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Evaluation of Geosynthetic Forces in GRSRW under Dynamic Condition

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***Abstract*—**Geosynthetics have proved to be suitable for reinforced soil retaining walls. Based on the increasing uses of geosynthetic reinforced soil systems in the regions, which bear frequent earthquakes, the study of dynamic behavior of structures seems necessary. Determining the reinforcement forces is; therefore, one of the most important and main points of discussions in designing retaining walls, by which we prevent from conservative planning. Thus, this paper intended to investigate the effects of such parameters as wall height, acceleration type, vertical spacing of reinforcement, type of reinforcement and soil type on forces and deformation through numerical modeling of the geosynthetic reinforced soil retaining walls (GRSRW) under dynamic loading with finite difference method by using FLAC. The findings indicate rather positive results with each parameter.

***Keywords*—**Geosynthetic Reinforced Soil Retaining Walls (GRSRW), dynamic analysis, Geosynthetic forces, Flac

I. INTRODUCTION

ASTM, defines *geosynthetic* as a planar product made of a polymeric material which is used with soil, rock, earth, or other geotechnical-related materials in civil engineering projects or systems. The three primary applications that soil reinforcement uses geosynthetics are (1) reinforcing the base of embankments constructed on very soft foundations, (2) increasing the stability and steepness of slopes, and (3) reducing the earth pressures behind retaining walls and abutments. In the first two applications, geosynthetics permit construction that otherwise would be cost prohibitive or technically not feasible. In the case of retaining walls, significant cost savings are possible in comparison with conventional retaining wall construction. Furthermore, these systems are more flexible than conventional earth retaining walls such as reinforced concrete cantilever or gravity walls. Therefore, they are very suitable for sites with poor foundations and for seismically active areas. H. Vidal developed modern reinforced soil technology in France in the mid 1960s. The use of geotextiles as reinforcing elements started in the early 1970's because of concern over possible corrosion of metallic reinforcement. There are some studies which have investigated the effects of reinforcement design parameters like length, stiffness and number of layers (i.e. vertical spacing between layers) on reinforced soil retaining walls under static gravity loading using numerical simulation approaches [1]–[5]. However, few studies have addressed reinforced soil walls response to the earthquake loading.

Yet, such analytical methods do not fully account for the influence of reinforcement stiffness on wall response. In addition, reinforcement layer vertical spacing is considered as an important design for reinforced soil walls under both static and earthquake loading conditions. Some researchers have proposed a new working stress method that explicitly considers the stiffness of the reinforcement layers and their distribution in the calculation of static design loads [6], [7]. Numerical modeling is a valuable tool to increase the understanding of behavior of different structures. In this paper, the influence of most important parameters such as wall height, maximum acceleration, vertical spacing of reinforcements, types of reinforcements and soils response to the reinforced soil retaining walls have been examined by the use finite difference method.

II. DESCRIPTION OF THE NUMERICAL MODELLING

A. Verification and Calibration

In numerical modeling, it is initially important to assure the validity and reliability of the model results. To do so, El-Emams and Bathurst experiments [8], were benefited. In these experiments, they examined the effect of vertical spacing of Geogrid in relation to the wall height and the Geogrid stiffness to the simulation response of earthquake in GRSRW by using shaking table experiment. The schematic view of the wall in their study is presented in fig.1.

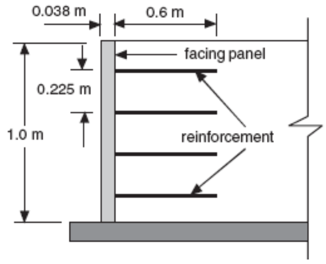

Fig. 1 The schematic view of GRSRW in shaking table experiment

Using the parameters of this experiment, the finite difference method was verificated in dynamic analysis. In fig.2, the numerical results were compared to their experimental results. In the figure 2, changes in induced forces of reinforcements against wave acceleration range for the two walls were examined from these experiments show the great correspondence.

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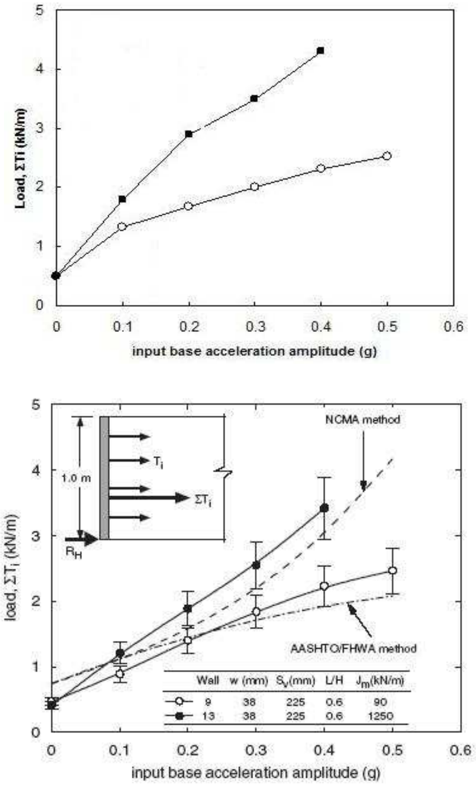

(a)

(b)

Fig 2 The comparison of changes in induced forces in reinforcements against wave acceleration range a. shaking table experiment b. FLAC Model

B. Boundary and Fixity Situations

For the down boundary of the models, rigid fixity in both X and Y directions are considered. At first, in the left boundary of models, rigid fixity in X directions is considered to estimate the initial stress in the static analysis. Then, in dynamic analysis, free field boundaries are replaced to absorb earthquake waves.

