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Effects of Dimensions of Tire Waste Cushion on Seismic Performance of Retaining Wall

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ABSTRACT

Geotechnical structures such as retaining walls are key elements of ports and harbors, transportation system lifelines, and other infrastructural facilities. These structures suffer excessive deformations or damages resulting from the increased earth pressure during the earthquakes. Inclusion of vertical compressible layers called as cushion layer can be a solution to increase the stability of the retaining structures in seismic regions. In the literature, two different compressible materials as geofoam and tire wastes-sand mixtures are studied to mitigate earthquake-induced dynamic earth pressures against rigid walls. This study proposes a seismic cushion material as tire crumb-sand mixture in decreasing structural hazard of retaining wall during earthquake loadings. Previous researches showed that the cushion thickness plays an important role on the seismic performance of retaining structures. The aim of this study is to determine the optimum seismic cushion thickness/height ratio (t/H) to increase the seismic performance of the wall. Both wall height and cushion thicknesses vary to achieve the desired cushion dimensions. A typical retaining wall with a tire waste-sand cushion is modelled by a finite element program called PLAXIS. This paper presents a series of numerical simulations to investigate the effects of dimensions of compressible tire waste-sand cushion to attenuate dynamic loads against rigid retaining walls. In addition, this research is an attempt towards developing an environmentally friendly earthquake resistant technique that has a reasonably good balance of cost and performance for improving the seismic performance of retaining structures.

Keywords: Retaining wall, seismic performance, tire crumb-sand mixtures, cushion, earthquake.

INTRODUCTION

The use of Tire Wastes (TW) are successfully adapted to many inter-disciplinary engineering applications due to their convenient engineering properties such as thermal insulation, permeability, compressibility, stiffness and also high damping properties. Another reason to such convenience is their different sizes and shapes. TW were mainly used in landfill construction and operations, landfill closures, alternative daily covers, leachate collection systems, gas venting systems, septic system drain fields, subgrade fill and embankments, backfill for walls and bridge abutments, subgrade insulation for roads, vibration dampening layers (STMC, 2010). TW are preferred in civil engineering applications as lightweight fill, embankment fill, and retaining wall backfill. The recent proposal of the new seismic buffer aims to use tire wastes as energy absorption material due to its enhanced damping and stiffness properties compared to the sand.

Scrap tires can be managed as whole, slit, shred, chip, ground, or crumb rubber according to transformation by means of a mechanical size reduction process into a collection of particles, with or without a coating of a partitioning agent to prevent agglomeration during production, transportation, or storage. For most practical purposes, tires and tire products function as homogeneous mixtures, but processing of tire wastes with different size and shapes can change their physical characteristics. The purpose of using tire wastes is to modify the properties of soil as an additive, rather than using it as fill material (Edinçliler, 2007).

Using tire wastes in construction requires an awareness of the properties and the limitations associated with their use. Edinçliler et al. (2010) investigated the influence of processing techniques on the mechanical properties of tires wastes. They found that the three factors as normal stress, processing techniques, and the tire waste content significantly affect the mechanical properties of the processed tire wastes. Typical processed tire wastes generally used in civil engineering applications are given in Figure 1 (Edinçliler et al. 2010).

Figure1. Typical shapes of different processed tire wastes (not to scale) (Edinçliler et al. 2010).

Retaining walls suffer excessive deformation and structural damage due to the increased earth pressure during the earthquake. It is necessary to implement a cost effective technique to retrofit such structures, hence enhancing their seismic performance. Inclusion of vertical compressible layers called as cushion can be a solution to increase the stability of the retaining structures in seismic regions. One function of the cushion is to reduce the load against the structure due to energy absorption capacity of the cushion material. Another function is to curtail permanent displacement of the structure due to inherited flexibilities derived from using such elastic and compressible materials (Hazarika et al. 2008).

In the literature, two different compressible layers as expanded polystyrene (EPS) which is called geofoam and tire wastes (tire chips and tire shreds)-sand mixtures placed against rigid soil retaining structures to attenuate earthquake-induced dynamic earth pressures against rigid walls and to reduce lateral static earth pressures has been reported in the literature by different researchers (Partos and Kazaniwsky, 1987; Horvath, 1997; and Karpurapu and Bathurst, 1992).

