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DYNAMIC RESPONSE OF BLOCK TYPE QUAY WALL

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Abstract: Gravity type quay walls are the most widely used type of earth retaining structures. Although, the static design of gravity type quay walls is well understood, the dynamic response of this structure due to the strong ground shaking is still being developed.

Block type quay wall is the simplest type of gravity quay wall, which consists of blocks of concrete or natural stone placed from the water side on a foundation consisting of a layer of gravel or crushed stone on top of each. Block type quay walls that require very expensive construction stage suffer significantly from earthquake and the economical and social impacts of this natural event can be devastating.

This paper is a study of analyzing dynamic response of block type quay wall during earthquake considering the both soil-structure interaction (SSI) and fluid-structure interaction (FSI) systems. The following parameters: (1) weight and friction angle of the soil material, (2) wall inclination, (3) backfill inclination, (4) wall roughness, (5) surcharge at soil surface, and (6) horizontal and vertical seismic acceleration (7) hydrodynamic effect are taken into account and the magnitude, distribution and the application point of the pressures due to the backfill, and water on block type quay walls under the seismic effect are investigated. The value of deformations; horizontal and vertical displacements, tilting are analyzed by using the experimental and numerical methodologies. The obtained results from both experimental and numerical results are compatible to each other.

Key Words: block type quay wall, 1g shaking table test, numerical model

1. INTRODUCTION

The heavy damage was observed on coastal structures such as refineries, petrochemical plants and ports the eastern Marmara earthquake occurred on 17 August 1999 with an Mw=7.4 and Izmit Bay and north-west Turkey had been seriously effected from this earthquake. Especially, earthquake was caused crucial damage mostly on block type quay walls at Derince Port in Izmit (Yuksel et al., 2002).

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The design of block type quay walls should be done considering stability, serviceability and safety as well as economy. Therefore several design guidelines are available to give recommendations for the design and construction of block type quay walls. And these guidelines use several approaches to evaluation of seismic slope stability, ranging from simple to complex, are available and it can be divided into three primary groups: pseudostatic methods; sliding block methods; and stress-deformation methods. These methods can be classified into two methodologies; these are; "conventional seismic design methodology", and "performance based design methodology". Conventional seismic design methodology can not provide the required design data and also can not provide any information about the performance of the structure after shaking. However, in performance based design, the design parameters (deformation; overturning, horizontal and vertical displacement) which are identified before the design stage are used as design parameters and the coastal structures are planned according to these parameters

For a defined performance of a structure in terms of a state of damage, strain and deformation give better indicators of damage than stresses. Therefore, it is recommended that performance based design methodology should be applied in the design of block type quay walls. Even if the force balance exceeds the limit values, it can be possible to get some information about the performance of a structure.

A review of existing literature show that; i) available methods used for analysis of the dynamic response of the block type quay walls are not adequate; ii) the most important step is to investigate the dynamic soil-wall interaction when studying the seismic behavior of block type quay walls; iii) one of the most important design parameters is the displacement value of the blocks after shaking; iv) the influence of wall roughness effect the design parameters; v) system is very complicated due to including four elements, namely soil, structure, water and earthquake.

2. EXPERIMENT

The main goal of performance based design is to determine the design parameters (deformation; overturning, horizontal and vertical displacement) of the structure. However, it is not possible to estimate the distribution of the nonlinear soil behavior, changes in acceleration and pore pressure values with an acceptable accuracy during earthquake. Thus all these methods explained before are not adequate to determine the design parameters correctly. In order to achieve this, "the development of performance-based design principle requires shaking model tests to be performed in order to validate and improve prediction of seismically generated displacement" (Torisu et al., 2010).

Thus in this study to determine the design parameters of block type quay walls, 1g shaking table tests are used.

2.1. Instruments

- **<u>1g shaking table</u>** : A series of 1-g shaking table tests were carried out to investigate the seismic performance of block type quay walls. For this purpose, the shaking table facility located at Yıldız Teknik University, İstanbul was used. However, using multi-degree shaking tables for tests may complicate the investigation of model response as well as the interaction of wall–soil. Therefore, here, the one-directional shaking table was used (Fig.1).

