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Dynamic responses of two blocks under dynamic loading using experimental and numerical studies

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ABSTRACT

Block type quay walls are one of the most generally used type of gravity quay walls however seismic risks of this kind of structures have not already received the proper amount of attention. In this study, stability of block type quay wall which consists of two concrete blocks is investigated experimentally and numerically. 1 g shaking table tests are used for experimental study. Model scale is 1/10 and model is placed on rigid bed to ignore damage due to foundation deformation. Two different granular materials (Soil 1 and Soil 2) which have different nominal diameters are used as backfill materials to understand the effect of nominal diameters on structure's stability. During the experiments accelerations, pore pressures, soil pressures and displacements are measured for two blocks under different cycling loadings. Soil pressure test results are presented in non-fluctuating and fluctuating components to determine the distribution and application point of the fluctuating component on two blocks. By using experiment results, the friction coefficients between the rubble-block and block-block are determined and compared with recommended friction coefficients in standards. PLAXIS V8.2 software program is used for numerical study to determine the material properties.

1. Introduction

Block type quay wall is the simplest type of gravity quay wall, which consists of blocks of concrete or natural stone placed from the waterside on a foundation including a layer of gravel or crushed stone on top of each other. After placing, the blocks a reinforced concrete cap is placed as cast in situ. Block walls require much building material however labor necessity is relatively little. The height of this structure exceeds 20 m. It is important to have a good filter structure behind the wall to prevent the leakage of soil. This filter structure should involve thick filling of rock fill material with a good filter structure (CUR [1]).

Block type quay wall is one of the most important gravity quay walls which would suffer during earthquakes; however, this truth is known clearly, seismic risk of this kind of structures have not studied in depth, yet.

Fig. 1 shows the typical section of block type quay wall.

Blocks maintain their stability through friction between themselves and between the bottom block and the seabed. Typical failure modes during earthquakes involve seaward displacement, settlement, and tilting of blocks.

The evidence of damage to gravity quay walls suggests that (PIANC [2]):

1. most damage to gravity quay walls is often associated with significant deformation of a soft or liquefiable soil deposit, and, hence, if liquefaction is an issue, implementing appropriate remediation measures against liquefaction may be an effective approach to attaining significantly better seismic performance;
2. most failures of gravity quay walls in practice result from excessive deformations, not catastrophic collapses, and, therefore, design methods based on displacements and ultimate stress states are desirable for defining the comprehensive seismic performance; and
3. overturning/collapse of concrete block type walls could occur when tilting is excessive, and this type of wall needs careful consideration in specifying damage criteria regarding the overturning/collapse mode.

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 İzmit Bay and north-west Turkey had been seriously affected from this earthquake. Especially, earthquake was caused crucial damage

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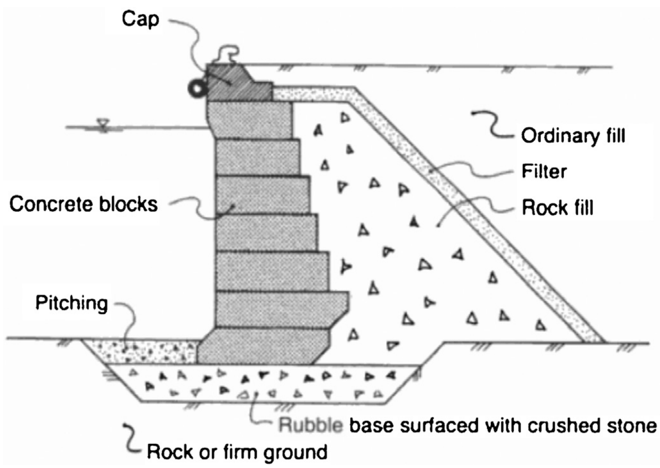

Fig. 1. Typical section of block type wall.

mostly on block type quay walls at Derince Port in İzmit (Yüksel et al. [3]).

The design of block type quay walls should be performed considering stability, serviceability and safety as well as economy. Conventional seismic design methodology is generally used for block type quay walls. However, this traditional design method cannot provide the required design data and also cannot provide any information about the performance of the structure after dynamic loading (Karakus [4]).

Sumer et al. [5] prepared an inventory including the observations of damage to marine structures caused by liquefaction in August 17, 1999 Eastern Marmara Earthquake. According to this study, backfills behind quay walls and sheet-piled structures were almost invariably liquefied; quay walls and sheet-piled structures were displaced seaward; storage tanks near the shoreline were tilted; there were cases where the seabed settled, and structures settled and collapsed. Furthermore, in Tuzla Port, the block type quay wall was displaced seaward by O (40 cm) and backfill settled by O (10 cm). There was no direct evidence of liquefaction (i.e., no sand boils) in this area.

