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Effect of deck load on seismic stability of segmental bridge abutments

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ABSTRACT: This paper presents the results of a finite difference analysis on a special geosynthetic reinforced soil segmental retaining wall under surcharge loading referred to as a "segmental bridge abutment", both during static serviceability and also subjected to seismic loading with special emphasis on deck vertical load. FLAC2D with the FISH programming option of it is used for implementing the desired model for the numerical analysis. An elastic nonlinear model is used up to the failure (peak), after which a Mohr-Coulomb softening model is used for plastic behavior for both static and seismic conditions. The Duncan Hyperbolic model is used for the nonlinear elastic part under static condition, while the Masing nonlinear hysteretic loading-unloading rule is used for the nonlinear elastic part under seismic condition. The reinforced geogrids are modeled by elasto-perfectly plastic cable elements. The slip limit of geogrid reinforcements determine by some factors such as the confining stresses, perimeter, and friction angle around the geogrid.

After numerical modeling verification, the effect of vertical deck load in static and seismic conditions are studied on; (1) facing deformation, (2) displacement and rotation of bridge footing, and (3) the geogrid load. The results show that the deck vertical load has resulted in increase of reinforcement load during seismic loading, but the horizontal deformation of system is reduced. This is probably attributed to the confining effects of the deck vertical load. The downward vertical displacement of the bridge footing has increased linearly with increase in deck load. The reinforcement loads are rapidly increased first, but the rate is decreased with increase in deck load. The results show that the segmental bridge abutments perform well both in static and seismic conditions, if properly designed.

1 INTRODUCTION

There have been uncertainties involved in application of reinforced soil as bridge abutments mostly due to the fact that a vertical concentrated load on top edge of the abutment would increase the reinforcement loads as well as the deformations. The lack of adequate experience on quantitative effects on increase in loads and deformations together with static and seismic instabilities on one hand, and the tendencies towards applications of reinforced systems as bridge abutments in recent years have motivated researchers to start some experimental and numerical studies. 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 conditions and traffic loads. Numerical model were developed by Fakharian & Mojtahedi to perform parametric studies for optimum design under static condition (e.g. Fakharian & Mojtahedi, 2002). Dynamic numerical models have also been developed for finding adequate seismic model (Fakharian and Attar, 2005), effect of bed-soil (Attar and Fakharian, 2005) and static/seismic verification of segmental bridge abutments that is under preparation by Fakharian and Attar.

The main objective of this paper is to study the effect of vertical load on the static and seismic response of segmental bridge abutments. The reinforcement load variations, horizontal deformation of facing, and vertical displacement and rotation of the bridge footing are studied with respect to increase in vertical deck load.

2 DYNAMIC NUMERICAL MODELING

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

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 $0.75 \times \Phi$ and zero, respectively. Considering the assigned perimeter around the cable element (in our case equivalent to 2 m 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.

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:

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

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

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 Fakharian and Attar (2005).

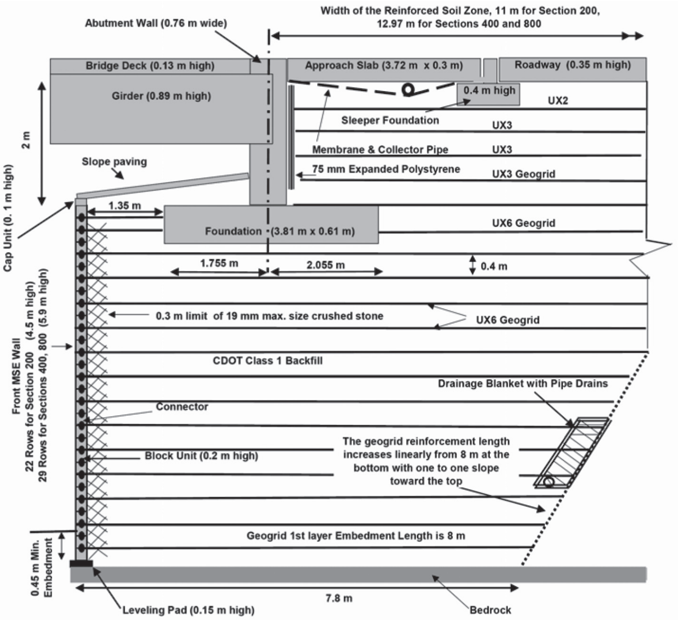

Figure 1. Veiw of the instrumented Founders/Meadow segmental bridge abutment near Denver, USA (Abu-Hejleh et al., 2000).

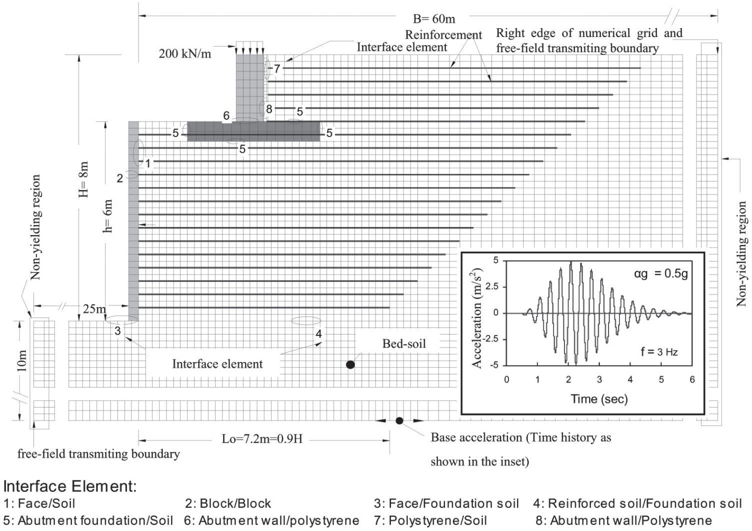

Figure 2. Numerical grid, interface elements, and boundary conditions for the seismic analysis of segmental bridge abutment.