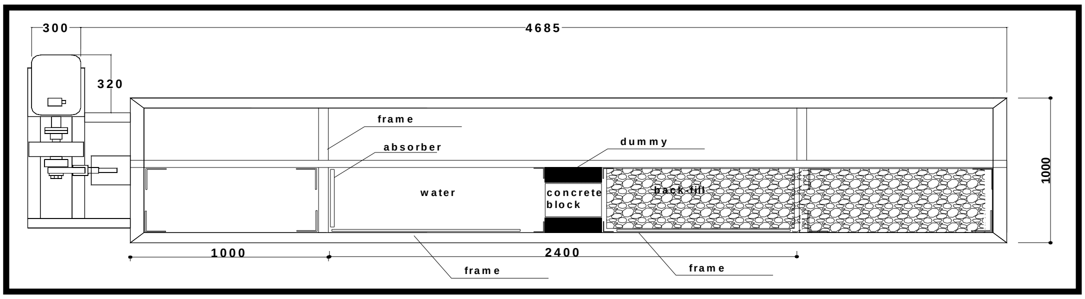


Fig. 1. Shaking table and raining system

To prevent the side effects of the test container, plain strain condition was aimed for the test preparation method. The one degree of freedom shaking table has deck dimensions of 400cm-100cm-100cm with a 4 ton load capacity. It is driven by a 100-kN capacity hydraulic actuator with operator controlling and PC software.

- **<u>Raining system:</u>** The method of raining was used to prepare the backfill behind the model wall. Falling height was chosen as 65 cm and was kept constant by lifting the sieve at each stage during backfilling. Relative density of the dense sand of backfill and foundation are taken as 70 %, 90 % respectively. (Fig. 2, Photo 1).

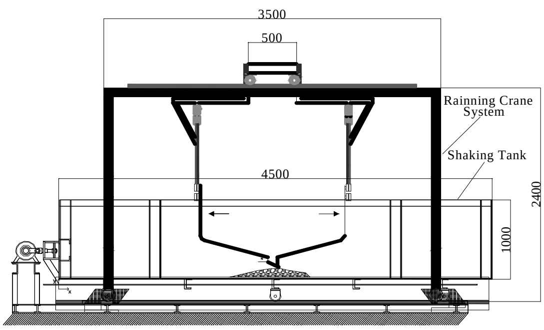


Fig. 2. Raining System

Photo 1. Raining system and shaking table

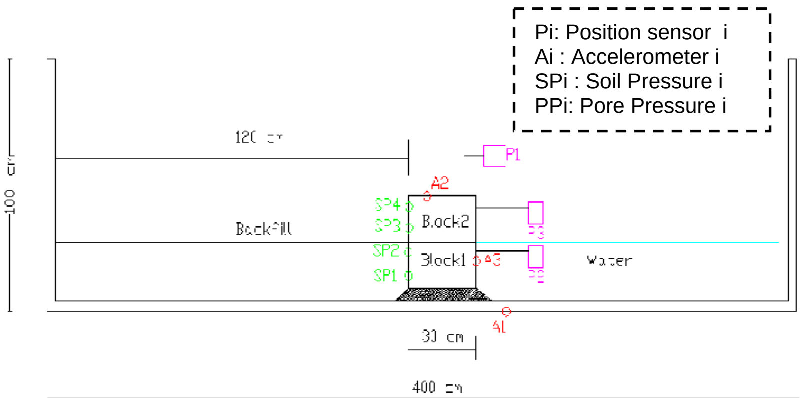


Fig. 3. Position of the sensors

<u>Sensors:</u> To obtain the earth pressure distribution acting on block type quay walls, earth pressure sensors are located between the bacfill and block(s), to obtain the displacement of the block(s) during and/or after cycling loading, position sensors are used, to obtain the accelerations of the block(s) during and/or after cycling loading, accelerometers are used, pore pressure sensors are are used to obtain pore pressure distributions.

In this study to modeled the block type quay wall, 2 blocks were used and for two blocks tests, 4 soil pressure sensors, 3 accelerometers, 2 pore pressure sensors and 3 position sensors were used to perform 1g shaking table tests. Figure 3 and Photo 2 show these instruments places and general view of the two blocks tests.

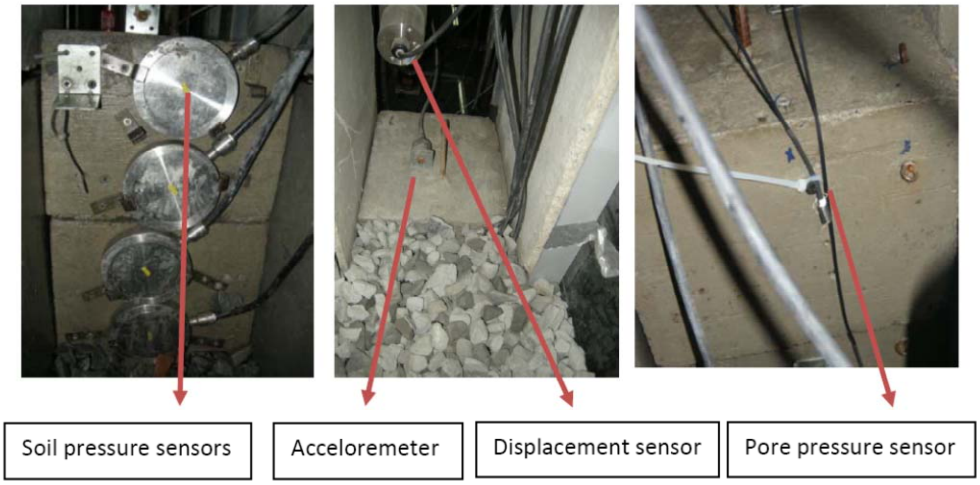


Photo 2. Position of the sensors on blocks

- **Sofware and hardware program**: All the instruments were connected to each other by SPARTAN software and hardware system.

