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Evaluation on the Performance of Bridge Abutment Using Flyash as the Backfill Material under Seismic Loading

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Abstract. Geosynthetic reinforced soil (GRS) bridge abutments are getting popular in recent days for various transportation infrastructures. Although several static analysis of bridge abutments have been carried out till date, very limited studies have been carried out regarding their dynamic performance. This paper carries out a numerical investigation of a bridge abutment subjected to seismic loading. Simulations were executed using the finite element software, ABAQUS. After proper validation of the numerical model, fly ash was used as the backfill material to study the variation in the performance of the abutment in comparison to conventional backfill material. The results showed that the performance of the reinforced soil abutment using fly ash as the backfill material is satisfactory.

Keywords: Numerical investigation, Bridge abutment, Reinforced soil, Seismic loading, Fly ash.

1 Introduction

Geosynthetic reinforced soil (GRS) bridge abutment includes a GRS bottom wall, the bridge seat, and also the upper GRS wall. In comparison to traditional retaining walls, these structures are less costly, easy to construct and shows acceptable performance under static as well as seismic loading (Helwany et al., 2003; Lee and Wu, 2004; Adams et al., 2014).

Due to the bridge superstructures, GRS bridge abutments are subjected to higher loads in comparison to conventional retaining walls. Various studies have reported satisfactory performance of these structures under service loading (Won et al. 1996, Abu-Hejleh et al. 2000, 2001).

GRS walls have been used in several seismically active parts of the world. The post-earthquake observations have reported that these GRS walls had satisfactory performance under seismic loading because of their flexibility. Ling et al. (2001) reported that GRS retaining walls consisting of modular blocks suffered moderate to serious damage succeeding the 1999 Chi-Chi earthquake. The damage was primarily due to poor quality backfill and more vertical spacing of the reinforcements.

Various numerical studies have been performed to study the efficiency of these structures under static load. Helwany et al. (2003) developed a numerical model using the program DACSAR and validated it with the measurements of the Founders/ Meadows GRS bridge abutment. Their results showed that the footing settlements were much larger for loose sand in comparison to dense sand foundation. A finite difference analysis of the Founders/ Meadows abutment was carried out by Fakharian and Attar (2007). Their results were in favorable agreement with the field data. Though several static analysis of these GRS bridge abutments have been carried out, very few studies regarding their dynamic performance have been carried out till date.

Fly ash are the by-products from thermal power stations. The massive quantities of flyash generated each and every single year creates several problems for their safe disposal. Various studies have proclaimed satisfactory use of fly ash as a proper backfill (Di Gioia et al. 1972; Joshi et al. 1975; Dayal et al. 1999).

This paper reports the performance of a GRS bridge abutment exposed to seismic loading considering fly ash as the backfill material. Verification of the numerical model is done with the results of the finite difference model reported by Mehdi et al. (2021).Then, the facing wall displacement after the ending of seismic loading using conventional backfill material is compared to the facing displacement using fly ash as backfill. After that, the load distribution along the reinforcement is also compared.

2 Numerical Model

A two dimensional, plane strain analysis was carried out using Abaqus CAE. Figure 1 shows the geometry of the numerical model. Total height of the GRS bridge abutment is 7.65 m. It includes a lower GRS wall, a bridge seat and a top GRS wall. The lower GRS wall is of height 5 m and it consists of 25 modular blocks. The L shaped bridge seat is positioned above it with a setback distance of 0.2 m. The bridge seat is 0.4 m thick with a width of 2.25 m. According to Federal Highway Administration (FHWA) recommendation, the reinforcement length is considered to be 5.35 m, which is 0.7H, where H is total height of bridge abutment. In the lower GRS wall, the vertical spacing is considered to be 0.2 m, and in the upper wall, it is considered to be 0.4 m (Mehdi et al. 2021).