C. Seismic Loading

Acceleration that used in this dynamic analysis belongs to Tabas, ELcentro and Lomaprieta Earthquakes. It was an attempt tried to use Accelerations that were registered on stone base so that it may be consistent with rigid foundation in the models (Figure 3).

D. Model Properties

All analyses have been done with FLAC 2D, since, grained soil is used to construct reinforced walls, two kinds of grained soil was used as the material of walls. It must be noticed that an increase in the soil type will increase our simulations volume. For this reason, we just focused on the two types of grained soil. For modeling the soil elements, Mohr-Coulomb model was selected. Also, cable elements were used for modeling the geosynthetics. For facing, the beam elements were chosen. To use more accurate tests, interface elements were used. It was supposed that using such elements would increase the calculation time. Model dimensions were selected in a manner that prevented any effect of boundaries. As far as the foundation is rigid in all models, it is assumed that the wall is constructed on a rigid and strong base to eliminate the role of foundation type in the analysis. Heights of the wall in this analysis are 5 and 10m and the length of the reinforcements is 2/3 times more than the wall height. This length was introduced by some researchers like Sakaguchi et al. [9], and Sakaguchi [10], as an effective boundary of the reinforcement. The range of geosynthetic stiffness is usually between 1000 to 10000 KN/m that are common for extensible polymeric geotextile and very stiff Geogrid (Tenax co., 2008). These values are considered as the lower and upper bound in these analyses.

Besides, the verification and calibration have been done for the models, which the schematic view have been presented of them in Fig. 4, and the complete reinforcement properties such as facing, backfill soil and foundation used in the analysis have been shown in Table1. All 48 models which were analyzed with different types of geosynthetics, soil type, vertical spacing of reinforcement, wall height and earthquake type have also been shown in table2.

