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Research Article

ANALYSIS OF THE EFFECT OF DYNAMIC LOAD ON DYNAMIC RESPONSE OF REINFORCED SOIL STRUCTURES

***Davood Soltani and Mahmoud Nikkhahshahmirzadi**
Department of Civil Engineering, Islamic Azad University, Semnan Branch, Semnan, Iran
**Author for Correspondence*

ABSTRACT
Accurate and realistic analysis of reinforced soil structures by taking into account the operating conditions of the embankment can lead to optimal design of reinforced soil slope. Using this method, the stress and displacement of soil and reinforcement could be optimally predicted. Given the history of earthquakes in Iran, the need to evaluate the behavior of reinforced soil structures under different seismic loads is evidently felt. Here, using coding and implementing the numerical model of finite difference of a soil slope, its behavior under different seismic loads was assessed. In order to validate the model, results of a physical model that was under seismic loading was used. 3D numerical analyses were conducted in which a reinforced embankment with common dimensions and characteristics was used. The study revealed that depending on the type of seismic loads, the response of reinforced soil structure can significantly vary. However, the response of the structure in all cases of loading was found to have similarities.

Keywords: *Reinforced Soil, Lateral Displacement, Geogrid, Dynamic Analysis, Numerical Simulation*

INTRODUCTION

Analysis of Reinforced Soil Structures under Seismic Loads

Soil as an natural aggregate environment produced by erosion and transformation of stones cannot endure and transmit tensile forces, cannot endure a shearing force more than its ultimate shearing resistance and deforms under load. Also, because of its permeable nature and existence of in the nature, it is always subject to humidity and sensitive to climate changes. Considering the increase in establishing building, roads and railways in mountainous and escarpment areas, the need to stabilize natural and artificial slopes is felt more and more. Today, analysis of stability and behaviors of buttressed walls and soil slopes, is considered as one of the important and basic topics in the science raised as a branch of geotechnical engineering.

The innovation of the reinforced soil system in the 60s and growing development thereof opened a new window to topics of soil mechanics. Advantages such as increased deformability, and improved resistance behavior of embankment, use of prefabricated elements and economic saving caused expansion and increasing use of these systems around the world.

The introduction of polymeric reinforcement known as geosynthetics in the 60s as an alternative to banded and metal reinforcement with the objective of solving issues such as corrosion and high costs, led to the acceleration of using these systems around the world. Therefore, the issue of reinforced soil structures behavior is among the new topics discussed in scientific assemblies and researched in many papers. Geogrids are groups of geosynthetics made of poly ester and poly ethylene and or a combination of these materials or similar materials which are produced as 3D networks in different thicknesses, and sizes. Geogrids are used as appropriate reinforcement as they have high tensile resistance and remarkable locking within the structure of the network. This category of geosynthetics is usually used in areas where soil is saturated and or humid. They are placed on top and below the geotextiles layer. Advantages of geogrids application in development projects are similar to those of geotextiles application.

One the major behaviors of reinforced slopes is their performance in earthquakes. Experience of earthquakes during the previous years has reflected the appropriate performance and ductile behavior of such structures. Level of overall destructions and ruptures of walls and reinforced soil slopes are limited

compared with other traditional stabilizing walls and systems. However, lack of adequate knowledge of responses reflected by this type of structures against earthquake has oriented designers toward applying more conservative assumptions in order to avoid the risk of failure. Among these assumptions, large confidence coefficients in pseudo-static design methods could be noted. These approaches yield uneconomic projects.
In general, the evolution of different methods and assumptions taken for analysis of soil slope against earthquakes is as follows.

- Assuming a rigid body
- Assuming a homogeneous elastic body
- Assuming a heterogeneous elastic body
- Assuming a heterogeneous non-elastic body

Nowadays, methods used for the analysis of soil slope stability and response to earthquakes are classified into certain branches that are listed in the following figure.

Numerical methods to analyze earth dam behavior

- 1- Stability methods
  - 1- Pseudo-static method
  - 2- New mark method
  - 3- Seed and MacDissie modified method
- 2- Dynamic assessment
  - 1- Searing beam
  - 2- Finite element analysis

Methods for Analysis of Slope Stability Against Earthquakes

Literature Review
Below some of the most important previous research are cited.
Khatibzadeh and Vafaeian (2006) investigated the effect of surface load on reinforced soil slope. They found that the tensile stiffness and the number of reinforcement beams do not have significant effects on distribution of the tensile force of enforcement in the slope height, whether in non-load condition or in different loading, and an increase in the tensile stiffness of reinforcement, the load capacity of the embankment and the confidence coefficient increase as well.
Askari, Farzaneh and Mohammadzadeh (2008) examined soil slope stability using 3D numerical analysis. It was indicated that the confidence coefficient was higher in the 3D mode than in the 2D one, and the higher length/height ratio of the slope, the lower the confidence coefficient.
Jamshidi Jam and Towfigh (2011) analyzed soil slopes under dynamic load in three-dimensionally. Based on the results, after implementing the dynamic force, the confidence coefficient increases initially and then decreases.
Mohammadi and Sedagh (2011) compared the effects of overload distance from the slope crest on reinforced slope stability in two and three dimensional conditions and concluded that with an increase in the overload distance from the slope crest, the effect of overload intensity decreases in the three-dimensional mode whereas this effect will be more for the two-dimensional mode.