The use of tire chips has been defined as an innovative cost-effective disaster mitigation technique which can be utilized as a seismic performance enhancer of geotechnical structures (Hazarika et al. 2008). This concept has been demonstrated using small-scale laboratory tests (Hazarika et al. 2003; Zarnani et al. 2005; Bathurst et al. 2007; Zarnani and Bathurst, 2007). The tests by Zarnani and Bathurst (2007) and Zarnani et al. (2005) have demonstrated that peak lateral loads acting on the compressible model walls during simulated earthquake loading were reduced by as much as 40% of the value measured for the nominally identical structure but with no compressible inclusion (Zarnani and Bathurst, 2008). Ravichandran and Huggins (2014) investigated the performance of retaining wall backfilled with shredded tires by applying design earthquake acceleration-time histories using FEM technique. Results show that the shredded tire backfill significantly reduces the wall tip deflection and maximum shear force and bending moment along the wall.

In the studies of Edinçliler and Toksoy (2014, 2017), it is revealed that the existence of a TW cushion layer can successfully and efficiently increase the seismic performance of retaining walls. From experiences and knowledge from previous studies, it is known that the geometry and the orientation of the seismic cushion affect the dynamic performance of geotechnical structures. This paper proposes a new potential seismic cushion as tire crumb material in minimizing structural hazard of retaining wall during earthquake loading by making good use of the lightweight, compressible, and ductile characteristics of the material which describes the numerical study to investigate the use of compressible tire crumb (TC) cushion to attenuate dynamic loads against rigid retaining wall structures. The aim of this study is to determine the optimum seismic cushion dimensions depending on the t/H ratio to increase the seismic performance of the retaining wall. Both wall height and cushion thicknesses vary to achieve the desired pre-defined cushion thickness ratios of 0.3 and 0.4. Four different Finite Element Models (FEM) were created and dynamic performance analyses have been performed using a real earthquake record. Obtained results have been compared by means of total displacements, rotations, axial and shear stresses, bending moments, transmitted accelerations and factor of safety values. Furthermore, this study can be explained as a direct attempt to develop an environmentally friendly earthquake resistant cushion technique that has a reasonably good balance of cost and performance for improving the seismic performance of retaining structures.

NUMERICAL STUDY

In order to determine the optimum (t/H) ratio for the seismic cushion to increase seismic performance of retaining walls, four different FEM models have been created with respect to the selected (t/H) ratios of 0.3 and 0.4. Models vary in cushion thickness (t) and wall height (H). Physical details of models are given in Table 1.

Table 1. Physical details of models.

Model No.	H (m)	t (m)	t/H
Model 1	5	2	0.4
Model 2	5	1.5	0.3
Model 3	7	2.8	0.4
Model 4	7	2.1	0.3

Materials

"Silivri Sand" which is locally found around Istanbul region has been used as sand material. According to the USCS system, the sand material is classified as poorly graded sand (SP) with C_u: 2.29 and C_c: 1.1 (Çağatay, 2008). Tire crumb used is a granular material and it is obtained by processing scrap tires. Tire crumb was purchased from a local company in Istanbul. The tire crumb used in the experiments has an aspect ratio of 1-1.5. The grain size distribution curve of tire crumb is represented in Figure 3.

Figure 2. Tire crumbs used in this study.

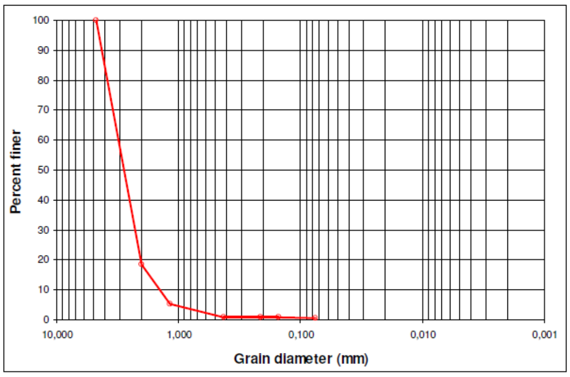

Figure 3. Grain size distribution of tire crumbs.