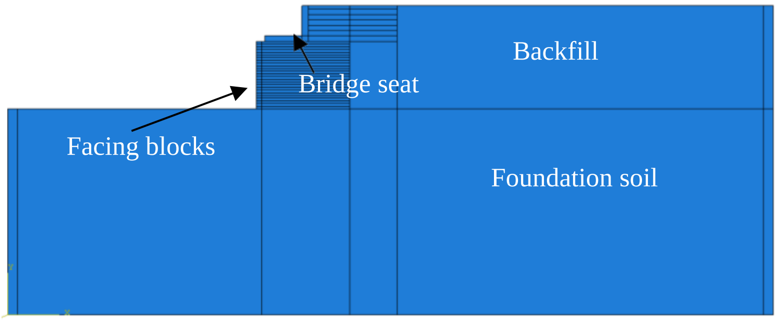

Fig. 1. Geometry of the numerical model

To simulate the construction process of the bridge abutment, layer by layer construction process is used. The foundation layer was first placed, and then the lower GRS wall was constructed in 25 different steps in addition to placement of the modular blocks, the backfill soil and the reinforcement layer. Every layer is 200 mm in height. After construction process of the lower wall, the bridge seat was placed and bridge deck load of 132 kPa was applied over it. To consider the effect of the bridge deck, the bridge seat was restrained in the lateral direction. After that, upper GRS wall of height 2.65 m was simulated through placement of 12 layers. Backfill soil of 200 mm was placed in each layer and the reinforcement layers were implanted at a vertical spacing of 400 mm. To simulate compaction of each layer, an 8 kPa uniform pressure was applied at the top of every layer. Before the placement of the next layer, it was deactivated. The numerical model was solved to attain static equilibrium at each stage. After solving the static part, the dynamic load was activated at the bottom nodes of the model. Figure 2 depicts the finite element mesh of the numerical model.

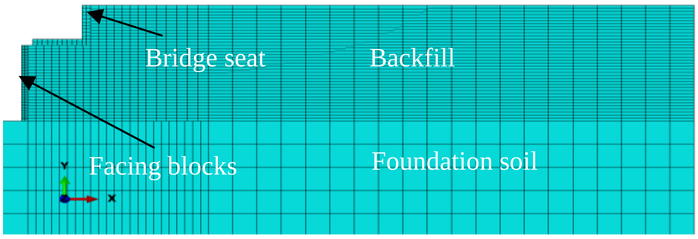

Fig. 2. Finite element mesh

2.1 Boundary Conditions

To reduce boundary effects, rear boundary is placed at 30.6 m (4H) from the facing wall. The bottom boundary is located at 15.3 m (2H) from the base of the lower GRS wall. During static analysis, the bottom boundary was fixed in both lateral as well as vertical direction. The lateral peripheries were fixed only in the horizontal direction. However, before applying the dynamic loading, the bottom boundary was modified. It was restrained only in the vertical direction. To dissipate the reflecting waves, a layer of 0.5 m thickness, with same material properties and very high damping properties ($\alpha = 220$, $\beta = 140$) was applied at the sides (Mellat et al. 2014).

2.2 Material Model and its Properties

The bridge seat and modular blocks were assigned linear elastic properties. The Young’s modulus was taken as 20 GPa and Poisson’s ratio as 0.2. Foundation soil was modelled using Mohr-Coulomb failure criteria. Its friction angle was taken as 35°, cohesion as 0 kPa, elastic modulus as 150 MPa, and Poisson’s ratio as 0.2 (Mehdi et al.

2021). Initially, to validate the numerical model, backfill soil was assigned Mohr-Coulomb failure criteria, and the properties are given in Table 1. In a similar way, fly ash was modelled using Mohr-Coulomb failure criteria, with unit weight and Poisson's ratio of 19.2 kN/m^3 and 0.3 respectively. The angle of friction was taken as 42°, elastic modulus as 40 MPa, and cohesion of 3 kPa (Bhatia et al. 2020). The reinforcements were modelled as beam elements of thickness 2 mm. To these elements ultimate tensile strength of 180 kN/m, and tensile stiffness of 1000 kN/m was applied (Zheng and Fox, 2016). To attach these reinforcements to the modular blocks, tie constraint was used. Also, these reinforcements were embedded in the backfill soil. To simulate the different interfaces such as block-block, soil-block, toe, and sill-soil interface, friction angle of 57º, 25.2º, 85º, and 25.2º respectively was used. Also, 5% damping was applied to the total model (Mehdi et al. 2021).

Table 1. Properties of the backfill soil (Mehdi et al. 2021).

Parameters	Values
Unit weight (kN/m^3)	22.1
G (MPa)	9.61
ν	0.3
ϕ (degree)	36
c (kPa)	0
Ψ (degree)	3.8

2.3 Input Base Acceleration

A harmonic base acceleration as used by Fakharian and Attar (2007) was activated at the basal nodes of the numerical model after the completion of static step. The acceleration-time plot is shown in Fig. 3.