Amel Sakhi and Manafi (2013) investigated static and pseudo-static stability of soil slopes reinforced with geofabric. The results indicated that with increased reinforcement in static or pseudo-static mode, the confidence coefficient of the slope stability increases. It was also found that the Janbo method yield the lowest while the Bishop method yields the highest confidence coefficient.
Azan (2013) compared 3D and 2D numerical methods of soil slope stability. It was indicated that the stress concentration in the 3D model is lower than that in the 2D model and the confidence coefficient is lower in the 2Dmode than the 3D one; therefore the results of the 2D model is more reliable.
Vieira *et al.*, (2011) analyzed reinforced slopes under seismic loading by numerical modeling. The numerical modeling for horizontal internal displacement seems appropriate, such that in far earthquakes, horizontal displacements of the reinforced embankment heel strongly follows the displacement of the foundation.
Chatterjee and Choudhury (2012) examined soil slope stability under seismic loads according to dynamic numerical analysis. Result revealed that the greatest displacement occurs in the upper part of the slope.
Hiraoka *et al.*, (2013) studied slope failure modes under seismic loads. An experimental model was performed and results were validated against numerical modeling.

Numerical Modeling

Here having designed a set of simulations, the behavior of a geogrid reinforced slope under seismic loads was studied. The analysis was performed on a 3D dynamic basis and loading was implemented as exerting the overload on the embankment and basic acceleration. These simulations helped the effect of seismic load on reinforced soil structure response to be studied.

A. General Information Simulations

Mohr-Coulomb model soil was included and soil attenuation was applied in the analysis. In general, four different soil types were included in the analysis. The specifications are given in the table below. The behavior of reinforcement was assumed elastic. It was also assumed that the reinforcement has sufficient resistance. It is also assumed that there exist full interlock between the reinforcement and soil. In the simulations, the tilt angle to the horizon was 50 degrees. Reinforced soil slope height was assumed 5 meters and the distance of geogrid layers was assumed 60 cm. Overhead placed on the upper part of the slope was 5 kPa and hardness/stiffness was 6e5 n/m per a unit of geogrid width.

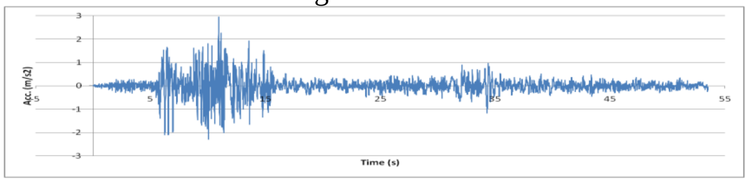
Table-???

Specifications of the Three Types of Soil	
Specific weight (ton /$m^{3)}$	1.78
Poisson's ratio	0.45
Bulk modulus (MPa)	213.0
Shear modulus (MPa)	22.0
Yankees modulus (MPa)	64.0
Friction angle (deg)	30
Adhesion (kPa)	5.0

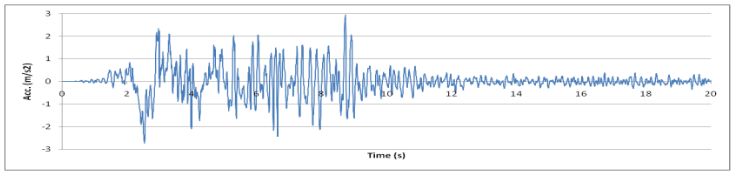
B. Dynamic Load Profile

In order to evaluate the behavior of geogrid reinforced soil slope four different accelerogramspertinent to historical earthquakes in Iran were used. To allow comparison of soil slope responses a variety of accelerograms exist. As shown below, all of the accelerograms were scaled such that the maximum acceleration (PGA) was 0.3g. Simulations performed by applying the four Accelerograms were called H1 to H4 respectively.

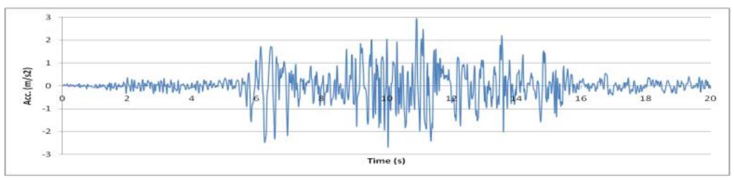
Figure no.-???