3 ANALYSIS RESULTS

The analysis results are intended to show the effect of deck vertical concentrated load on deformation and load variations throughout the system. The horizontal deformation of the abutment facing, the vertical displacement of the bridge footing, and the reinforcement forces are selected to be discussed in the subsequent section.

3.1 *Horizontal displacement of abutment facing*

Figure 3 presents the maximum normalized horizontal displacement variations of the abutment facing with respect to vertical deck load variations under static condition, indicating increase in deformation with increase in deck load. Linear displacement-load relationship of Fig. 3 is an indication that the system response to the vertical deck load under static condition is within elastic limit. The system was then subjected to earthquake loads to evaluate the effect of vertical load under seismic conditions. Figure 4 presents the horizontal deformation of the abutment facing due to seismic loading for different vertical deck load levels. As opposed to the static condition, lower deformations are resulted with increase in deck vertical load. This is an interesting observation attributed to the fact that higher vertical load results in higher confinement for reinforcing geogrids. Due to the granular nature of the soil, the higher confinement allows for mobilizing higher forces in reinforcement and hence lower horizontal deformation.

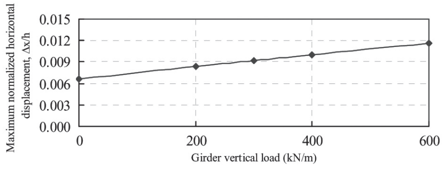

Figure 3. Effect of girder vertical load on horizontal displacement of abutment facing under static condition.

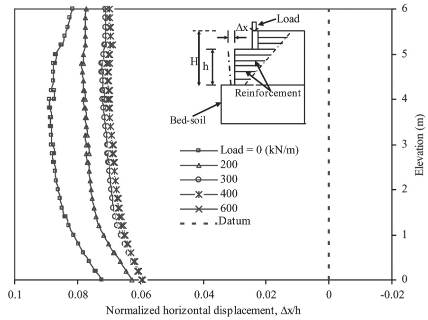

Figure 4. Profile of abutment facing at end of seismic excitation for various girder vertical loads.

3.2 *Vertical displacement of the bridge footing*

Figure 5 presents the vertical displacement of the bridge footing bottom at the end of the seismic loading analysis for various deck vertical load levels. As observed, with placing the deck vertical load, the footing tiling direction has shifted towards the abutment facing indicating tendency to overturning. The tilting is very small, however, limited to 1^0 and no change in observed in tilt with increase in the deck vertical load. The footing settlement has increased at higher deck load levels.

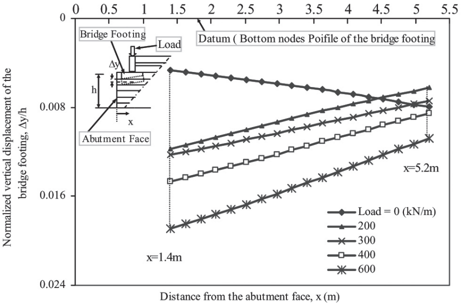

Figure 5. Profile of abutment footing at end of seismic excitation for various girder vertical loads.

3.3 *Reinforcement forces*

The variations of normalized reinforcement forces with abutment elevation below the bridge footing at the end of seismic analysis with different load levels are presented in Figure 6. Increase in the deck vertical load increases noticeably the reinforcement forces first, but the rate decreases at higher load levels. To reduce the reinforcement forces, the geogrid spacing can be reduced. Attar (2004) showed linear correlation between reductions of the reinforcement loads with decrease in geogrid spacing.

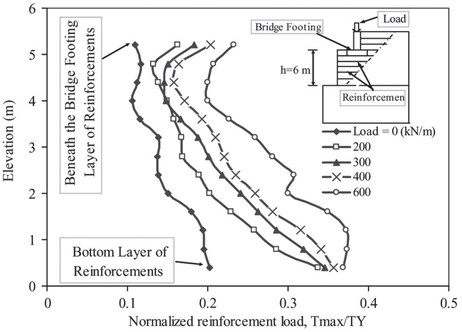

Figure 6. Influence of girder vertical loads on reinforcement loads at various elevation.

4 SUMMARY AND CONCLUSIONS

The main objective of the paper was to study the effect of deck vertical load variations on load-deformation characteristics of the system. The deck vertical load was varied between zero to 600 kN per meter length of the bridge footing. A variable-amplitude harmonic motion (shown in the inset of Fig. 2), with a frequency close to the fundamental frequency of the reference structure was applied to the bottom nodes of the model mesh. The main conclusions are pointed out below:

A linear correlation exists between the deck vertical load and horizontal displacement of abutment facing under static condition, indicating elastic response of the system.

Lower horizontal deformation occurs at the abutment facing at higher deck loads due to confinement effects under seismic loads.

Attention has to be paid on the till and settlement of bridge footing for design during cyclic loads.

Higher deck loads results in higher reinforcement loads during cyclic loading. Reinforcements may be spaced closer if excessive loads in the reinforcement disturb the design purposes.

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