Sadrekarimi et al. [6] investigated both static and dynamic behavior of hunchbacked gravity quay wall by using the 1 g shaking table tests for various base accelerations on models with different subsoil relative densities. The results revealed that (i) negative back-slope (elevations below the breaking point of the hunch) reduces the lateral earth pressure however positive back-slope (elevations above the breaking point of the hunch) increases the lateral earth pressure, (ii) relative density of sea bed affected the movement of the wall significantly, the wall moved more with large acceleration when the sea bed was softer, (iii) if the model was exposed to same earthquake again, due to the subsoil densification less wall movement was observed, (iv) application point of the lateral thrust fluctuated within the mid-third of wall's height (v) larger the height provided safer area behind the wall.

Sadrekarimi [7] studied seismic displacement of broken-back quay walls by shaking table model experiments. Sadrekarimi [7] tried to estimate the sliding displacements of structure by using an improved sliding block model that incorporates the pseudo-static method of Mononobe-Okabe for lateral earth pressures. Chakraborty and Choudhury [8,9] study on the stability of a general no-vertical waterfront retaining wall supporting inclined backfill under earthquake forces and combined action of the earthquake and tsunami forces using limit equilibrium method. The factor of the sliding was computed using pseudo-dynamic approach.

There are several studies which are conducted by numerical and model studies in order to understand the stability of gravity quay wall especially for caisson type quay wall under dynamic loading; Towhata et al. [10], Woodward and Griffiths [11], Ghalandarzadeh et al. [12], Zeng [13], Madabhushi and Zeng [14], Kim et al. [15,16], Choudhury and Ahmad [17,18], Lee [19], Moghadam et al. [20], Maleki and Mahjoubi [21], Na et al. [22], Tiznado and Roa [23], Torisu et al. [24], Dewoolkar et al. [25].

In this study, a block type quay wall which is composed of two blocks are used to understand the dynamic response of these type of structures both experimentally and numerically. By using 1 g shaking test method, block displacements, accelerations, soil pressures are measured. Additionally, friction coefficients between block-block and block-rubble are determined and compared with the values given in literature. Since usage of rock fill material is suggested behind the wall (CUR [1]), granular materials (Soil 1 and Soil 2) are used as backfill material for the first time in such type of experiments. And, experimental study is modeled numerically by using PLAXIS V8.2 software program to define the material parameters.

2. Experimental set-up

In general, three types of laboratory model studies are available for evaluating the dynamic response of structures: the real scaled modeling test, the centrifuge test and 1 g shaking table test.

Real scaled modeling tests investigations are expensive and require the services of a construction contractor in most of the cases. Centrifuge tests can be more reliable than the 1 g tests due to point of reduced stress level which affected the soil behavior significantly. On the other hand, relatively small model scale is recommended for the centrifuge tests since it affects the soil grain size.

In literature, disadvantages of 1 g shaking table tests and solutions suggested are given as;

i. dilatancy of sand and development of excess pore water pressure. *This problem can be solved by compacting sand in the model looser than in the corresponding real-life structure* (Torisu et al. [24]).
ii. It is difficult to simulate the stress–strain behavior of granular soil over a wide range of strain and different confining stress levels. *According to Towhatam (1995)*, "*the density of sand should be reduced in the model scale in order to create a similar type of stress–strain behavior in the lower confining stress level*". "*The value of reduced density is calculated by the formula proposed by Ghalandarzadeh* [12]" (Moghadam et al. [20]).
iii. The boundary effects formed by the physical modeling might affect the responses of the whole model (Moghadam et al. [20]). *According to Dewoolkar et al.* [25], "*If the ratio of backfill length to the wall height is high enough (over 2), then the boundary has no significant effect on the wall structure response*".
iv. Dissipation of excess pore pressure is faster in the model than that of prototype when the pore fluid and soil particles in model and prototype are the same (Yoshimi and Tokimatsu [26]). *According to Ghalandarzadeh* [12], "*Regarding the fast dissipation problem, occurring in excess pore pressure, the input shaking is recommended to be applied in a longer duration time*".

The experimental study is carried out by using 1 g shaking table, which is available in laboratory as a part of infrastructure. In this study above given recommendations are considered to overcome the limitations of this instrument as:

i. granular backfill materials (Soil 1 and Soil 2) are used to reduce the scale effect and significance of pore pressure generation,