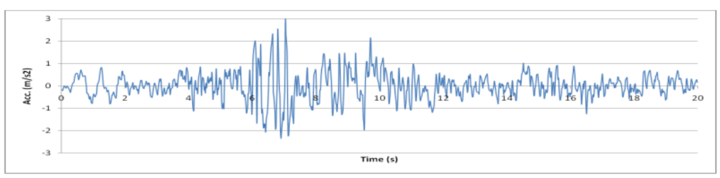
Manjil Earthquake Accelerogram



Bam Earthquake Accelerogram



Rudbar Earthquake Accelerogram



Tabas Earthquake Accelerogram

Figure …: Dynamic Load Profile

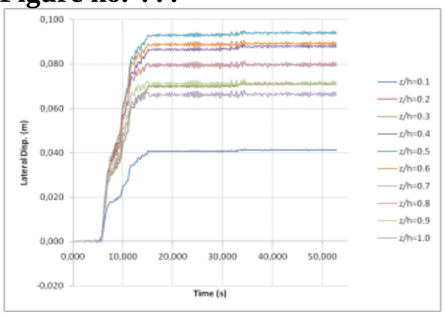
RESULTS AND DISCUSSION

Numerical Results

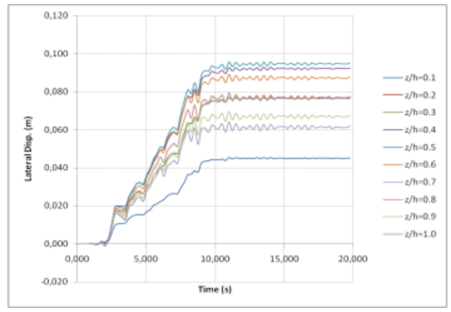
In this section in order to assess the impact of dynamic load (Accelerogram) imposed on the behavior of geo-grid reinforced soil slope, results of simulations H1 to H4 was studied. In these simulations earthquake accelerograms of Manjil, Bam, Roudbar and Tabs were applied as dynamic loads. As mentioned in the previous sections, these accelerograms were modified and scaled for maximum acceleration of 0.35g.

In the following graphs the time history of embankment horizontal displacement at different levels corresponding to simulations H1 to H4 are shown. In order to allow a better comparison, levels (the height of the draft point of displacement divided by the total height of the embankment) is expressed relatively. As the comparison of these figures clarifies, the change in the accelerogram applied is associated with the horizontal displacement of the reinforced embankment under seismic loads. This is due to the difference in the frequency content of the accelerogram applied as well as the different seismic responses of the soil slope to these Accelerograms. The graphs also show that with dynamic load change, the pattern of horizontal displacement will be experiencing major changes. According to the time history of horizontal replacement change it could be argued that by changing the dynamic load applied, the start as well as the end time of the horizontal displacement change as well.

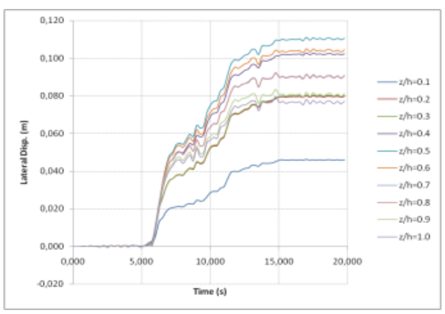
Figure no.-???



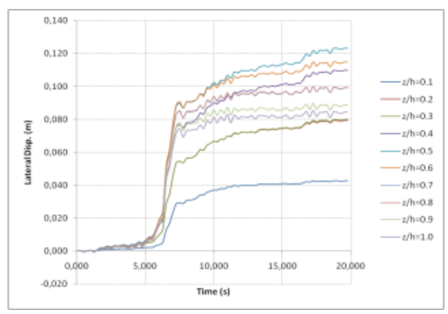
Figure…: Embankment Horizontal Displacement Time History at Different Levels (Simulation H1)



Figure…: Embankment Horizontal Displacement Time History at Different Levels (Simulation H2)



Figure…: Embankment Horizontal Displacement Time History at Different Levels (Simulation H3)



Figure…: Embankment Horizontal Displacement Time History at Different Levels (Simulation H4)

The level of subsidence (vertical displacement) occurred in the center of the top of the reinforced soil slope, corresponding to simulations G1 to G4 are shown in the following graph. The subsidence is related to the steady-state of the embankment after dynamic load. As the graph clearly shows, a change in the accelerogram applied to the soil slope, remaining vertical displacement after dynamic load show significant changes.