2.2. Soil Parameters

The soil parameters used during the shaking table tests should be defined clearly (Table 1).

Table 1. Soil parameters for foundation rubble and rubble backfill

Soil Parameters	(γ_{dry}) (kN/m^3)	(ϕ) (°)	Dn50
Foundation rubble and rubble backfill	17	40	2.2 cm

γ_{dry} : Dry unit weight of the soil (foundation or backfill), ϕ : internal friction angle. Dn50: nominal diameter of soil.

2.3. Block(s) dimensions and Scaling:

Block dimensions and scaling were determined by considering to;
i) real block(s) dimensions which are generally used for block type quay wall,
ii) portability of the block(s) during the preperation of the experiment set- up, and
iii) dimensions of the shaking table device.

Thus, the general block dimensions and scale were determined as 3m-2m-2.5m and 1/10, respectively (Fig.4.) . Only one kind of block was used in this study, this means that dimension effect was omitted.

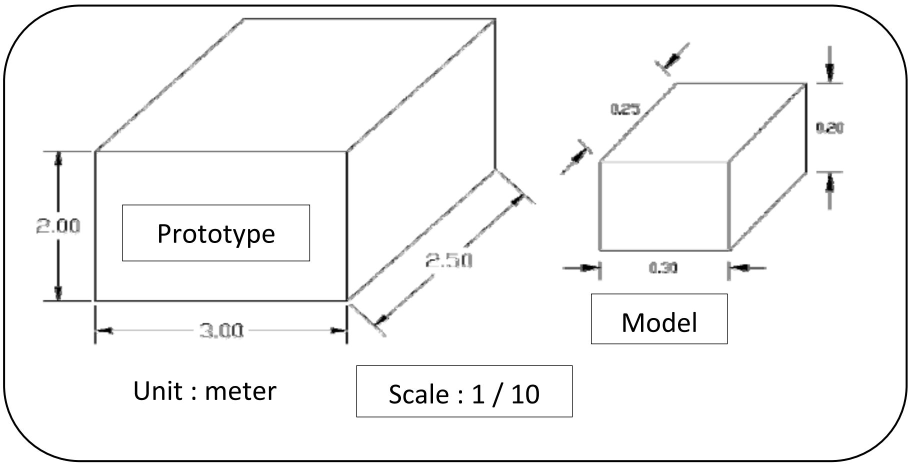


Fig. 4. Dimensions of the blocks (prototype and model) used in the 1g shaking table tests

The corresponding scaling of parameters between the prototype and model used in this experiment were derived as follows, and the results are listed in Table 2.

Table 2. Items and scaling factors

Items	Scaling factors in general	Scaling factors for the present model (prototype / model)
Length	λ	10
Time	$\lambda^{0.5}$	3.16
Acceleration	1	1
Displacement	$\lambda^{1.5}$	31.62
Force	λ^{3}	1000
Density	1	1
Water Pressure	λ	10
Stress	λ	10
Strain	$\lambda^{0.5}$	3.16
Young's Modulus	λ	10
Stiffnes	λ^{2}	100

2.4. Frequencies

"Measurements of earthquake motions on rock sites indicate that dominant frequencies are normally in the range of 0.1 Hz to 10.0 Hz" (Ashford and Sitar, 2002; Bhasin and Kaynia, 2004). The frequency range of interest in civil engineering for a typical real (prototype) earthquake is approximately 0-15 Hz. Thus in this study the frequencies are taken as 2 Hz to 7 Hz with sine wave form under slope angles $\theta=0^{\circ}$

3. RESULTS

All measurements (accelerations, pore pressures, lateral earth pressures, displacements) are shown in Fig. 5-8

