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Deformation of breakwater armoured artificial units under cyclic loading

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ABSTRACT

Rubble mound breakwaters usually consist of armour, filter and core layers. The units used in the armour layer are natural rock or concrete. Although natural rock is usually preferred, it is not always possible to apply it. There are some advantages to using concrete units: they have a high stability coefficient under wave attack, and they are easily produced at work sites. Tetrapod and cube blocks are widely used in breakwaters as armour units.

Rubble mound breakwaters are subjected not only to wave activity but also other types of environmental loading, such as earthquakes. Although rubble-mound breakwaters are most likely the most common type of breakwaters, they have received little attention regarding their response to seismic activity. The objective of this study is to present the dynamic response of a breakwater armoured by tetrapods placed by two different placement methods and armoured by cubes during seismic loadings experimentally and numerically. A shaking tank was developed for the experimental study. The breakwater models sit on a rigid bed, and the model scale is 1/50. A one-dimensional shaking tank was used to understand simple responses of the rubble mound breakwaters under seismic loads. The tank allows only one degree of freedom. A raining crane system was developed to achieve the same packing density and porosity for the core material. The shape of the model breakwater before and after the tests was measured using a profiler and was recorded by computer. However, crest lowering and the level of damage on slopes were determined from profiler records. The dynamic responses of the model breakwaters were also investigated using an image processing technique. For numerical simulation, software using finite element method was used.

The results obtained from the experiment and numerical model may help designers build breakwaters armoured by artificial units.

1. Introduction

Breakwaters are marine structures constructed for the safe harbouring of ships, the handling of regular harbour activities and the protection of harbours from sedimentation and coasts from erosion.

Rubble mound breakwaters are the most common type, followed by composite breakwaters. Rubble mound breakwaters usually consist of armour, filter and core layers. The units used in the armour layer are natural rock or concrete. Although natural rock is usually preferred, it cannot always be used because supplying quarry stone for the armour layer may not be possible due to the location of the construction site. Thus, using quarry stone is not economical due to the high transportation cost. Adding to the preference for artificial units is that quarry stones have low stability against wave attacks. There are some advantages to using concrete units. These units have a high stability coefficient, and they are easily produced at work sites. In conventional two-layer systems, various armour units, such as tetrapod, cube, dolos, and tribar, are commonly used. The stability of such breakwaters under wave effects has been the subject of many studies to date. The armouring unit placement method has an important effect on the stability of breakwaters. Sotramer [1] and Gürer [2] studied the effect of the armouring unit placement method on the stability of tetrapod breakwaters under wave loading.

Rubble mound breakwaters are subjected not only to wave actions but also other types of environmental loadings, such as earthquakes. Although there are numerous studies regarding the response of these breakwaters under wave effects, investigations concerning their seismic response are limited. However, it is known that some breakwaters can be seriously damaged even under earthquakes of medium magnitude. The design of coastal structures should take into account the most relevant factors in each case, including seismic loading. Earthquakes may cause destructive loading in many areas around the world and should be considered in the design of coastal structures, especially in areas of high seismicity. If the breakwaters settle due to an earthquake, the overtopping waves will be more sensitive in harbour installations and distract operations, and they may damage the crown

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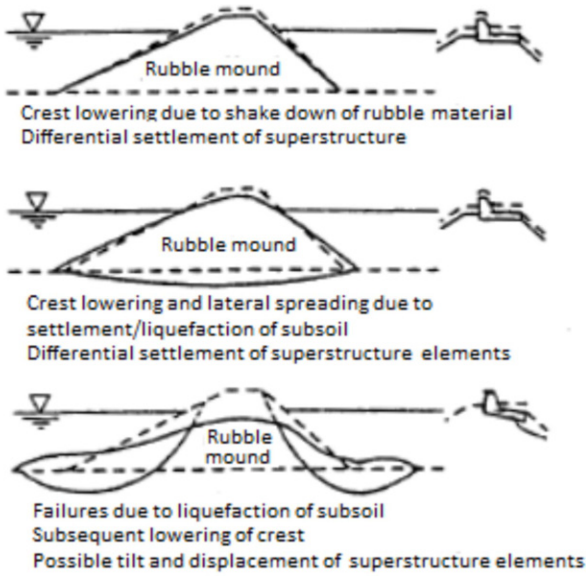

Fig. 1. Typical failure modes for rubble mound breakwaters [3].

structure and leeside quays. For this reason, the effect of earthquakes on breakwaters must be taken into account during their design.

Typical failure modes induced earthquake are shown in Fig. 1. Although damage criteria for breakwaters have not been defined completely, the performance grade is described by PIANC [3]. The damage levels for various kinds of breakwater are as follows:

- reduce wave penetration in basins (Grade C),
- recreational (access for people) (Grade C; but can be A or B depending on the level of acceptable human life safety),
- provision of berthing on the port side of the breakwater and related access roads (Grade B), and
- provision of cargo handling facilities on the breakwater, including conveyor belts (Grade B), and pipelines for oil and liquid gas (Grade A or S, depending on the level of threat of explosion).