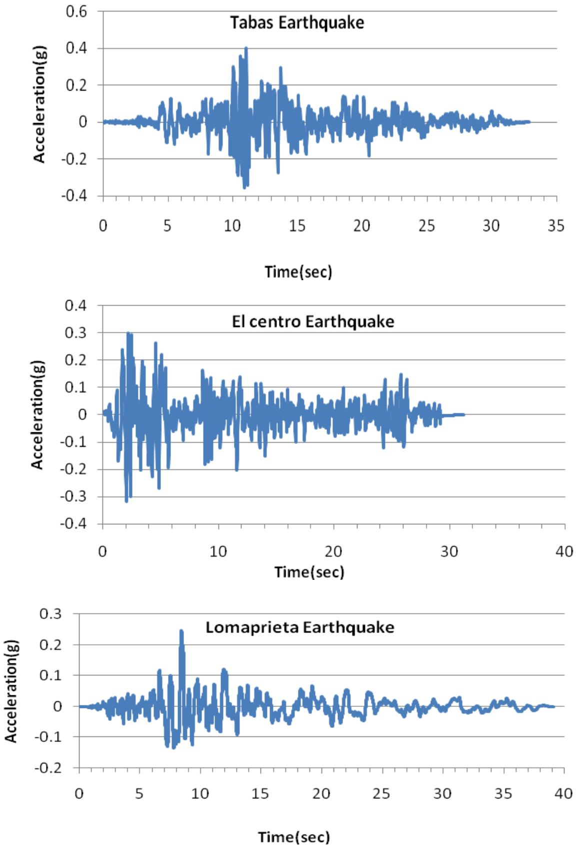

Fig. 3 Time-acceleration diagram for Tabas El centro and Lomaprieta earthquake

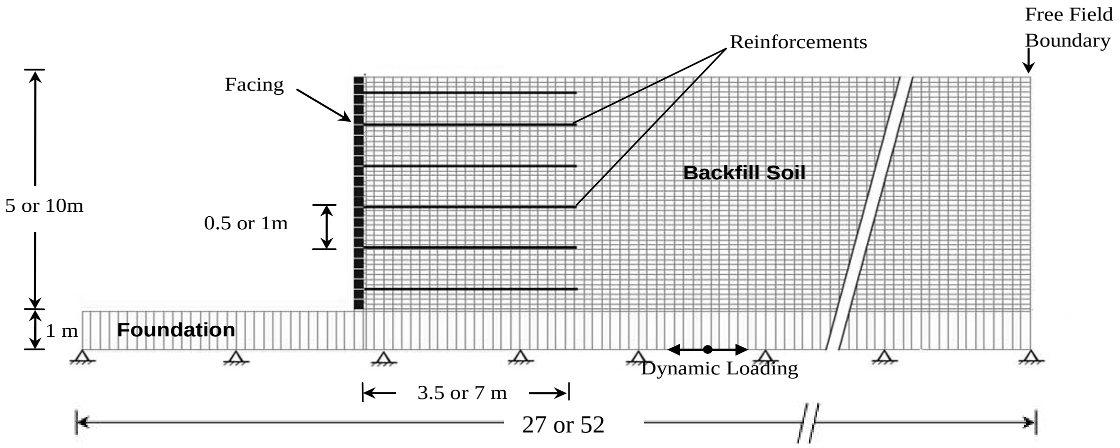

Fig. 4 Schematic view of the models

TABLE I
MATERIAL PROPERTIES USED IN THE FINITE DIFFERENCE SIMULATIONS

Reinforcement	
Model	Elastic Perfectly Plastic
K or J (Stiffness=EA)	No.1: 1000 (KN/m) → Extensible Polymeric Geotextile No.2: 10000 (KN/m) → Very Stiff Geogrid
T_y (Yield Stress)	200 (KN/m)
Sectional Area	0.002 (m^2/m)
Interface Parameters	K_b=2×10^3 (MN/m/m) S_b=1×10^3 (KN/m)
Backfill Soil No.1	
Model	Elastic Perfectly Plastic Mohr-Coulomb
γ (Unit Weight)	18 (KN/m^3)
ϕ (Soil Friction Angle)	34°
ψ (Dilation Angle)	4°
E (Elastic Modulus)	35 (Mpa)
ν (Poisson's Ratio)	0.3
Backfill Soil No. 2	
Model	Elastic Perfectly Plastic Mohr-Coulomb
γ (Unit Weight)	17 (KN/m^3)
ϕ (Soil Friction Angle)	30°
ψ (Dilation Angle)	0°
E (Elastic Modulus)	32 (Mpa)
ν (Poisson's Ratio)	0.3
Foundation	
Model	Linear Elastic
γ (Unit Weight)	20 (KN/m^3)
E (Elastic Modulus)	25 (Gpa)
ν (Poisson's Ratio)	0.2
Facing	
Model	Linear Elastic
γ (Unit Weight)	24 (KN/m3)
E (Elastic Modulus)	25 (Gpa)
Thickness	0.2 (m)

TABLE II
MODEL PROPERTIES

ID	Geosynthetic No.	Soil No.	Geosynthetic Spacing	Wall Height	Earthquake
H5-d0.5-S1-G1-T	1	1	0.5 m	5 m	Tabas
H5-d0.5-S1-G2-T	2				
H5-d0.5-S2-G1-T	1	2			
H5-d0.5-S2-G2-T	2				
H5-d1-S1-G1-T	1	1	1 m		
H5-d1-S1-G2-T	2				
H5-d1-S2-G1-T	1	2			
H5-d1-S2-G2-T	2				
H10-d0.5-S1-G1-T	1	1	0.5 m	10 m	
H10-d0.5-S1-G2-T	2				
H10-d0.5-S2-G1-T	1	2			
H10-d0.5-S2-G2-T	2				
H10-d1-S1-G1-T	1	1	1 m		
H10-d1-S1-G2-T	2				
H10-d1-S2-G1-T	1	2			
H10-d1-S2-G2-T	2				
H5-d0.5-S1-G1-E	1	1	0.5 m	5 m	Elcentro
H5-d0.5-S1-G2-E	2				
H5-d0.5-S2-G1-E	1	2			
H5-d0.5-S2-G2-E	2				
H5-d1-S1-G1-E	1	1	1 m		
H5-d1-S1-G2-E	2				
H5-d1-S2-G1-E	1	2			
H5-d1-S2-G2-E	2				
H10-d0.5-S1-G1-E	1	1	0.5 m	10 m	
H10-d0.5-S1-G2-E	2				
H10-d0.5-S2-G1-E	1	2			
H10-d0.5-S2-G2-E	2				
H10-d1-S1-G1-E	1	1	1 m		
H10-d1-S1-G2-E	2				
H10-d1-S2-G1-E	1	2			
H10-d1-S2-G2-E	2				
H5-d0.5-S1-G1-L	1	1	0.5 m	5 m	Lomaprieta
H5-d0.5-S1-G2-L	2				
H5-d0.5-S2-G1-L	1	2			
H5-d0.5-S2-G2-L	2				
H5-d1-S1-G1-L	1	1	1 m		
H5-d1-S1-G2-L	2				
H5-d1-S2-G1-L	1	2			
H5-d1-S2-G2-L	2				
H10-d0.5-S1-G1-L	1	1	0.5 m	10 m	
H10-d0.5-S1-G2-L	2				
H10-d0.5-S2-G1-L	1	2			
H10-d0.5-S2-G2-L	2				
H10-d1-S1-G1-L	1	1	1 m		
H10-d1-S1-G2-L	2				
H10-d1-S2-G1-L	1	2			
H10-d1-S2-G2-L	2				

III. RESULTS

A. Result of the dynamic analysis

Static and Dynamic analyses of all walls have been done which each took about 36 hours. The results of dynamic analysis to determine the reinforcement forces are shown in figure 5,6,7 and 8.