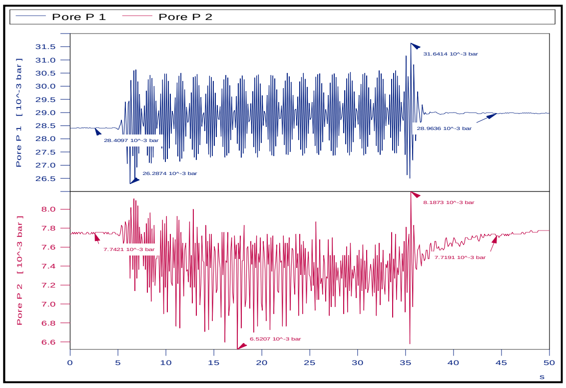


Fig. 5. Pore pressure results

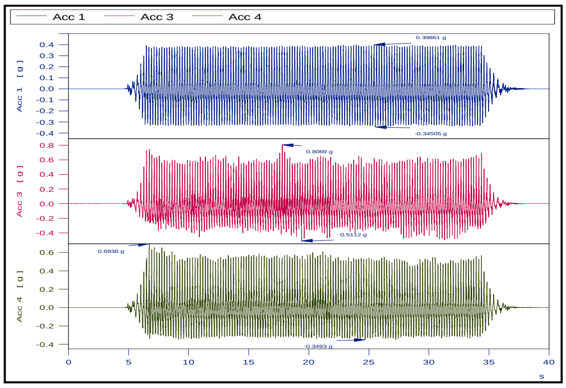


Fig. 6. Accelerometer results

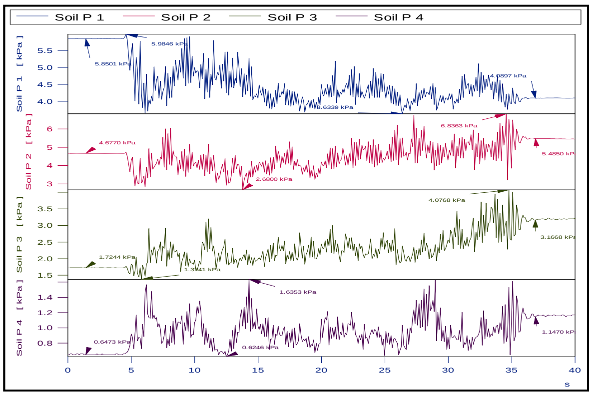


Fig. 7. Pore pressure results

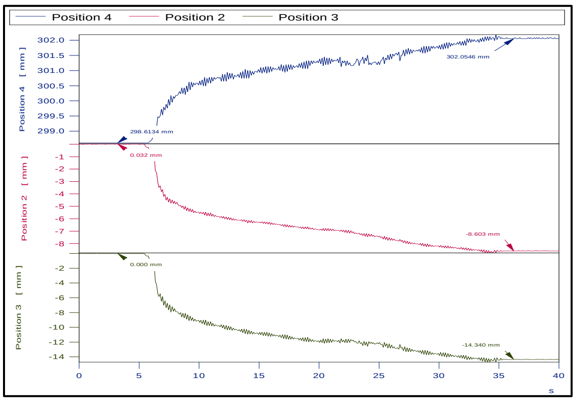


Fig. 8. Accelerometer results

- **Soil pressure:**

Lateral earth pressure changes acting on blocks due to soil versus depth relations for each frequencies are given in Figure 9.

- As it is seen from the figures lateral, earth pressure distrubitions on blocks are so similar to linear distribution. Furthermore, it can be seen that the lateral earth pressure values for both before and after shaking are nearly same and these values increase while depth is increasing for 2Hz, 3 Hz, 4 Hz. It can be seen that the lateral earth pressure values for both before and after shaking show dissimilarity and these values increase while depth is increasing for 4 Hz, 5 Hz, 6 Hz and 7 Hz.

