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Damage pattern and damage progression on breakwater roundheads under multidirectional waves

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ABSTRACT

An experimental model test study is carried out to investigate damage pattern and progression on a rock armoured breakwater roundhead subjected to multidirectional waves. Concerning damage pattern, the most critical sector is observed to shift leeward with increasing wave period. Taking angles relative to mean wave direction, the critical sector is observed in the sector 10°–55° for short waves and in the sector 100°–145° for long waves. A probabilistic approach is developed to predict for one typical roundhead geometry the damage distribution depending on the incoming waves and structural characteristics. The damage progression is observed dependent on significant wave height and peak wave period, but not on the directional spreading and the spectral width of the incident waves. Combining the results of both damage pattern and damage progression, a stability formula for the distribution of damage over the roundhead is developed. Thus the formula also considers the shifting of the critical sector due to increasing wave period which existing formulae do not include. Finally, analysing the damage produced by double peaked spectra, it is shown that the armour may be designed by the formula when using the total significant wave height and an equivalent peak period.

1. Introduction

The roundhead is a critical section of a rubble-mound breakwater in terms of armour unit stability. In fact the roundhead requires armour units that are significantly larger than on the trunk. This is due to an energy concentration at the roundhead caused by the combination of refraction, diffraction and shoaling but mainly due to the lack of support from neighbour armour units, and the large overflow velocities. Moreover, the stones are less interlocked and, if displaced, they are moved towards the rear side, failing to provide any residual stability to the section.

Over the last decades, many experimental studies have provided a deeper knowledge on roundhead stability, investigating the effect of the main hydraulic and structural parameters. Vidal et al. (1989, 1991), carrying out experiments using concrete cubes, observed that wave steepness has no effect on the occurrence of the start of damage, but has a noteworthy influence on damage progression. The same influence was observed by Madrigal and Lozano (1992) and by Berenguer and Baonza (1999). Carver and Heimbaugh (1989) observed that, for rock and dolos units, the minimum of stability occurs for a specific value of Iribarren number. The results obtained by Matsumi et al. (1996) evidenced that the spatial correlation of velocity magnitudes around the roundhead is much stronger under long waves than under short waves. Burcharth et al. (2003) identified a suitable parameter, given by a combination of H_s, T_m and D_n, to characterize the threshold for damage initiation. A large number of authors, e.g. Jensen (1984), Vidal et al. (1991), Madrigal and Lozano (1992), Berenguer and Baonza (1999), Matsumi et al. (2000), and Burcharth et al. (2003), identified the effect of incident wave angle by observing that the most critical part of the roundhead is always in a sector between 90° and 150° from the wave mean direction. Maciñeira and Burcharth (2008) also observed for a cube armoured roundhead the critical sector to be from 90 to 135° in most of the tests. However, they observed the same damage in the sectors 45–90° and 90–135° for waves with peak wave steepness above 0.04. For head radius less than 12 D_n the difference in damage between sectors also was reduced. Systematic investigations performed by Matsumi et al. (1994, 1996, 1998, 2000) evidenced that the load applied to armour units increased with the directional spreading of the waves. No significant differences in roundhead stability between different types of armour units can be seen for roundhead stability in the investigations by Madrigal and Lozano (1992), who compared Accropodes and parallelepipedic blocks, and Berenguer and Baonza (1999), who compared antifer blocks and hollowed cubes. Jensen (1984), instead, found that interlocked units are more stable than massive units of the same mass but suggested, like Burcharth and Thompson (1983) and Burcharth et al. (2003), that increasing mass density is a much more efficient way to improve stability. Finally, the effect of roundhead radius at sea water level R

