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EFFECTS OF CHARACTERISTICS OF EARTHQUAKE MOTION ON SEISMIC PERFORMANCE OF RETAINING WALL WITH TIRE WASTE-SAND CUSHION: EXPERIMENTAL STUDY

EFFECTS OF CHARACTERISTICS OF EARTHQUAKE MOTION ON SEISMIC PERFORMANCE OF RETAINING WALL WITH TIRE WASTE-SAND CUSHION: EXPERIMENTAL STUDY

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ABSTRACT

Retaining walls are commonly constructed in earthquake-prone areas. The seismic performance of retaining walls can be increased by using one of the improvement techniques. Recently, lightweight materials as a "cushion layer" has been included behind the retaining wall. These materials have many advantages, including low unit weight, low bulk density, and high vibration absorption capacity. Waste tire-derived materials-sand mixtures and expanded polystyrene (EPS geofoam) are some of the lightweight materials used as cushions behind a retaining wall. This study aims to investigate the effects of earthquake characteristics on the seismic performance of the retaining wall with a tire waste-sand cushion. Tire waste-sand cushion material was used as a 10 percent tire crumb addition to the sand by weight (TC10). Shaking table experiments were carried out by constructing the 1/25 scale retaining wall model with a cushion layer in a rigid-sided soil box. It is observed that the characteristics of input motions have a significant influence on the seismic performance of the cushioned retaining wall.
Keywords: *Tire Waste-Sand Mixtures, Shake Table Tests, Soil Improvement, Retaining Walls, Cushion.*

1. INTRODUCTION

In the literature, two different compressible layers as expanded polystyrene (EPS), which is called geofoam, and tire wastes-sand mixtures are placed against the retaining structures to attenuate earthquake-induced dynamic earth pressures against rigid walls and to reduce lateral static earth pressures. Bathurst et al. (2007) showed that the inclusion of geofoam behind the retaining wall reduces lateral earth pressure at varying rates depending on the geofoam properties. Hazarika et al. (2008) used tire chips behind caisson-type walls in shaking table experiments and stated that the cushion layer reduced both seismic forces and permanent displacements. Ertuğrul and Trandafir (2014) stated that adding a compressible layer behind the wall reduces the lateral loads affecting the retaining wall model.

The aim of this study is to examine the influence of the characteristics of earthquake motions on the seismic behavior of retaining walls with cushions. The seismic performance of the 1/25 scaled retaining wall was evaluated by conducting a series of shaking table tests. Edinçliler and Yıldız (2022) observed that tire waste content significantly affects the shear modulus and damping ratio of the tire waste-sand mixtures. The cyclic triaxial tests performed by Edinçliler and Yıldız (2022) showed that 10 percent tire crumb addition to the sand by weight (TC10) had a higher damping ratio compared to the sand. In the shake table tests, the material properties of TC10 are used as cushion material. The cushion material is placed behind the wall by using the (t) thickness of the cushion material under three different earthquake motions. The effects of input motion characteristics on the retaining wall with TC10 cushion are evaluated by comparing the acceleration and displacement response of the retaining wall under the given earthquake motions.

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2. MATERIALS AND METHODS

Details on the shake table tests conducted on a 1/25 scaled retaining wall model are given in the following parts:

2.1. Sand

The experiments were conducted using dry, cohesionless sand called "Silivri Sand." The grain size distribution of Silivri sand was determined using ASTM D422 and D6913 (Figure 1). According to the United Soil Classification System (USCS), Silivri sand is poorly graded sand (SP).

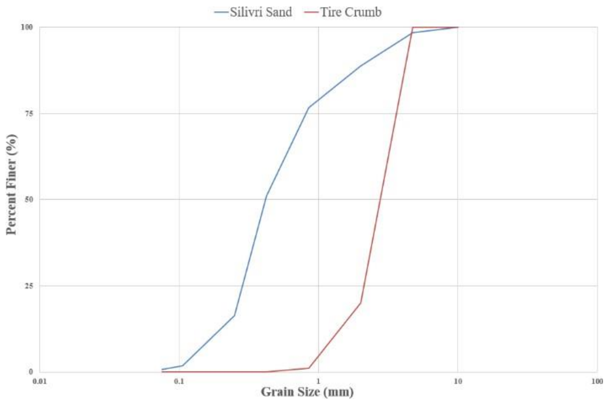

Figure 1. The grain size distribution of Silivri Sand and Tire Crumb.