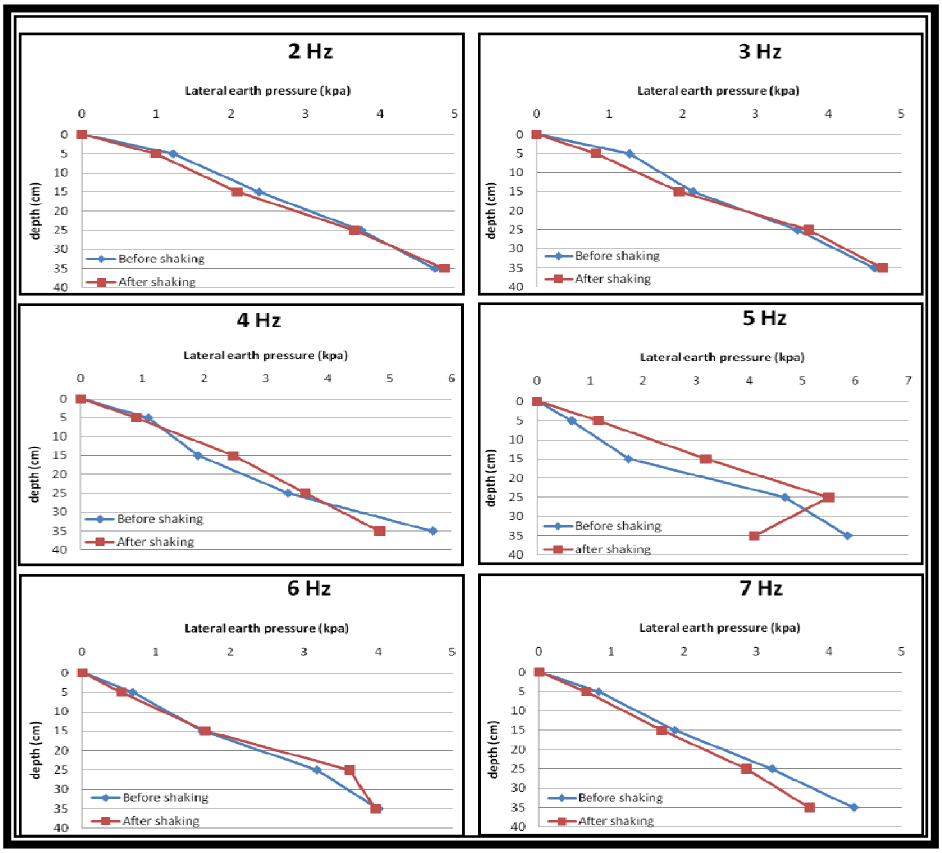


Fig. 9. Lateral earth pressure changes vs depth

As it is known that there are two components of obtained lateral earth pressure values and these values are shown in Figure 10 for different frequencies.

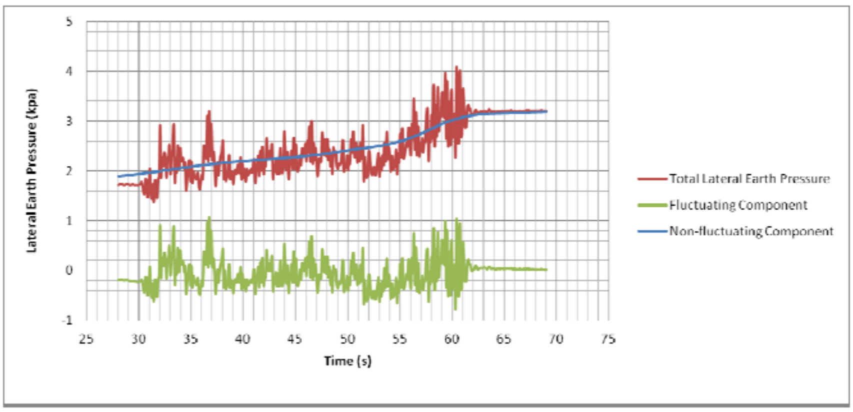


Fig. 10. Total lateral earth pressure, fluctuating and non-fluctuating component for 5 Hz for EP3

All lateral earth pressure data measured by 4 different earth pressure sensors (EP1, EP2, EP3, EP4) positioned on blocks (5, 15, 25, 35 cm) are shown in Fig. 11. Max. fluctuating component of lateral earth pressure versus depth figures for all frequencies show that dynamic effect of the soil increases while depth is increasing however at certain depth this component value begins to decrease till bottom of the block. It is realized that, this certain depth is generally between 0.4 H – 0.6 H (H is the structure height). This result is compatible with the suggested application point position to define the dynamic effect of bacfill acting on retaining wall.

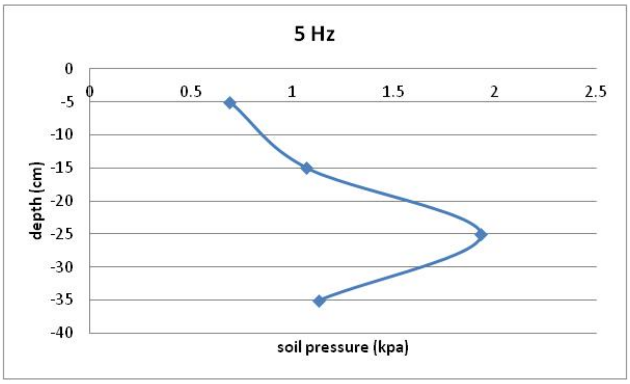


Fig. 11. Max. value of fluctuating component vs depth for 5 Hz.

- **Acceleration**

3 different accelerometers were used with 6 different frequency selected for 1g shaking table tests and these frequecies caused different acceleration values at the base and the blocks . Table 3 show the given frequency values and the corressponding average of the base, block 1 and block 2. Figure 12 shows the max and average base, block 1 and block 2 accelerations.