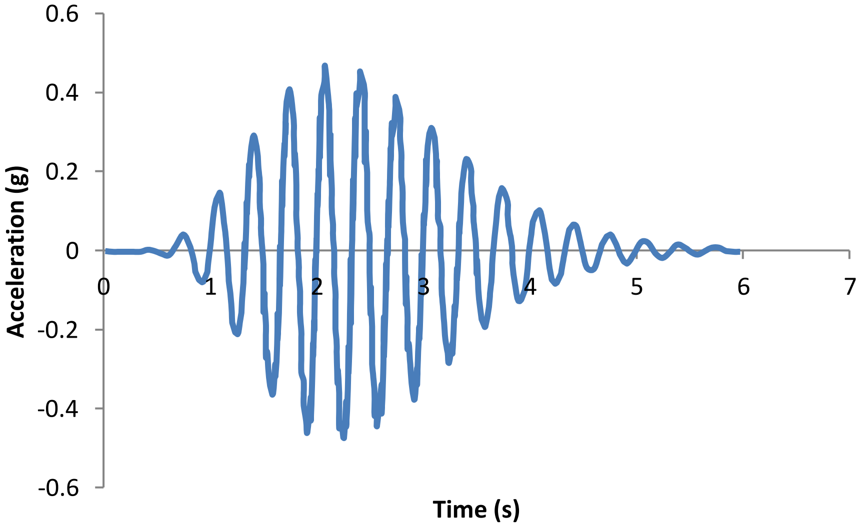

Fig. 3. Input base acceleration

3 Verification of the Numerical Model

The finite element model is verified with facing lateral displacement and load distribution in the geogrid at the completion of construction as proclaimed by Mehdi et al. (2021). It can be observed from Fig. 4 and Fig. 5 that the numerical model is in good agreement with the results reported by Mehdi et al. (2021). Here, h is the height of lower wall.

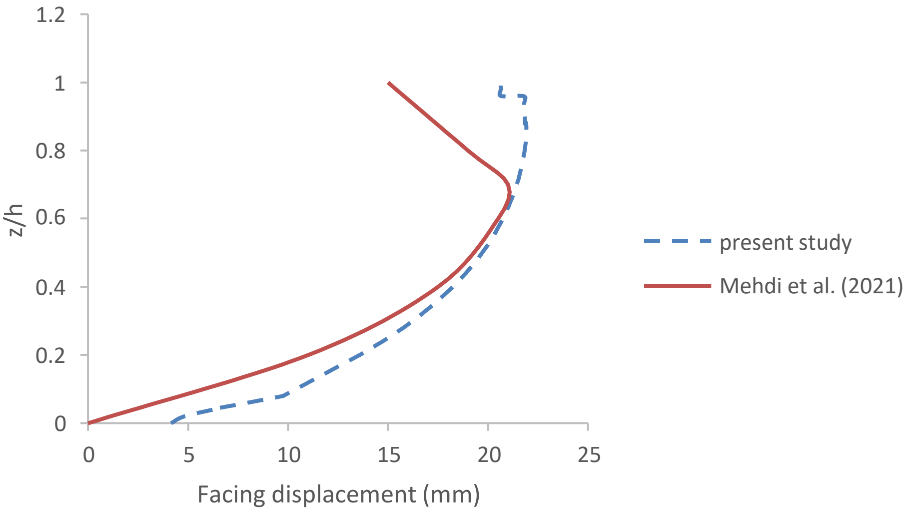

Fig. 4. Facing displacement vs normalized height

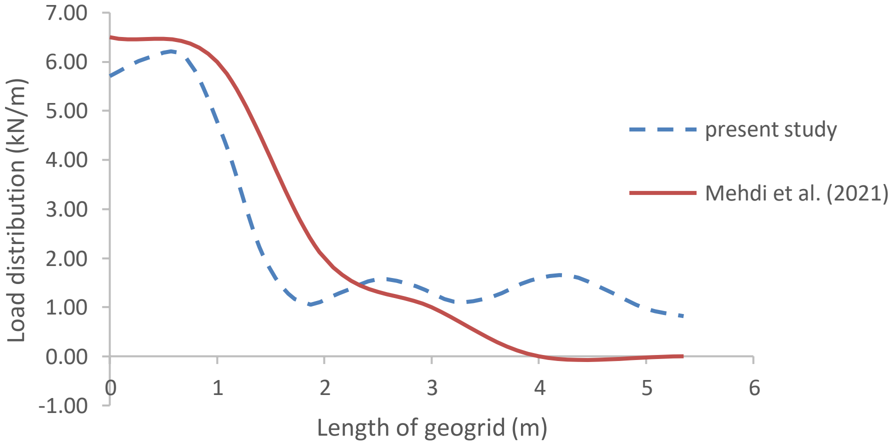

Fig. 5. Length of geogrid vs load distribution

4 Results

4.1 Horizontal Facing Displacement

Figure 6 shows horizontal facing displacement at the ending of seismic loading. Maximum horizontal displacement of 24.29 mm was noticed at 0.96h, (where h is height of the bottom wall) when the conventional backfill material was used. But this maximum value reduced to 18.30 mm at the same location, with fly ash as the backfill. Greater shear strength of fly ash in analogy to conventional granular backfill is responsible for reduction in the maximum facing displacement.