2.2. Tire Crumb

The grain size distribution of tire crumb is presented in Figure 1. The D50 value for the tire crumb was found to be 2.7. The tire waste material is depicted in Figure 2, while TC10 was selected as the cushion material. The unit weight of the TC10 material was determined to be 14.5 kN/m^3. The TC10 cushion material was placed behind the model wall with a thickness of 2 cm, corresponding to 50 cm at the prototype wall.

Figure 2. Tire crumbs used in the mixture.

2.3. Experimental Program

<u>Wall Model</u>

The retaining wall model was created with a scaling factor of 1/25, which was carefully selected based on the dimensions of the rigid-sided soil box. Scaling relations proposed by Iai (1989) and developed by Muir Wood et al. (2002) and Muir Wood (2004), as presented in Table 1, were utilized to determine the scaled model properties. The model itself was constructed using aluminum material, and a comparison of the prototype wall and the 1/25 scaled wall model can be seen in Figure 3.

Table 1. The scale factor for the 1g shaking table test (Iai, 1989)

Variable	For 1g Model	Scale Factor
Length	n	25
Density	1	1
Stiffness	$n^{0.5}$	5
Acceleration	1	1
Velocity	$n^{0.5}$	5
Displacement	n	25
Stress	n	25
Strain	1	1
Dynamic Time	$n^{0.5}$	5
Frequency	$1/n^{0.5}$	1/5

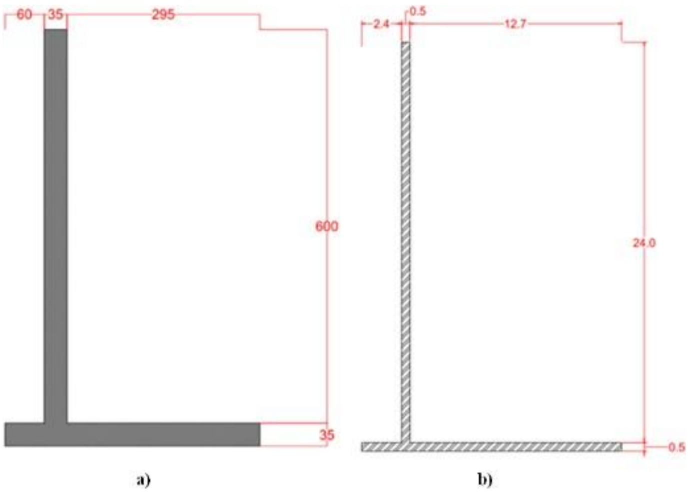

Figure 3. Retaining wall models a) the prototype wall and b) the scaled wall.

Sample Preparation

The shake table tests were conducted using a rigid-sided soil box measuring 900x400x500 mm with a thickness of 15 mm developed by Edinçliler and Toksoy (2017a and 2017b). The scaled model of a retaining wall was utilized to establish shaking table models with a TC10 cushion. The foundation soil was then poured into two layers and compacted to reach a density of 16.5 kN/m^3. Then, the retaining wall model was placed on the foundation layer. The cushioned case was prepared by placing a 2 cm thick TC10 cushion layer behind the wall before backfill soil was poured. The backfill soil was filled and compacted in two layers. The experimental plan is given in Figure 4.

Shake Table Tests

The test model was subjected to three different earthquake recordings. The north-south component of the 1999 Kocaeli Earthquake (Mw=7.4), the north-south component of the 2020 İzmir Earthquake (Mw=6.9), and the north-south component of the 1940 El-Centro Earthquake (Mw=6.9) motions were selected for the experiments. The date, station, predominant frequency, and peak ground acceleration information for selected earthquakes are listed in Table 2. The time-scaled earthquake motions based on the similitude laws by Iai (1989) are shown in Figure 5. During the tests, the acceleration and displacement response are measured.

Table 2. The input motions used in the experimental study.