Table 3. Frequency and average accelerration relations for base and block for soil

Frequency (Hz)	Average Base Acceleration (g)	Avarege Block 1 Acceleration (g)	Avarege Block 2 Acceleration (g)
2	0.0675	0.0685	0.073
3	0.15	0.145	0.165
4	0.275	0.31	0.435
5	0.375	0.52	0.66
6	0.54	0.97	1.24
7	0.72	1.91	2.425

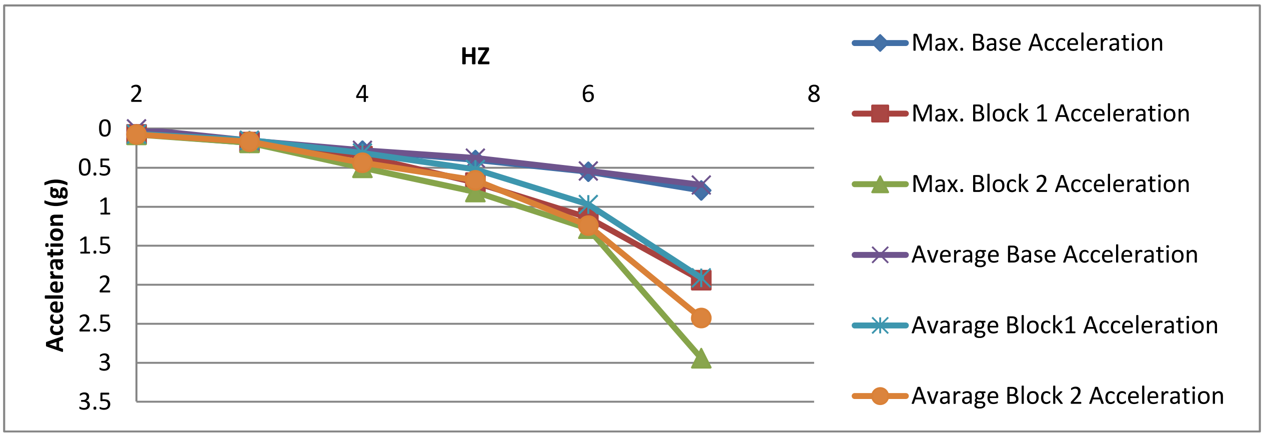


Fig. 12. Acceleration values (g) versus frequencies (Hz)

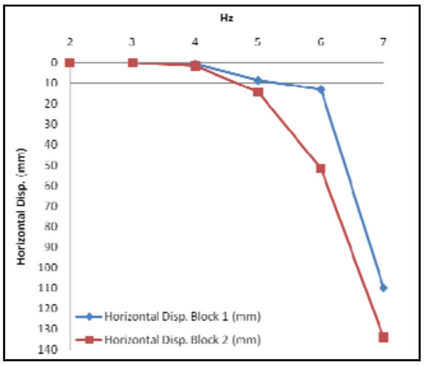
- As it is seen from the Table 3 and Figure 12, maximum and average acceleration values (g) of the base, block 1 and block 2 are so close to each other between 2 Hz - 7 Hz
- Furthermore, according to derived data, the max / average values of the blocks (block 1 and block 2) accelerations are always greater than the max / average values of the base acceleration
- Although, block 2 accelerations are always greater than the block 1 and base accelerations and block1 accelerations are always greater than the base accelerations, Blocks and base accelerations are not so much different between 2Hz-4Hz. After 4 Hz, the differency between accelations increases and the block 2 acceleration becomes approximately 3 times of base acceleration for 7 Hz.

- **Displacements**

Three position sensors – two of them were used for evaluating the horizontal displacements, the other one was used for evaluating the vertical displacement – were used with 6 different frequency which were selected for 1g shaking table tests and these frequencies cause different horizontal and vertical displacement values for the blocks. Table 4 and Fig. 13 show the given frequency values and the corressponding horizontal and vertical displacement values.

Table 4. Frequency vs horizontal / vertical displacement and tilting

Frequency (hz)	Horizontal Disp. Block 1 (mm)	Horizontal Disp. Block 2 (mm)	Vertical Disp. (mm)	Tilting (degree)
2	0	0	0	0
3	0	0.13	0	0
4	0.68	1.56	0.22	0.6
5	8.6	14.34	3.1	2.72
6	13.07	51.56	2.5	18.8
7	109.67	133.92	5.3	40.35



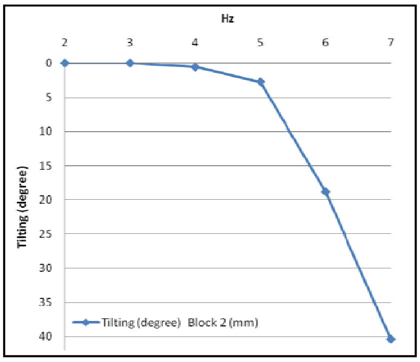


Fig. 13.Horizontal and vertical displacements of the blocks vs frequencies

- As it seen from the Table 4 and Fig.13, the horizontal displacements of the blocks increase while frequency is increasing. This increment is more than when the frequency is greater than 5 Hz (0.38 g for base, 0.52g for block 1 and 0.66g for block 2).
- The vertical displacements and tilting degree also increase while frequency is increasing. Alhough tilting degree continues to increasing, due to the observed very big horizontal displacement (51.56 mm) for 6 Hz, the vertical distance changes become smaller (2.5 mm) than the previous frequency (5 Hz – 3.1mm). Thus, it is more convinient to give tilting degree instead of vertical displacement to specify the vertical damage level of the structure after cycling loading.