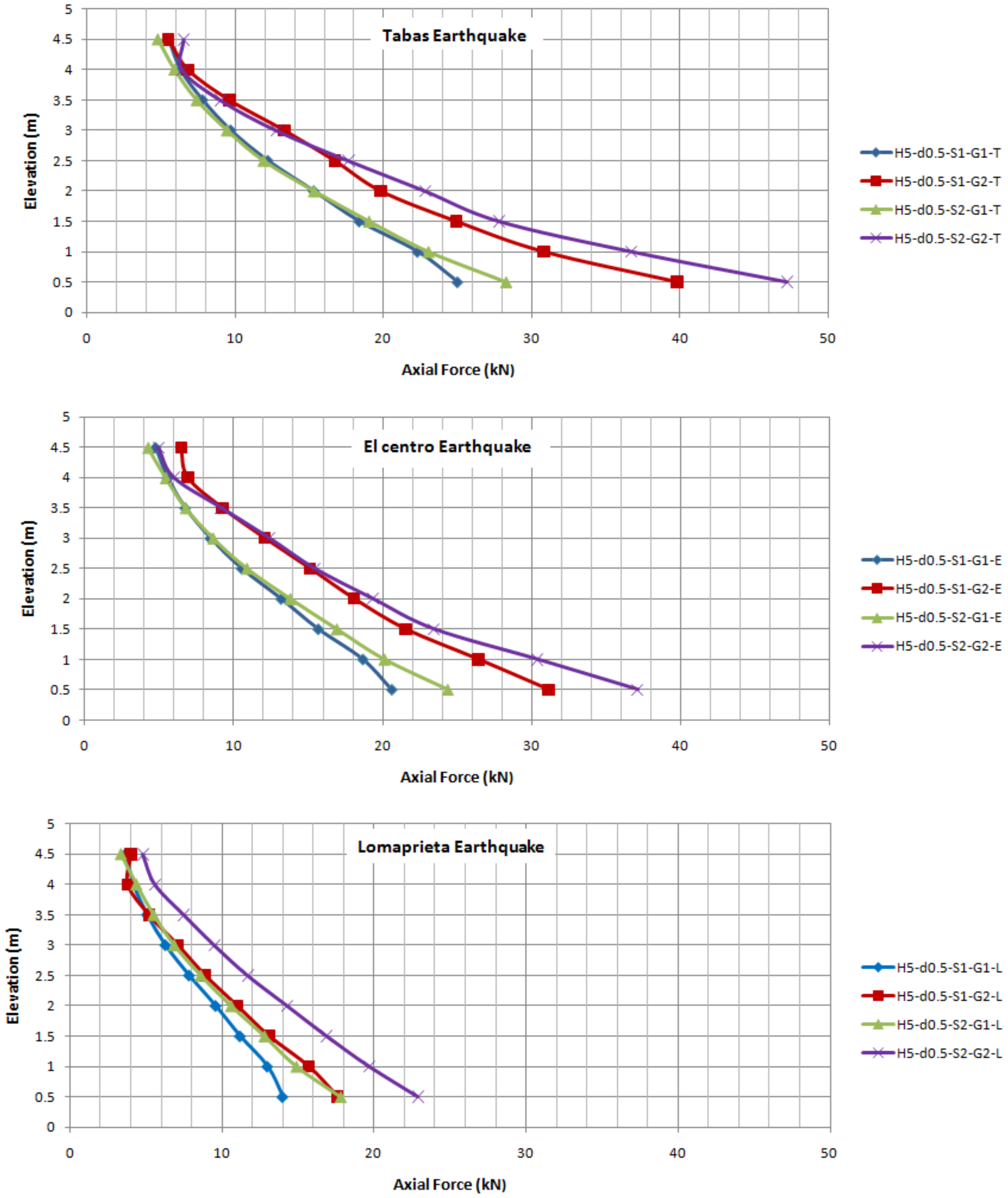

Fig. 5 The variation of geosynthetic forces based on the wall height for 5m wall with d = 0.5m