As can be seen in Fig. 1, there are two significant mechanisms causing the damage of breakwaters. One of them is the settlement on structure's body and sliding on slope without liquefaction on subsoil, the other is settlement and sliding with liquefaction on subsoil.

However, it is difficult to estimate the relative importance of these mechanisms on the damage. Generally breakwaters did not show serious damage unless they sit on soft subsoil. In case of soft soil on sea bed, ground improvement methods can be applied before construction. There are some applications to improve subsoil layer against liquefaction risk.

Some examples of the failure of rubble mound breakwaters due to seismic loading have been reported in previous studies. Memos [4] investigated the stability of rubble mound breakwaters under seismic activity using physical and mathematical modelling. Their investigation included two breakwater models: the first was placed on a rigid bed, the second on loose sand. They stated that soft foundation soil played a dominant role in the seismic response of such breakwaters and led to high residual deformation. Yüksel et al. [5] investigated the effects of the Eastern Marmara Earthquake of 17 August 1999 on marine structures and coastal areas. In their study, damage to a rubble mound breakwater protecting the Karamürsel Ereğli fishing harbour was determined according to measurements made after the earthquake. It was found that the breakwater settled under the seismic effect. Yüksel et al. [6] studied the seismic responses of the rubble mound breakwater and presented some preliminary results for the physical models of the rubble mound sitting on a rigid foundation.

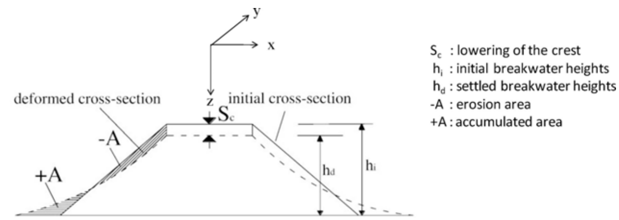

Fig. 2. Cross section of breakwater.

Cihan et al. [7] performed an experiment on a rubble mound breakwater structure consisting of a core material and armoured with cubes under cyclic loading. Cihan and Yuksel [8] investigated deformation-induced cyclic loading on conventional rubble mound breakwaters. They explained damage to a conventional breakwater during cyclic loading experimentally and numerically. Cihan et al [9] studied the seismic response of homogenous rubble mound breakwaters experimentally and numerically. Although the previous studies attempted to understand the behaviour of the natural rock, the response of the concrete materials under cyclic load is poorly understood.

The objective of this study is to present the dynamic response of a breakwater with tetrapods placed using two different placement methods and cube blocks during cyclic loadings experimentally and numerically. For simplicity, this study only takes the effect of the former mechanism into account on the damage rather than the latter (liquefaction). Every earthquake and subsoil conditions may not cause liquefaction on subsoil. Therefore, the determination of the input parameters needed to define the breakwater material for numerical simulations becomes relatively straightforward. An experiment was performed for breakwaters, which consist of a core material and are armoured with tetrapods applied with different placement methods and cubes at different cyclic frequencies. The material properties of the tetrapod and the cube blocks were determined numerically and compared with natural rock properties. For this purpose, software that solves the problem using finite element methods was used. The results obtained from this study will be useful for designers to take into account the effect of dynamic loading.

2. Experimental study

The modelled breakwater sits on a rigid bed, and the model scale is 1/50. The slopes of the models are 1/2. The crest height is 60 cm and the crest width is 40 cm. The nominal diameters of the tetrapods and cubes are $D_n = 4.55$ cm and $D_n = 5.00$ cm, respectively. Armour layer width is two times that of D_n. The grain-size distribution of the core material (D_{85}/D_{15}) is 1.38 according to the filter rule. In Fig. 2 a typical cross section of breakwaters before and after earthquake is shown. As can be seen, one of the dimensions of the breakwater (y-axis) is very long with respect to others (x, z-axis). Due to the relatively lower possibility of damage occurring along the y-axis, the damage along this axis may be ignored. Hence, a one-dimensional shaking tank is used to determine the simple responses of the breakwaters under cyclic loads.

This tank allows only one degree of freedom (Fig. 3). The shaking tank has a length of 4.5 m, a width of 1.0 m and a depth of 1.0 m. The water depth is 0.40 m in the tank for all models. Additionally, a laying system was developed to achieve the same packing density and porosity for the core material for each test. The porosity of core material was 45%.

The dynamic responses of the two different breakwater models with tetrapods placed according to the two different placement methods and breakwaters with cubes having a toe were investigated. In the first placement method (Case 1), one leg of the tetrapod is directed inwards and is at a right angle to the breakwater slope. For the second method (Case 2), the tetrapod is identical to that of the first layer. In