4. NUMERICAL RESULTS

In this research, numerical stress–strain analyses were performed for physical models of block type quay wall. A software program that uses the finite-element method (FEM), PLAXIS V8.2, was utilized for a selected frequency of the models as 5 Hz. Fifteen noded, triangular, 2D plane-strain elements were used in the FEM model. The analyses were performed in the time domain, and nonlinear soil behavior was considered. Mohr Coulomb Model was used for modeling the dynamic behavior of the granular material. FEM analyses were performed for only one horizontal shaking as an input, which had displacement amplitude of 3 mm and a frequency of 5 Hz. The input motion, which was obtained by an accelerometer during the test, was applied at the bottom of the finite-element model. Ten-seconds acceleration records were used as input motions. Horizontal displacements obtained by using the Plaxis program and 1 g shaking table tests for 5 Hz for block 1 and block 2 in 10 sec. are shown in Fig. 15 and Fig. 16.

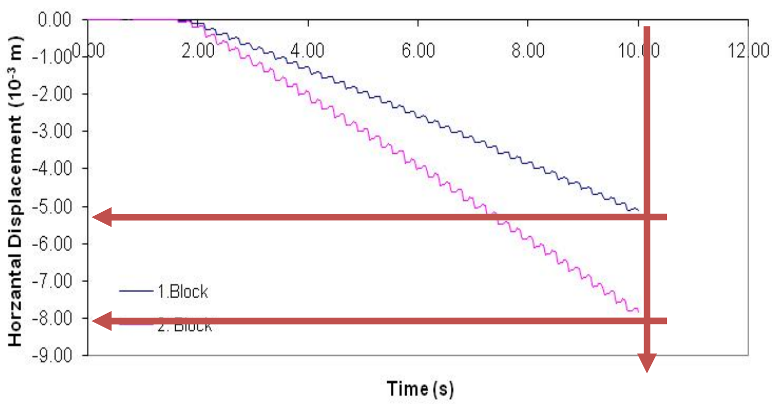


Fig. 15. Horizontal displacement for block 1 and block 2 by using Plaxis program for 5 Hz

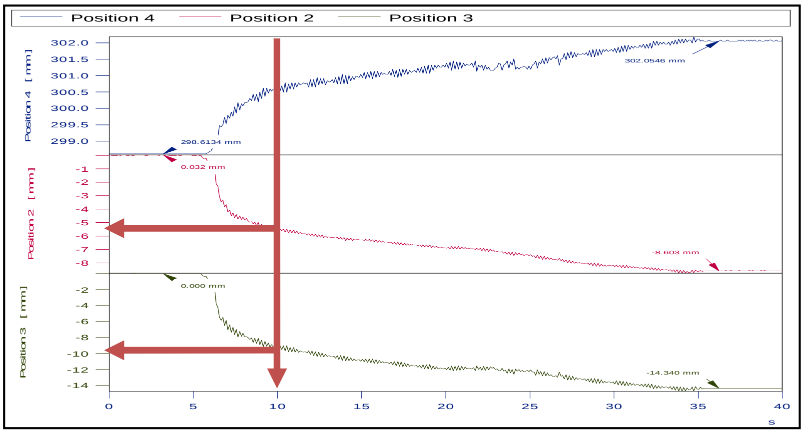


Fig. 16. Horizontal displacement for block 1 and block 2 by using 1 g tests for 5 Hz

The horizontal displacement for block 1 is aproximately 5.2 mm for Plaxis program and aproximately 5.3 mm for 1 g shaking table test. The horizontal displacement for block 2 is aproximately 7.8 mm for Plaxis program and aproximately 9 mm for 1 g shaking table test.

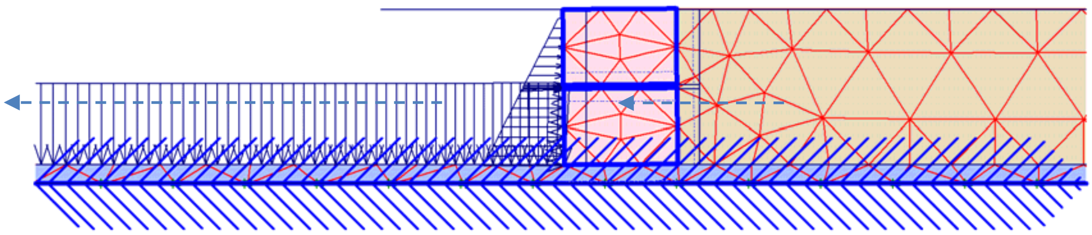


Fig. 17. Blocks positions after cycling loading by using Plaxis program

5. CONCLUSION

The value of deformations; horizontal and vertical displacements, tilting are analyzed by using the experimental and numerical methodologies. The obtained results from both experimental and numerical results are compatible to each other.