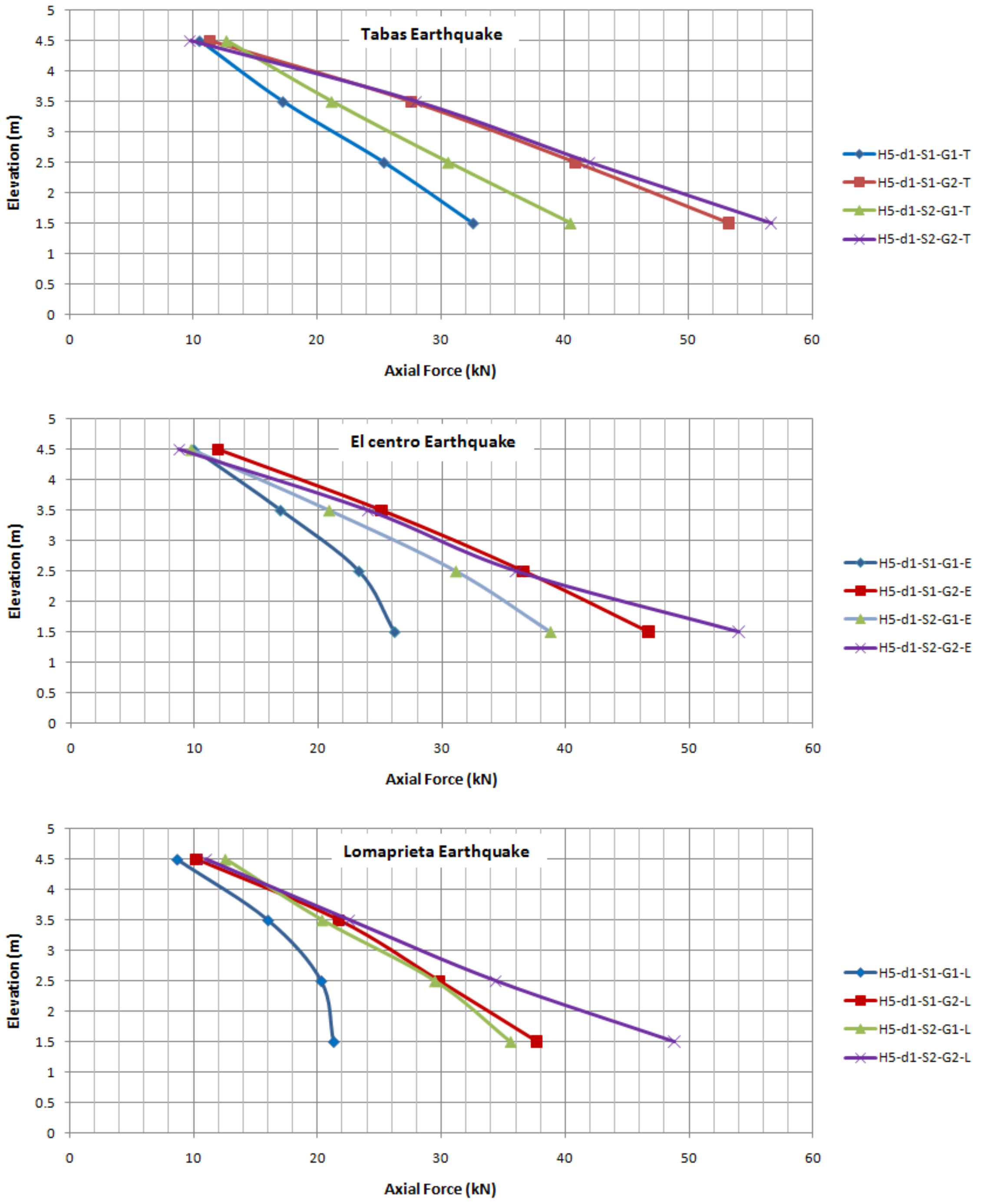

Fig. 6 The variation of geosynthetic forces based on wall height for 5m wall with d = 1m

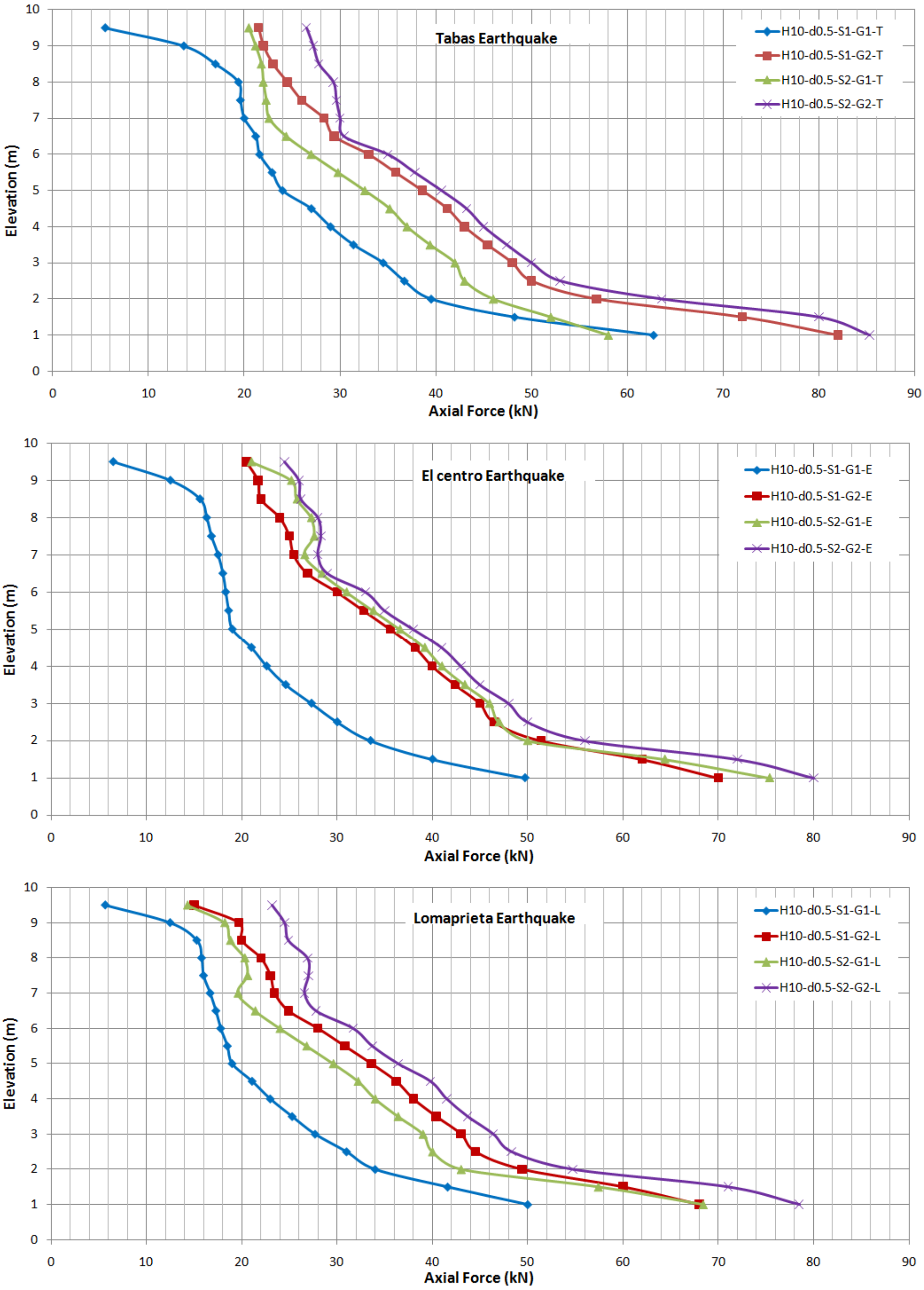

Fig. 7 The variation of geosynthetic forces based on wall height for 10m wall with d = 0.5m