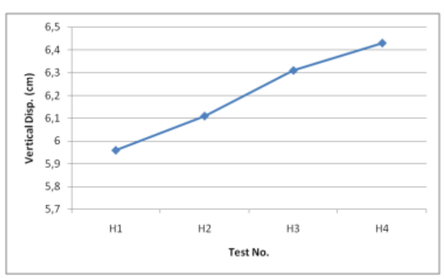


Figure …: Vertical Displacement in the Center of Soil Slope (Simulation H1 to H4)

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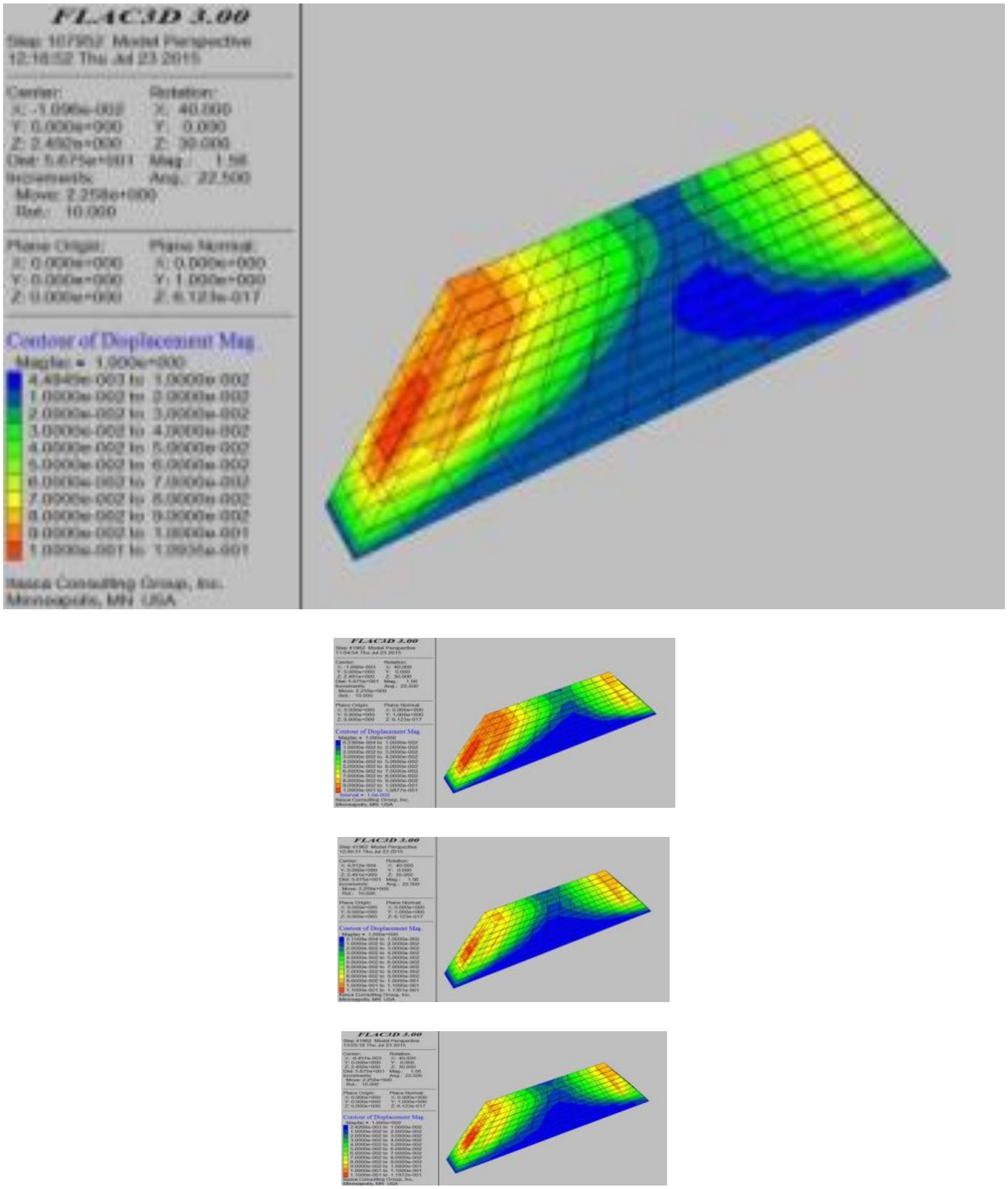
In order to evaluate the failure wedge in simulations H1 to H4 displacement contours under seismic load to the soil slope are shown. As can be seen, a change in the type of accelerogram applied to the embankment, failure wedges also change relatively due to various frequency content of different accelerograms.

Figure no.-???



Figure…: Displacement Contours in Simulations H1 to H4

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