The system consists of four basic elements, namely: rigid blocks (in this study two blocks were modelled) – backfill, subsoil, water and earthquake. Due to complicated interaction couplings between these elements -soil behavior; soil-structure interaction; soil – fluid interaction- under cyclic loading on block type quay wall, 6 different frequencies namely, 2Hz, 3 Hz, 4 Hz, 5 Hz, 6 Hz, 7Hz sinusoidal base motions with constant amplitude perpendicular to the coast direction were used to perform 1g shaking table tests.

The cycling loading duration was selected as 30 s and it was almost equal in all tests. Based on the similitude relations, it is corresspondent to a seismic event with time duration of approximately 90 s in the real scale (scale: 1/10). The main aim of this study is to determine the seismic distribution of the lateral earth pressure acting on block type quay walls thus effects of the block dimensions were omitted during this study.

In this research, a two-dimensional (2D) reference model has been developed to simulate seismic performance of block type-type quay walls in a rational way. Nonlinear time history analysis has been conducted with this 2D plain strain analysis model using the computer program Plaxis V8.2. FEM analyses were performed for only one horizontal shaking as an input, which had displacement amplitude of 3 mm and a frequency of 5 Hz. The input motion, which was obtained by an accelerometer during the test, was applied at the bottom of the finite-element model. Ten-seconds acceleration records were used as input motions.

And it is realized that;

- The horizontal displacements of the blocks increase while frequency is increasing. The vertical displacements and tilting degree also increase while frequency is increasing.
- The max / average values of the blocks (block 1 and block 2) accelerations are always greater than the max / average values of the base acceleration
- Block 2 accelerations are always greater than the block 1 and base accelerations and block1 accelerations are always greater than the base accelerations .
- Max. fluctuating component of lateral earth pressure versus depth figures for all frequencies show that dynamic effect of the soil increases while depth is increasing however at certain depth this component value begins to decrease till bottom of the block. It is realized that, this certain depth is generally between 0.4 H – 0.6 H.
- The lateral earth pressures, accelerations displacements are measured by using 1g shaking table tests. And these obtained experimental results were compared with the numerical results (Plaxis program). Range of the lateral earth pressures obtained by using Plaxis program and 1g shaking table tests are similar and
- Comparions of the horizontal displacements obtained by using Plaxis and 1g shaking table tests are shown in Table 5. In this study, experimental results coincide with the numerical results for block 1 and experimental results are greater then numerical results, nearly 4 cm, for block 2. The scale effects of 1 g shaking table tests and the assumed soil parameters used in Plaxis can cause this differency.

Table 5. Comparisons of horizontal displacements results

	Horizontal Displacement Block 1		**Horizontal Displacement Block 2**	
Methods	**Model**	**Prototype**	**Model**	**Prototype**
PLAXIS	5.2 mm	164.42 mm	7.8 mm	246.64 mm
1G Shaking Table Test	5.3 mm	167.58mm	9 mm	284.58 mm
Differences	0.1 mm	3.16 mm	1.2 mm	37.94 mm

REFERENCES

Ashford, S. A. , Sitar, N., 2002, “Simplified method for evaluating seismic stability of sttep slopes”, *Journal of Geotechnical and Geoenvironmental Engineering* 128 (2), 119-128

Bhasin, R., Kaynia, A.M., 2004, “Static and dynamic simulation of a 700-m high rock slope in western Norway*, Engineering Geology* 71, 213-226.

Kramer S.L., (1996), “Geotechnical Earthquake Engineering”, Editor; Hall W.J. 653 sayfa, ISBN 0-13-374943-6.

S. S. Torisu, J. Sato., I. Towhata, T. Honda (2010), “1g model tests and hollow cylindrical torsional shear experiments on seismic residual displacements of fill dams from the viewpoint of seismic performance-based design” *Soil Dynamics and Earthquake Engineering* 30 (2010) 423-437.

Yuksel, Y., Alpar, B., Yalciner, A.C., Cevik, E., Ozguven, O., Celikoglu, Y., 2002, “ Effects of the eastern Marmara Earthquake on marine structures and coastal areas”, *Proceedings of the Instution of Civil Engineers, Water & Maritime Engineers* 156, June 2002, Issue WM2, pages 147-163