Previously, a series of static tests were conducted on only sand, mixtures of TW in percentages of 10, 20 and 30 by weight. Cyclic triaxial tests were performed under three different confining pressures which are 40kPa, 100kPa and 200kPa (Yildiz, 2012). The best performance by the cyclic triaxial tests was obtained for tire crumbs-sand mixtures having 70%Sand + 30% tire crumbs by weight (TC30). The behaviour of TW show a more elastic behavior with increasing rubber content. Damping in a rubber/sand mixture is due to the friction of the particle contacts, and the deformation of particles. The sand particles are very stiff and thus dissipate very little energy in particle deformation. In contrast, the rubber consumes energy through the deformation of rubber particles themselves. In this study, the rubber content is limited to 30% by weight which makes 50-60% by volume to maximize the damping properties (TC30).

FEM Modelling

Numerical studies using FEM technique are performed by PLAXIS 2D software which is a commercially available multi-purpose FEM software and enables to model various types of real geotechnical applications. Plane strain model is used and 15-node triangle option is selected which provides more accurate and detailed stress results for complex problems.

Four different cantilever type retaining wall structures have been modelled (Table 1). The retaining structure is modelled as a plate element. For the dynamic analysis, prescribed displacement is introduced for the selected earthquake record. Due to prevent unexpected spurious wave reflections and stress concentrations at the boundaries of the model, absorbent boundaries are applied to the model. Developed FEM model is given in Figure 4.

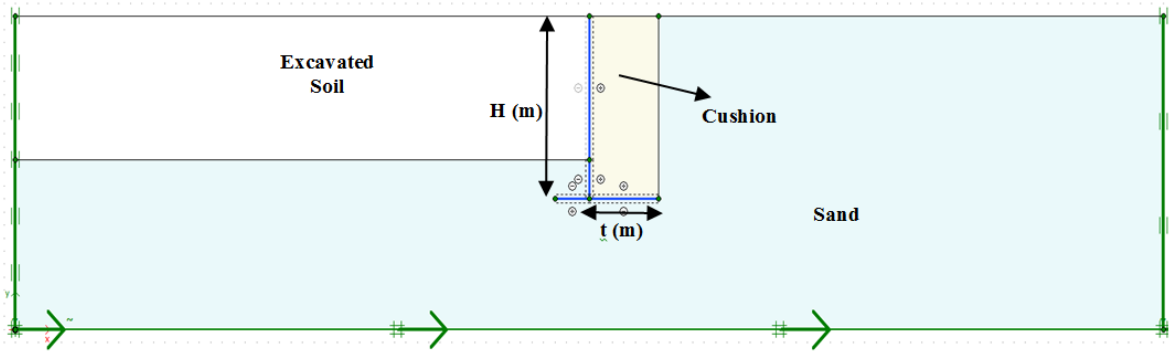

Figure 4. Developed FEM model.

The hardening soil model was used to define the materials in the models. The hardening soil model is an advanced model in order to simulate the behavior of different kinds of soils. This soil model considers both shear hardening and compression hardening situations that is why it is also named as isotropic hardening. Input parameters for Silivri Sand and TC30 are represented in Table 2.

Table 2. Input parameters of materials for hardening soil model.

	Silivri Sand	TC30
γ_{unsat}	16.5kN/m^3	10.3kN/m^3
c'_{ref}	0kN/m^2	14kN/m^2
Ø	33°	29.5°
E_{50}^{ref}	13560kN/m^2	10000kN/m^2
E_{oed}^{ref}	13560kN/m^2	10000kN/m^2
E_{ur}^{ref}	40680kN/m^2	30000kN/m^2

Dynamic analyses were performed using the real earthquake record of the 1995 Kobe earthquake (PGA=0.68g). The record has been obtained from BU-KOERI-BDTIM and used after baseline corrected and filtered from noise contamination (Figure 5).