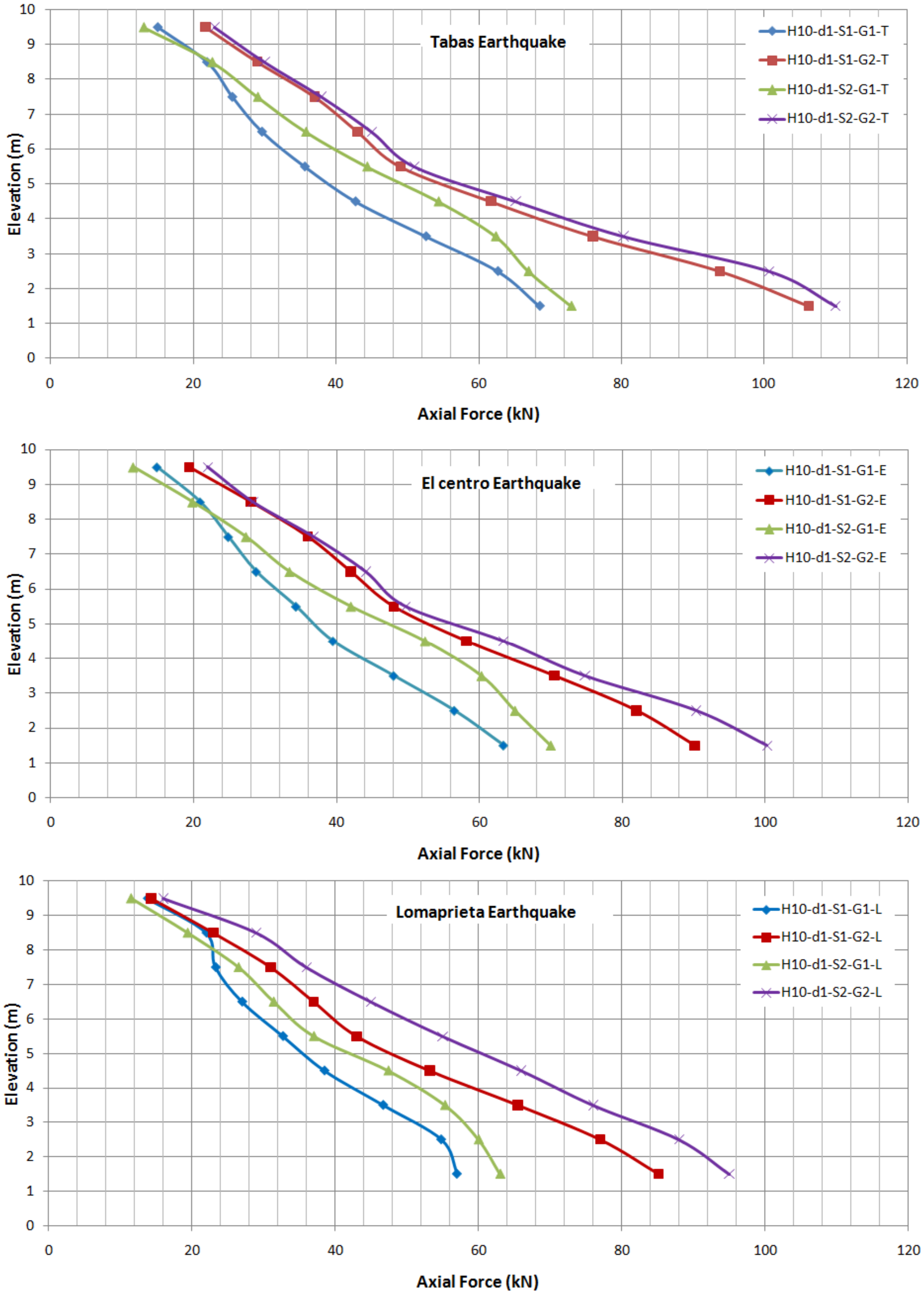

Fig. 8 The variation of geosynthetic forces according to wall height for 10m wall with d = 1m

The Results gained from these illustrations are as follow:

- The reinforcement loads have increased from the top of the wall to the base. At the region where it is 1/3 of the wall base, the reinforcement forces were bigger than the top. This region, hence, needs more accuracy in design.

- The comparison between forces induced in geosynthetics with 0.5 and 1m vertical spacing in the walls with other similar properties (Compare figures 5 and 6 with figures 7 and 8) shows that the forces in geosynthetics with 1m vertical spacing were more than geosynthetics with 0.5m vertical spacing. It can be said that the former, the maximum forces in geosynthetics often are 20-50% more than the latter. That is to say, by duplicating the reinforcement vertical spacing, the maximum induced forces in geosynthetics were not increasing with the same rate.

- By increasing the angle of internal friction, module of elasticity and unit weight of the soil decreased the induced reinforcement forces. In other words, in sand soils, the more the angle of internal friction and the more the unit weight of the soil, the more suitable it will be for use. This decreasing rate is different for the other parameters.

- Using type 2 of geosynthetics with the stiffness which 10 times more than type 1 increased the amount of forces in geosynthetics. This leads to using the Extensible Polymeric Geotextile instead of Very Stiff Geogrid. By taking a look at the figures (5,6,7 and 8), it can be realized that the effect of type of the geosynthetic was more effective than soil type; whereas, the backfill soils for retaining walls were chosen from the suitable soil (sandy soil), This kind of change in sand parameters had little effect on the result. (To study the effect of soil type or geosynthetic stiffness on geosynthetic forces for 5 m walls with 0.5 m geosynthetic vertical spacing, see figures 9 & 10).

- For models with the same wall height and geosynthetic vertical spacing, the start point of all graphs at top of the wall were almost the same, but in the bottom the graphs had the maximum difference. It implies that the difference between reinforcement forces in different conditions of geosynthetic stiffness or soil type will increase with depth.

- By comparing the reinforcement forces under different earthquake acceleration, It can be concluded that the maximum base input acceleration is counted as effective and important parameter. Results show that the walls that Tabas earthquake had applied to them had the biggest induced forces in their reinforcements.