Name	Date	Station	Component	f (Hz.)	PGA (g)
Kocaeli Eq.	17.08.1999	Izmit	N-S	2.3	0.22
İzmir Eq.	30.10.2020	Kuşadası	N-S	7.0	0.18
El-Centro Eq.	18.05.1940	ImperialValley-02	N-S	3.4	0.32

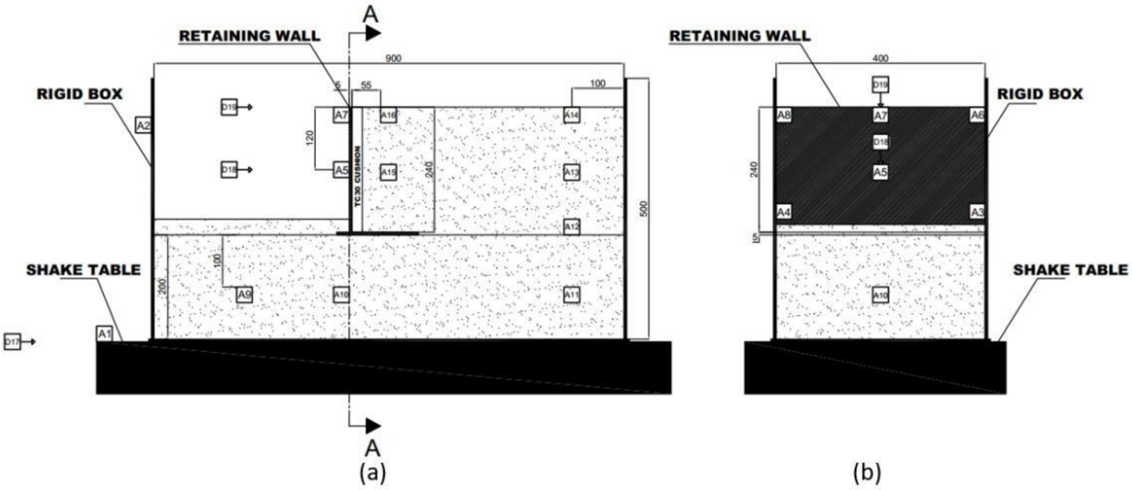

Figure 4. The instrumentation plan a) the side view and b) the cross-section (A-A).