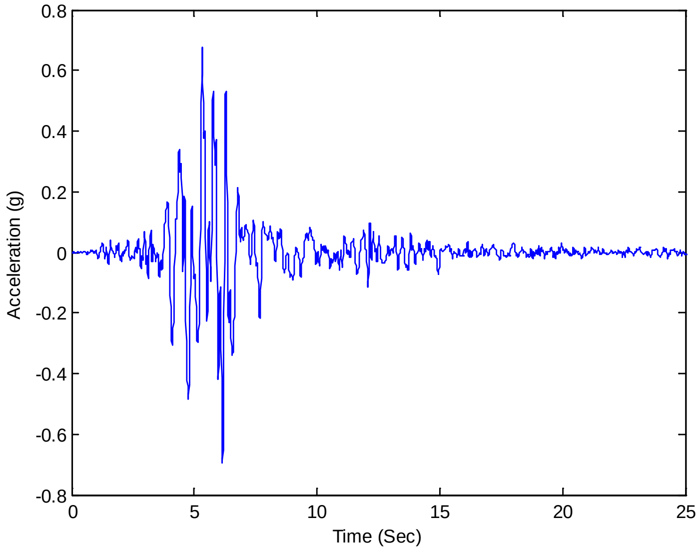

Figure 5. The accelerogram of the 1995 Kobe Earthquake.

RESULTS

Obtained results from performed numerical analyses are presented by means of total displacements, rotations, axial and shear forces, bending moments, peak transmitted accelerations, accelerations at top of the wall and the factor of safety for each model. These results are carefully evaluated to determine the influence of (t/H) ratio on the seismic performance of retaining wall structures with cushion. Obtained numerical results from FEM analyses are given in Table 3.

Table 3. Obtained numerical results from FEM analyses

	Model 1 (t/H=0.4)	Model 2 (t/H=0.3)	Model 3 (t/H=0.4)	Model 4 (t/H=0.3)
Wall Height (m)	5	5	7	7
Total Displacements (cm)	33.9	34.9	78.0	67.9
Rotations (°)	2.1	2.2	3.4	2.8
Axial Force (kN/m)	138.7	139.2	192.3	201.6
Shear Force (kN/m)	155.2	159.6	266.6	281.3
Bending Moment (kNm/m)	131.9	147.8	342.6	427.7
Peak Transmitted Acceleration (g)	4.10	3.51	3.70	3.57
Acceleration at Top of the Wall (g)	1.21	0.74	2.72	0.56
Factor of Safety (FS)	1.62	1.72	1.72	1.75

Model 1 and Model 2 experience 33.9cm and 34.9cm of displacement and 2.1° and 2.2° of rotation from the normal, respectively (Figure 6). Similarly, earthquake induced forces acting on Model 2 are slightly higher than Model 1 as seen in Table 3. Model 1 is subjected to 138.7 kN/m axial force and 155.2kN/m shear force whereas the same forces are 139.2kN/m and 159.6kN/m in Model 2. The behavior pattern does not change for bending moments. As can be inferred from Table 3, transmitted accelerations are higher in Model 1 than Model 2. As seen in Figure 7, obtained 4.1g of peak transmitted acceleration value and the 1.21g of acceleration at top of the wall in Model 1 decreases to 3.51g and to 0.74g respectively, when the (t/H) ratio is 0.3. Expectedly, the factor of safety (FS) increases from 1.62 to 1.72.

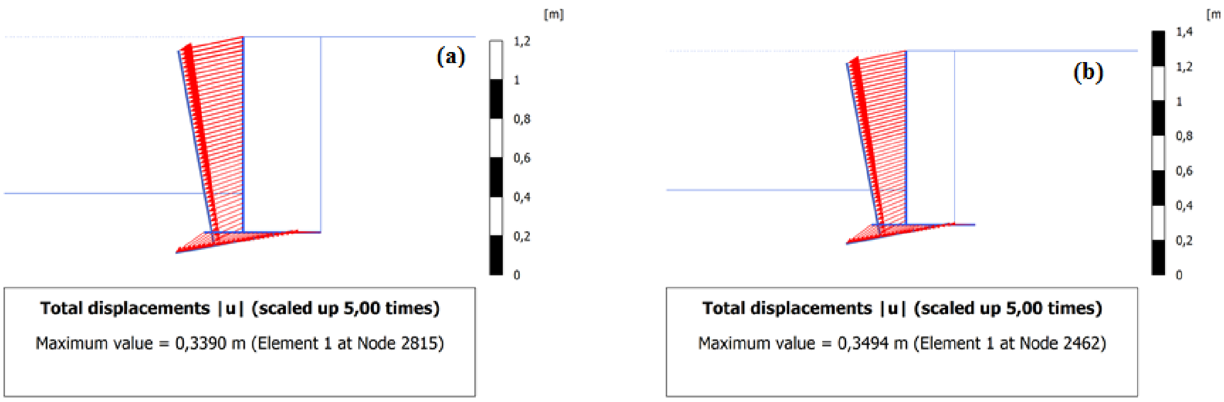

Figure 6. Total displacements a) Model 1, b) Model 2.