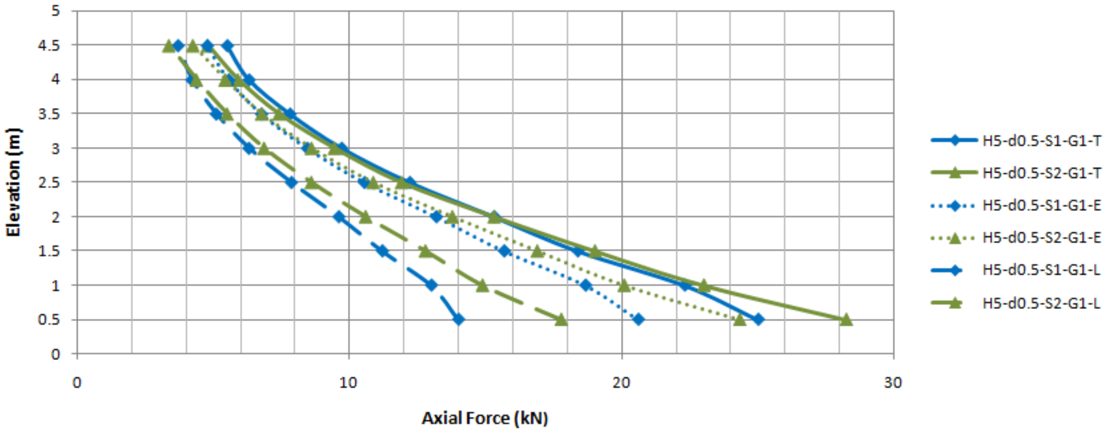

Fig. 9 The effect of soil type on geosynthetic forces for 5m wall with d = 0.5m

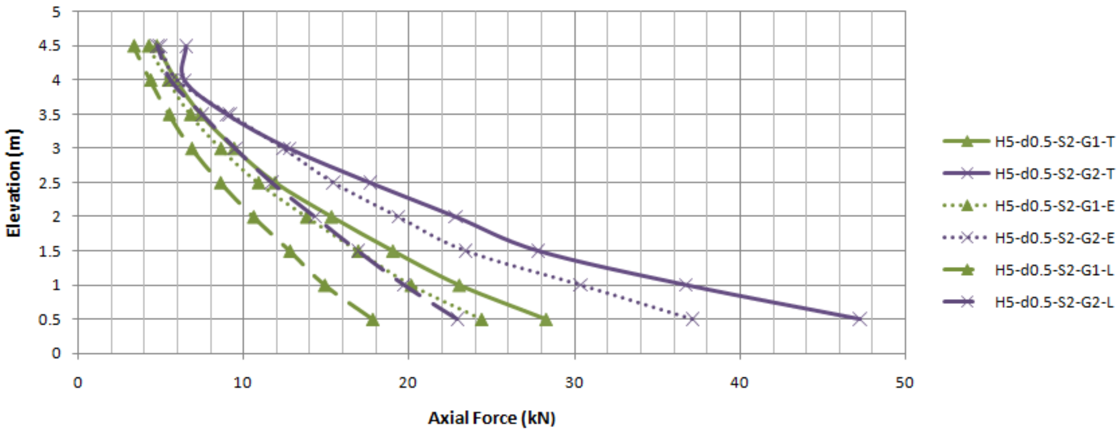

Fig. 10 The effect of geosynthetic stiffness on geosynthetic forces for 5m wall with d = 0.5m

B. The Comparison between static and dynamic analyses

Figures 11 and 12 show the comparison between the results gained from the static and dynamic analyses. They show the result of 5 m walls with 0.5 m geosynthetic vertical spacing and the result of 10 m walls with 1 m geosynthetic vertical spacing, respectively. As the result shows, the dynamic loading induced more forces in reinforcement in comparison with the static loading. At the top of the wall, the dynamic and static forces were almost near, but as the depth increased, the difference became slightly more. The earthquakes with bigger maximum base input acceleration had more effect on difference between the static and dynamic forces. For example, in Tabas earthquake, the force coefficient at the bottom of the wall increased from static to dynamic which was around 1.2 to 3.8, and, in ELcentro Earthquake, it was around 1.6 to 3 and, in Lomaprieta Earthquake, it was 1.2 to 1.8. In addition, this coefficient for 10 m walls with 1 m geosynthetic vertical spacing in Tabas earthquake was about 1.8 to 2.5, while in ELcentro Earthquake and Lomaprieta earthquake; it was between 1.6 to 2.4, and 1.5 to 2.2, respectively.

