Stability of High Density Cubes on Breakwater Roundheads

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ABSTRACT
Due to the three-dimensional flow field formed by the diffraction and refraction effects of waves in breakwaters, the stability of the armour layer of roundheads is more critical than the trunk sections. For this reason, roundheads require heavier units or a gentler slope. In this research, the stability of breakwater roundheads consisting of high-density cube blocks in a single layer under the influence of wind and swell waves was examined.

INTRODUCTION
The roundhead is a critical section of a rubble-mound breakwater in terms of armour unit stability. The wave-structure interaction at the breakwater roundheads differs from the wave-structure interaction in the trunk section due to the curvature and discontinuity in this section of the structure, and the three-dimensional flow structure has an effect on the stability of the structure. It is not only under the direct influence of waves but also due to the energy component arising from the diffraction effect of the wave. This complex wave structure interaction can only be evaluated with three-dimensional wave tests in a wave basin. For this reason, there are relatively few systematic studies in the literature compared to breakwater trunk studies.
In practice, the recommendations of Hudson (1959) and CIRIA (2012) are taken into consideration. Hudson (1959) proposed different stability coefficients (KD) for the breakwater trunk section and roundhead. In CIRIA (2012), instead of using different equations for breakwater trunk and breakwater roundhead calculations, it was also suggested that the stone weight in the head section should be taken as 1.5-2.0 times the stone weight used in the trunk section.
To date, some of the main studies on the stability of the breakwater roundhead are; Carver and Heimbaugh (1989), Vidal et al. (1991), Matsumi et al. (1996), Burcharth and Hughes (2002).
Moreover, the effect of the density of concrete blocks has been investigated by only a very few studies in the past. In order to get more information about the density influence of concrete blocks, further experiments have been recommended in the literature.
Normal concrete density is 2.4 t/m^3, but increasing the density of units (for the same loading conditions) will reduce the required size of the armour units according to stability formulas.
High density concrete elements may be preferred for various reasons, such as it is very difficult to find large rock material and it may also not economical to use normal density concrete armor units. Ito et al. (1994), Van Gent et al. (2001), Hoe and Cox (2018) and Yuksel et al. (2022) did some experiments with high concrete blocks.
In this study, the stability of the armour layer consisting of a single row of high density cube blocks at the breakwater head is investigated and presented.

EXPERIMENTAL SETUP AND PROCEDURES
The experimental study was carried out in the wave basin established in the “Hydrodynamics Research Laboratory” at YTU. The wave basin has dimensions of 28.84×36.40 m^2 and the maximum depth is 2.20 m (Figure 1). The wave generator is capable of producing regular, irregular, long-crested and short-crested (directional) waves. The wave generator has an active reflection compensation system.
Normal and high-density concrete cube armor unit breakwater models for a roundhead were tested to provide insight into their behavior. The nominal diameters for both normal and high density cube models were 40 mm to avoid scale effects. Concrete densities in the tests were 24.0 kN/m^3 and 31.5 kN/m^3 for normal and high-density cube armour units, respectively. The breakwater model was placed on a horizontal foreshore. The breakwater slope was 1:1.5. Two different packing densities of the blocks were kept 69 and 60 % by using the single layer regular placement method (Figure 2). The three-dimensional breakwater roundhead model plan is shown in Figure 3. Seven wave probes were placed around the breakwater model. Four of these probes were placed just in front of the breakwater for reflection analysis.
The water depth was 0.60 m. A total of 10 irregular wave conditions with a JONSWAP spectrum were selected for the tests. Before each test series the structure was rebuilt. Each test lasted about 1000 waves. The relative damage (N_0) was determined by using a visualization technique; before and after each run, digital photos were taken from a fixed location perpendicular to the slope.

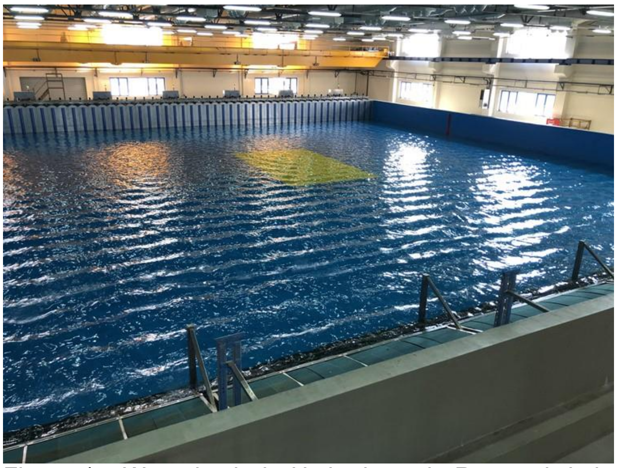

Figure 1 - Wave basin in Hydrodynamic Research Lab. (HRL) at Yildiz Technical University (YTU)

CONCLUSIONS
Although movement at the breakwater roundhead starts earlier than at the breakwater trunk section, cube block tests are agreed with previous results.

It has been observed that the regularly placed cube block breakwater roundhead with 69 % packing density is quite stable under the influence of wind and swell waves with average peak wave steepness S_p= 0.034 and 0.013, respectively. Although movements were observed earlier in the swell wave, more movements were detected in the wind wave effect. It has been observed that mobility started in the front sectors of the roundhead in wind waves, and while the blocks do not move in the last sector (135^0-180^0), swell waves are more effective in the sectors behind the roundhead section.

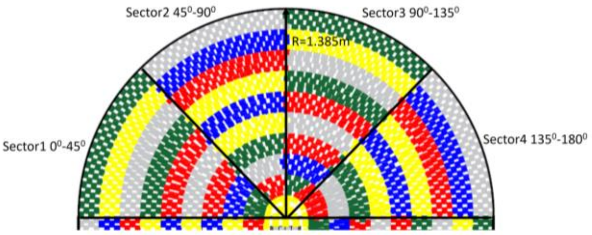

Figure 2 - Placement with 69 % packing density

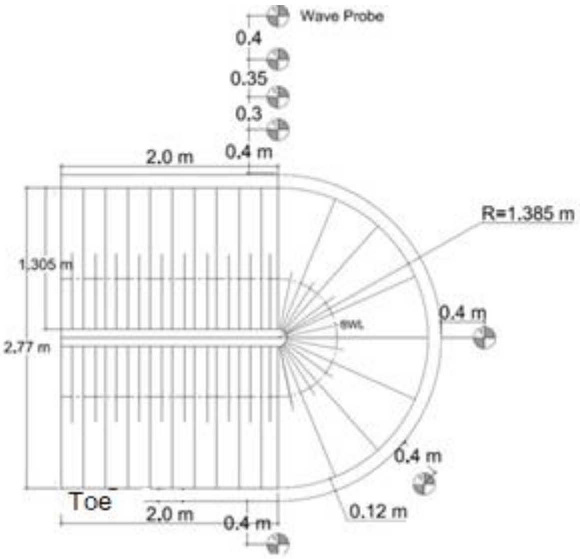

Figure 3-Three-dimensional breakwater model roundhead plan

The experimental results show that the stability of high density blocks were found to be more stable and the damage initiation for high density blocks started at higher stability numbers compared to normal density cubes.

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