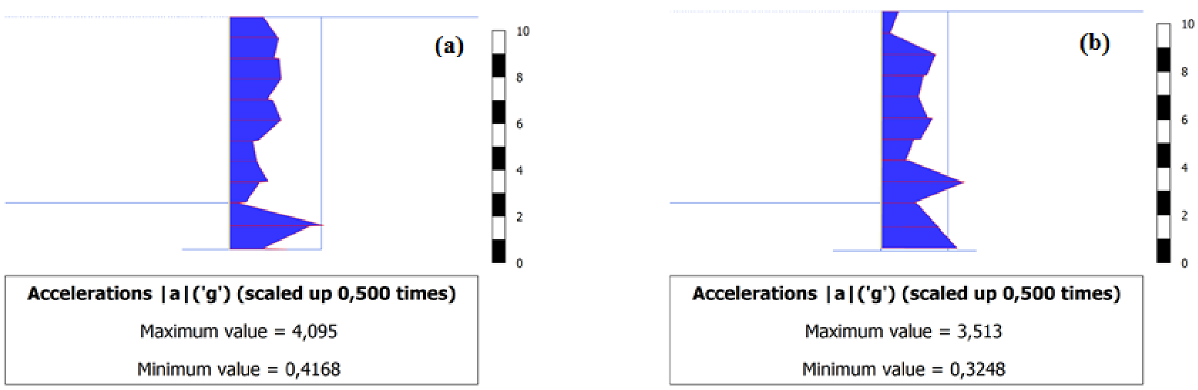

Figure 7. Transmitted accelerations a) Model 1, b) Model 2.

The increase of obtained results in Model 3 and Model 4 is directly related with the increased wall height. Model 3 experiences 78 cm of total displacement and 3.4° of rotation and Model 4 is displaces 67.9cm and rotates 2.8° (Figure 8). It is seen that earthquake induced forces are higher in Model 4 than Model 3. Axial forces, shear forces and bending moments increase from 192.3kN/m to 201.6kN/m, 266.6kN/m to 281.3kN/m and 342.6kNm/m to 427.7kNm/m in Model 4, where the (t/H) ratio is 0.3. Transmitted acceleration values are decreased when the (t/H) ratio decreases. Peak transmitted accelerations decrease from 3.70g to 3.57g and acceleration values at top of the wall decrease from 2.72g to 0.56g in Model 4 (Figure 9). The FS also increases from 1.72 to 1.75 in Model 2. Overall, comparison of the results showed that inclusion of the seismic cushion against the retaining wall models can successfully and efficiently increase the seismic performance of such structures under dynamic motions.

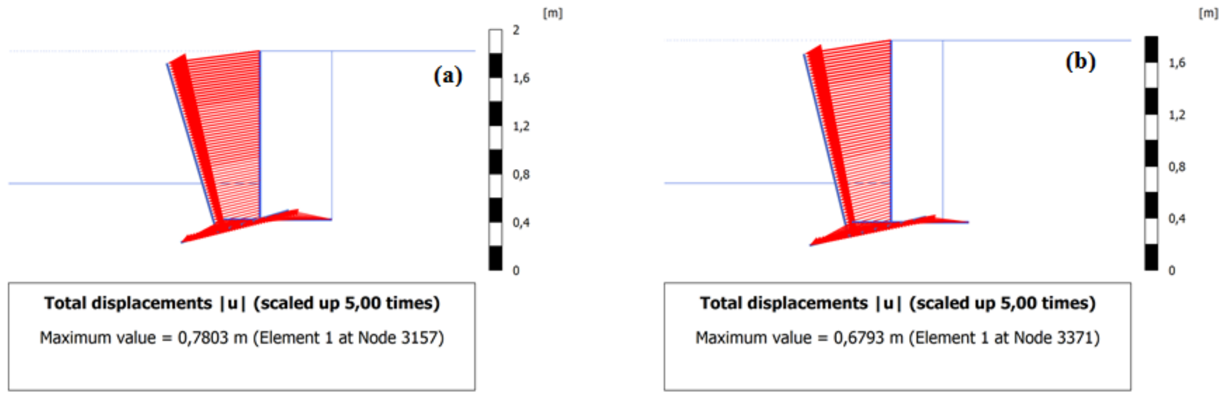

Figure 8. Total displacements a) Model 3, b) Model 4.

