seismic excitations.

REFERENCES

Abu-Hejleh, N., Outcalt, S., Wang, T. and Zornberg, J. (2000). "Performance of Geosynthetic-Reinforced Walls Supporting the Founders/Meadows Bridge and Approaching Roadway Structures", Report 1: Design, Materials, Construction, Instrumentation, and Preliminary Results, Report No. CDOT-DTD-R-2000-5, Colorado Department of Transportation.

Abu-Hejleh, N., Outcalt, S., Wang, T., and Zornberg, J. (2001). "Performance of Geosynthetic-Reinforced Walls Supporting the Founders/Meadows Bridge and Approaching Roadway Structures", Report 2: Assessment of the performance and design of the front GRS walls and Recommendations for future GRS abutments, Report No. CDOT-DTD-R-2001-12, Colorado Department of Transportation.

Attar, I.H. (2004). "Dynamic and nonlinear analysis of geogrid reinforced soil in bridge abutment", M.Sc. Thesis, Amirkabir Univ. of Technalogy, Tehran, Iran.

Attar, I.H. and Fakharian, K. (2006). "Effect of Reinforcement Characteristics on Seismic Response of Geosynthetic-reinforced Soil Bridge Abutments", The 59th Canadian Geotechnical Conference and 7th Joint CGS/IAH-CNC Groundwater Specialty Conference, Vancouver, British Columbia.

Bathurst, R.J., and Blatz, J.A. and Burger M.H. (2003). "Performance of instrumented large-scale unreinforced and reinforced embankments loaded by strip footing to failure", Canadian Geotechnical J., Vol. 40, pp. 1067-1083.

Bathurst, R.J. and Cai, Z. (1994). "In-isolation cyclic load-extension behavior of two geogrids", Geosynthetics International, Vol. 1, No. 1, pp. 3-17.

Bathurst, R.J., El-Emam, M.M., and Mashhour, M.M. (2002). "Shaking table model study on dynamic response of reinforced retaining walls", Seventh International Conference on Geosynthetics Society, Nice, PP. 99-102

Fakharian, K. and Attar, I.H. (2005). "Effect of Soil Model Type on Seismic Response of Segmental Bridge Abutments", Soil-structure interaction: Calculation Methods and Engineering Practice, Saint Petersburg, Russia.

Fakharian, K. and Attar, I.H. (2006). "Effect of deck load on seismic stability of segmental bridge abutments, 8th International Conference on Geosynthetics, Yokohama, Japan.

Fakharian, K. and Attar, I.H. (2006). "Static and Seismic Stability of Geosynthetic Reinforced-Soil Segmental Bridge Abutment Constructed on Soft-Soil", Fourth International Conference on Soft Soil Engineering, Vancouver, British Columbia.

Fakharian, K. and Attar, I.H. (2007). "Static and seismic numerical modeling of geosynthetic-reinforced soil segmental bridge abutments", Geosynthetic International, 14(4), 228-243.

Fakharian, K. and Mojtahedi, M. (2002). "Behavior of bridge abutments reinforced with geogrid I: Parameters affecting internal stability", Proc., 3rd Iranian Int. Conf. on Geotechnical Engineering & Soil Mechanics. Tehran, Iran, Vol. II, 290-298.