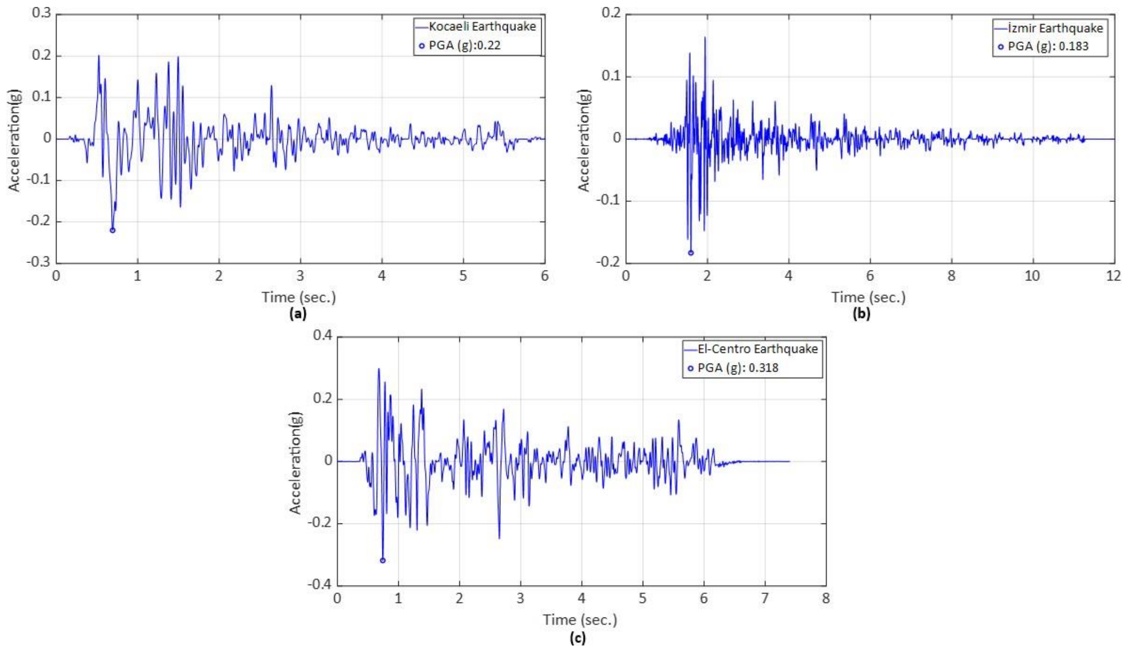

Figure 5. The scaled acceleration-time histories a) Kocaeli Earthquake (Izmit station), b) Izmir Earthquake (Kuşadası Station), and c) El-Centro Earthquake (Imperial Valley-02) motion

RESULTS AND DISCUSSION

Effects of tire waste-sand cushion under three different earthquake motions are given below:

3.1. Acceleration Response

Acceleration time histories measured at the top of the wall with TC10 cushion under the input motions are given in Figure 6. The greatest increase in maximum acceleration at the top of the wall (99%) was observed under the Izmir earthquake motion. Under Kocaeli and El-Centro earthquake motions, 21% and 29% increases in maximum acceleration value were determined. The Izmir earthquake motion has the lowest PGA and the highest predominant frequency values compared to other input motions. This feature may be the reason for the considerable change in the PGA at the top of the wall.

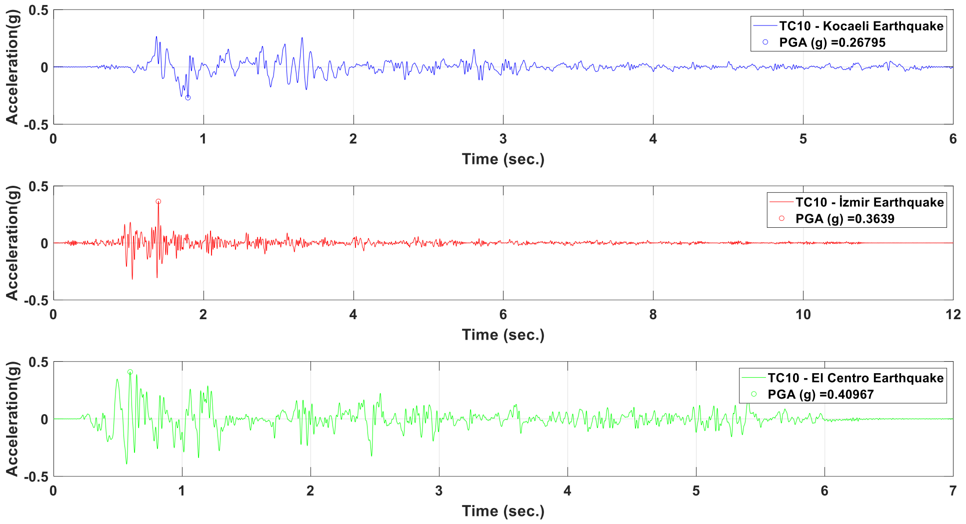

Figure 6. Acceleration time histories measured at the top of the wall with a TC10 cushion under the input motions.

The peak spectral acceleration (SA) values of the scaled input motions as Kocaeli, İzmir, and El Centro earthquake motions are determined as 0.85g (at T=0.060 sec), 0.54g (at T=0.085 sec), and 1.01g (at T=0.110 sec), respectively. Spectral Accelerations at the top of the wall with TC10 cushion under the input motions are given in Figure 7. The increase rates in peak SA at the top of the wall are 28%, 93%, and 15% under Kocaeli, İzmir, and El Centro earthquake motions, respectively. Similar to acceleration response, the greatest increase in short-period spectral acceleration was observed under İzmir earthquake motions.