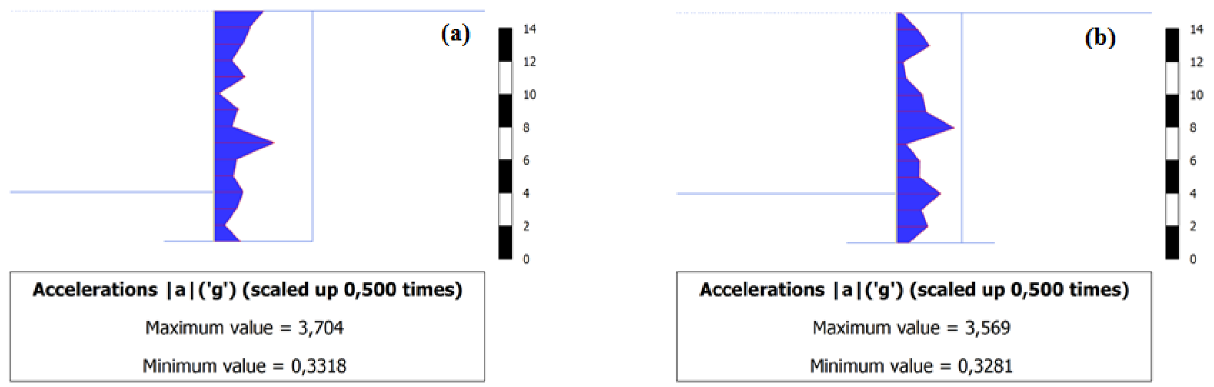

Figure 9. Transmitted accelerations a) Model 3, b) Model 4.

CONCLUSIONS

Experiences from present and previous studies clearly reveals that TW Cushion can be used to mitigate the earthquake effects of retaining structures. In this study, a series of FEM analyses have been performed to determine the influence of (t/H) ratio on the seismic performance of cantilever retaining wall with seismic cushion. Four different numerical models with (t/H) ratios of 0.3 and 0.4 have been studied.

For Model 1 and Model 2, where the wall height is 5m, the reduction in (t/H) ratio leads to increased total displacements and rotations. It is seen that total displacements increase around 3% in Model 2 where (t/H) =0.3. On the other hand, for Model 3 and Model 4, where the wall height is 7m, the reduction in (t/H) ratio leads to decreased total displacements and rotations. Model 4 displaces around 13% and rotates 17% less. For all models, the reduction in (t/H) ratio increases the earthquake induced forces on retaining wall. This is an expected result as the reduction in cushion area results in less dynamic energy absorption. Acting axial and shear forces and bending moments increase up to 4.8%, 5.5% and 24.8% in Model 4 when compared with Model 3. By means of peak transmitted accelerations and accelerations at top of the wall, obtained results are up to 38.8% and 79.4% less when (t/H) ratio was set to 0.3. As shown in Table 3, deamplification was observed for Model 4. By means of FS values, the (t/H) ratio of 0.3 presents higher factor of safety values.

To sum up, the detailed evaluation of numerical results revealed that (t/H) ratio plays an important role on the dynamic performance of retaining wall with seismic cushion. Performed dynamic performance analyses on four different models show that the selection of (t/H) ratio 0.3 instead of 0.4, increases the stability of retaining structures considerably. For Model 4, deamplification is observed at the top of the wall. It should be highlighted that presented results are directly related to the selected dynamic motion, (t/H) ratio and soil properties. Future studies are planned with respect to the different values of abovementioned parameters. This research is an attempt towards achieving a better seismic performance of retaining wall using cost-effective disaster mitigation technique.

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