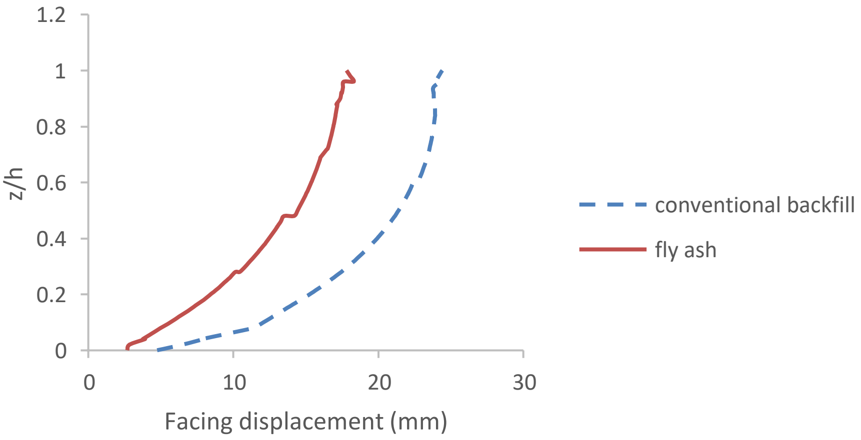

Fig. 6. Facing displacement vs normalized height

4.2 Load Distribution in Reinforcement

Figure 7 depicts the load distribution in the 5th reinforcement layer from bottom. It can be seen that maximum load of 10.17 kN/m is detected at the end of seismic loading on using conventional backfill. But this got substantially reduced to 6.10 kN/m with fly ash as backfill material. This reduction is mainly as a result lower unit weight of fly ash.

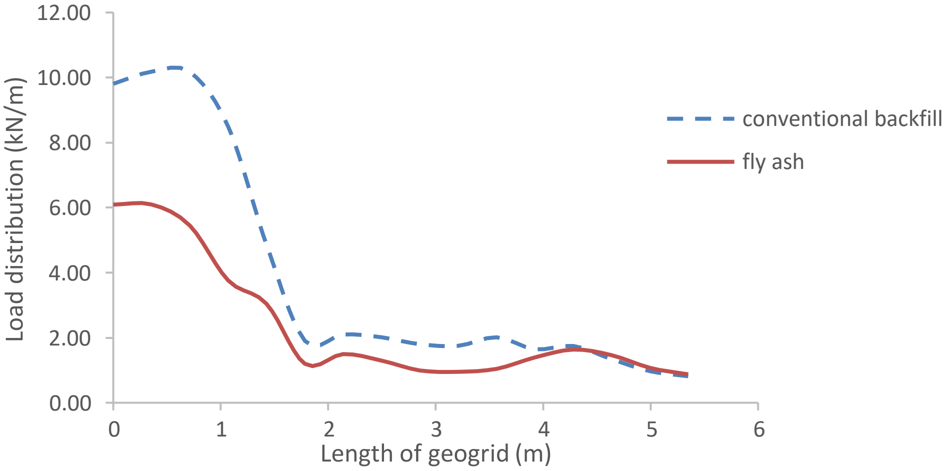

Fig. 7. Length of geogrid vs load distribution

5 Conclusions

In this paper, a numerical analysis was carried out to study the behavior of GRS bridge abutment after being subjected to seismic loading. The sequential construction of the abutment was simulated in different steps. First, the model is solved for static steps and then seismic loading was applied to the bottom nodes of the model. The results are compared with the results reported by Mehdi et al. (2021). Based on the results of this present study, the following conclusions can be made:

1. The numerical model is in good agreement with the model developed by Mehdi et al. (2021).
2. On using granular backfill material, the maximum horizontal facing displacement at the end of seismic loading is observed to be 24.29 mm, whereas with fly ash as backfill material, this value dropped to 18.30 mm. This shows that, the performance of the facing wall improved on adopting fly ash as the backfill.
3. The maximum load on the 5th reinforcement (from the bottom) along its length is observed to 10.17 kN/m on using the conventional backfill material. On using fly ash, the maximum load reduced to 6.10 kN/m along its length.

These results show that fly ash improves the performance of GRS bridge abutment under the effect of seismic loading. Thus, it can be concluded that fly ash can be utilized as an advantageous backfill material for GRS bridge abutments.

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