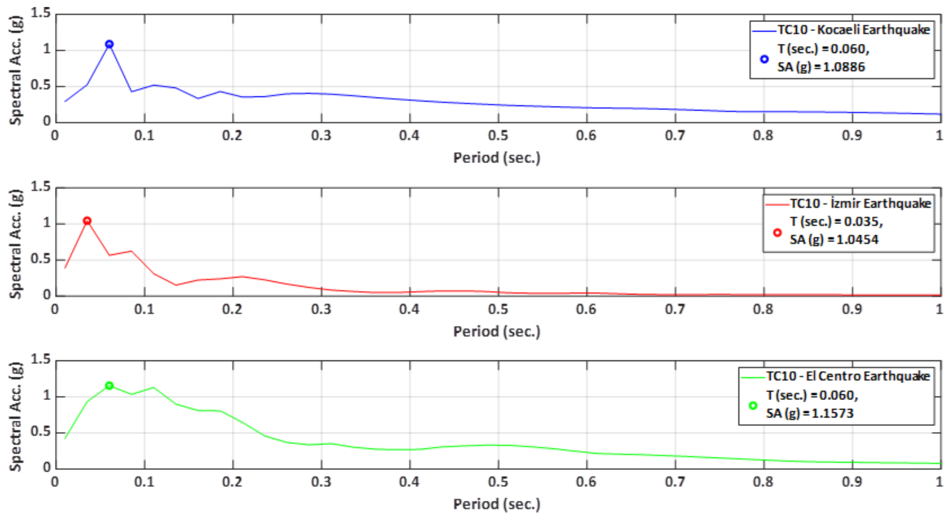

Figure 7. Spectral Accelerations at the top of the wall with TC10 cushion under the input motions.

3.2. Displacement Response

The maximum displacements of the scaled Kocaeli, İzmir, and El Centro earthquake motions were measured as 1.69 cm, 0.90 cm, and 1.79 cm, respectively. Displacement time histories at the top of the wall with TC10 cushion under the input motions are given in Figure 8. The lateral displacement values at the top of the wall are lower than those of input motions. The lowest displacement response is observed under İzmir Earthquake. The frequency content of the motion may be the reason for the lowest displacement response.

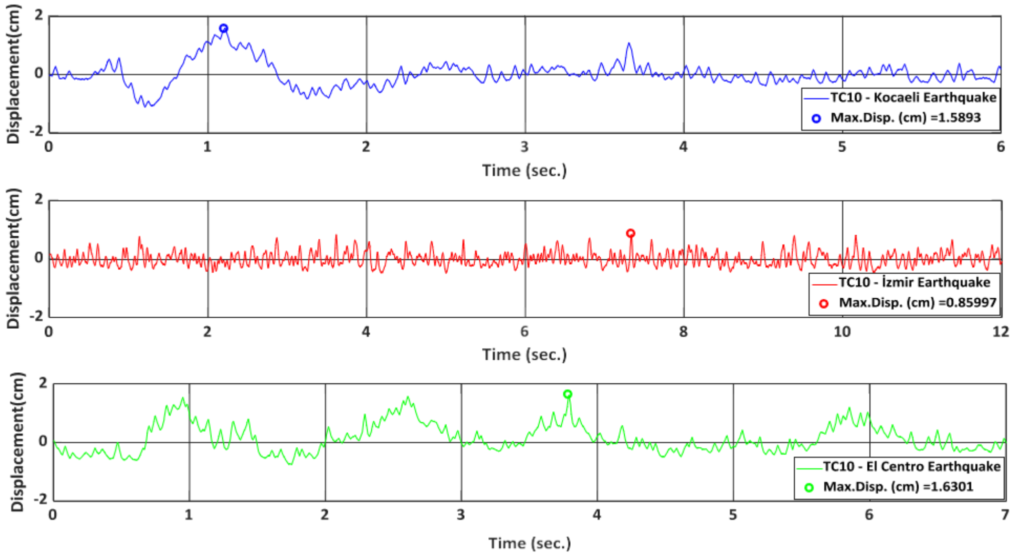

Figure 8. Displacement time histories at the top of the wall with TC10 cushion under the input motions.

3. CONCLUSIONS

Test results showed that the seismic performance of the retaining wall model with TC10 cushion is significantly influenced by the earthquake characteristics, including frequency content, PGA, and duration. The effects of these properties have been found to be particularly important in acceleration responses. The findings are based on the test conditions and input motions used in this study.

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