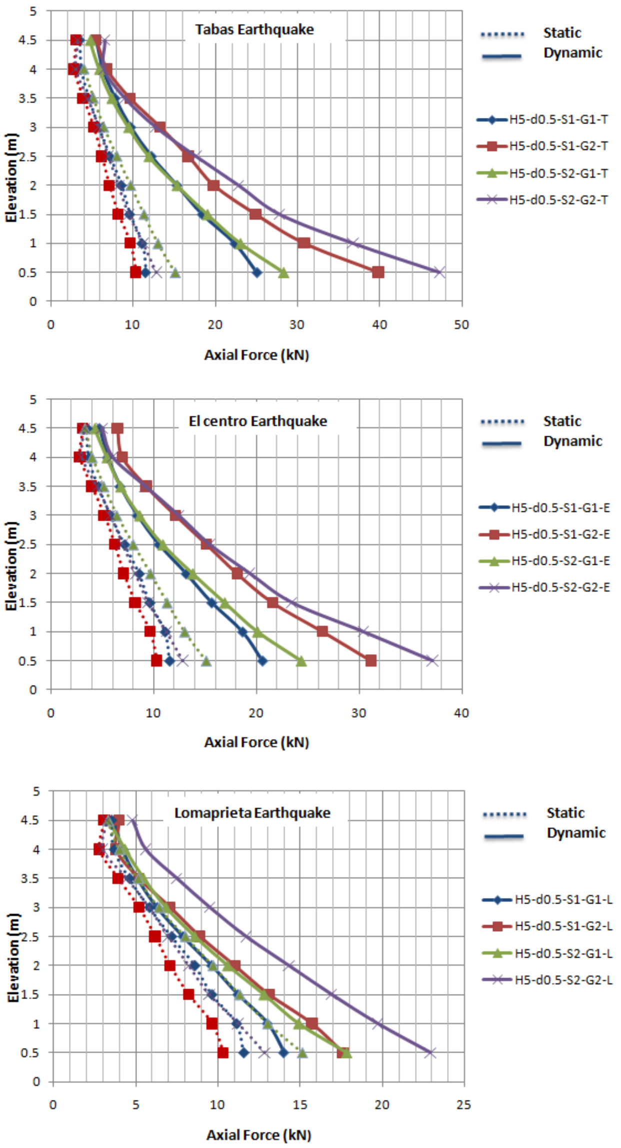

Fig. 11 The comparison between geosynthetic forces in static and dynamic analyses for 5m wall with d = 0.5m

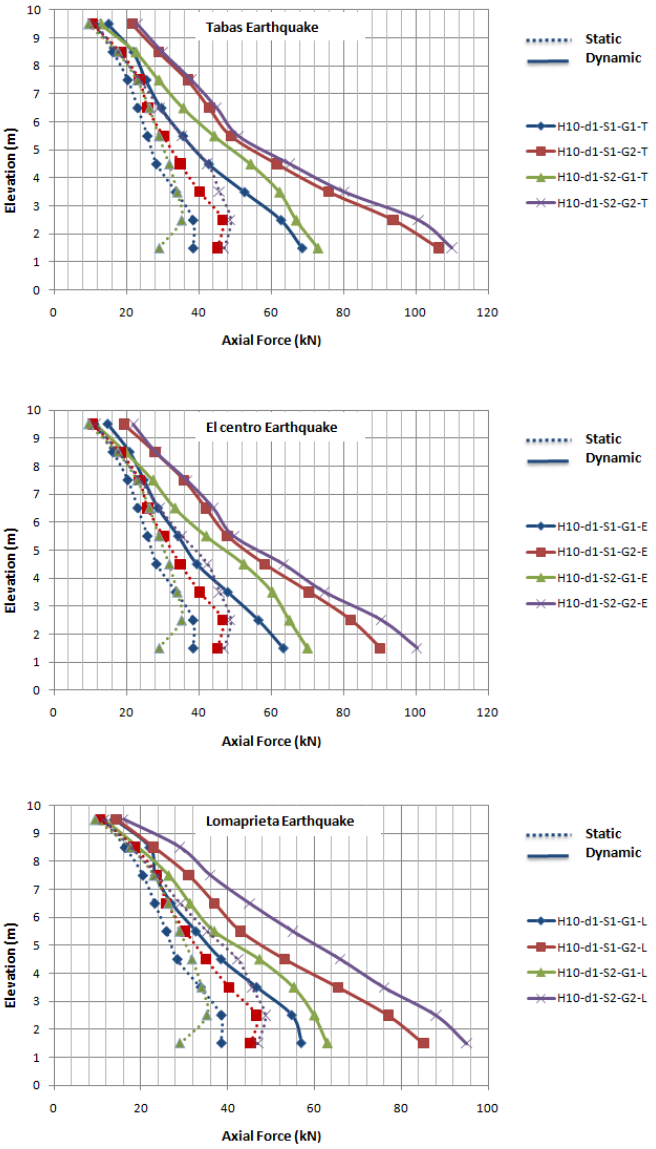

Fig. 12 The comparison between geosynthetic forces in static and dynamic analyses for 10m wall with d = 1m

IV. CONCLUSIONS

In this paper, the static and dynamic analyses on geosynthetic forces and numerical analysis using finite difference method (FLAC 2D), and the diagrams of the maximum forces of reinforcements versus wall heights have been produced. The summarized results are presented below:

1) The reinforcement loads increased from top of the wall to base. At the region of 1/3 of base of the wall, the reinforcement forces were bigger than the top.
2) With duplicating the reinforcement vertical spacing, the maximum induced forces in geosynthetics were not increasing with the same rate. To put it into other word, to determine the change rate of induced forces into vertical spacing of geosynthetic implementing more simulation is suggested.

3) An increase in the angle of internal friction, module of elasticity and unit weight of the soil, decreased the induced reinforcement forces. This reduction rate was different with other parameters.
4) The use of stiffer geosynthetic increased the amount of forces in it.
5) In similar cases, the effect of geosynthetic type was more effective than the sand type.
6) For models with the same wall height and geosynthetic vertical spacing, the starting point of all the graphs at the top of the wall was almost the same, but in the bottom, the graphs had the maximum difference. This shows that the difference between the reinforcement forces in different cases of geosynthetic stiffness or soil type increases with depth.
7) The maximum base input acceleration is an effective and important parameter. The walls at the time of the occurrence of Tabas Earthquake had the biggest induced forces in their reinforcements.
8) Dynamic loading induces more forces in reinforcement in comparison with static loading. At the top of the wall, the dynamic and static forces were almost near, but with an increase in depth, the difference became slightly more. The earthquakes with more maximum base input acceleration; therefore, had more effect on difference between static and dynamic forces.

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