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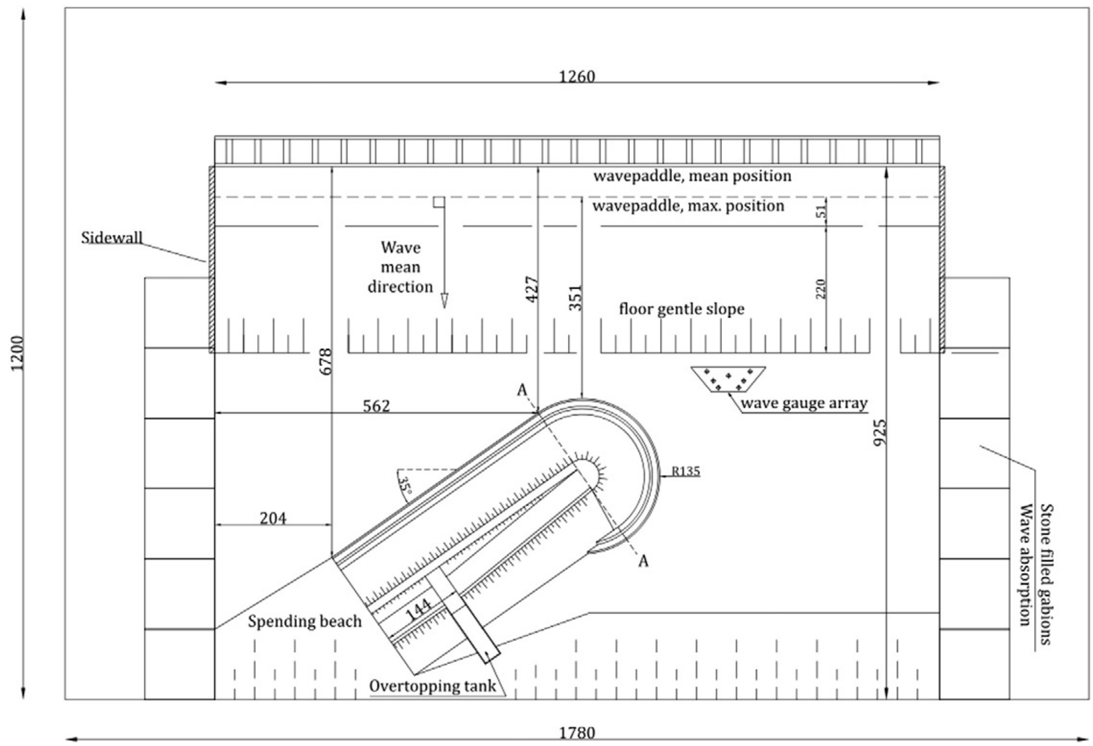

Fig. 1. Layout of the roundhead model (measures in centimetres).

has been investigated by Jensen (1984), who observed that stability increases if the radius increases. Moreover, Vidal et al. (1989) and Losada et al. (1990) suggested that the dimensionless ratio R/L between radius and wave length is a suitable parameter to investigate the effect of diffraction and refraction on roundhead stability. The influence of radius was further studied by Maciñeira and Burcharth (2007) who concluded that the residual stability between start of damage and failure decreases with decrease in radius, but the effect was not found to be linear with the radius. In case of long period waves, they found a larger radius to have higher residual stability (7% in case of 1:2 slope and 14% in case of 1:1.5 slope), while in case of short-period waves and steeper slopes, the behaviour was found to be opposite.

Many systematic investigations were also carried out to develop stability formulae, i.e. equations used to design the minimum mass of armour units required for stability. In general, the stability formulae developed for trunk sections may not be applied for roundheads, unless some of the parameters are modified to take into account the major brittleness of the roundhead compared to the trunk. For instance, the Hudson formula (United States Army Corps of Engineers, 1984) provides lower K_D values for roundhead than for trunk section. There exist also stability formulae specifically developed for roundheads, that eventually consider the damage level D among the variables defining the mass of armour units. By using this type of formulae, the designer can decide the acceptable damage level that is supposed to take place under the design sea state conditions. However, being the damage level D not homogeneous along the roundhead, most of the stability formulae proposed in literature (Berenguer and Baonza, 1999; Maciñeira and Burcharth, 2007) just consider the damage level in the critical sector, i.e. to the most damaged sector.

The formula of Berenguer and Baonza (1999) (Eq. (1)) was developed by analysing roundheads armoured with cubes and BCRs (antifer cubes), with slope angle 1:2, under unidirectional waves. The formula of Maciñeira and Burcharth (2007) (Eq. (2)), instead, was developed considering cube armoured roundheads having slope angles 1:1.5 and 1:2, both under unidirectional and directional waves. Moreover, Berenguer and Baonza divided the roundhead in three sectors

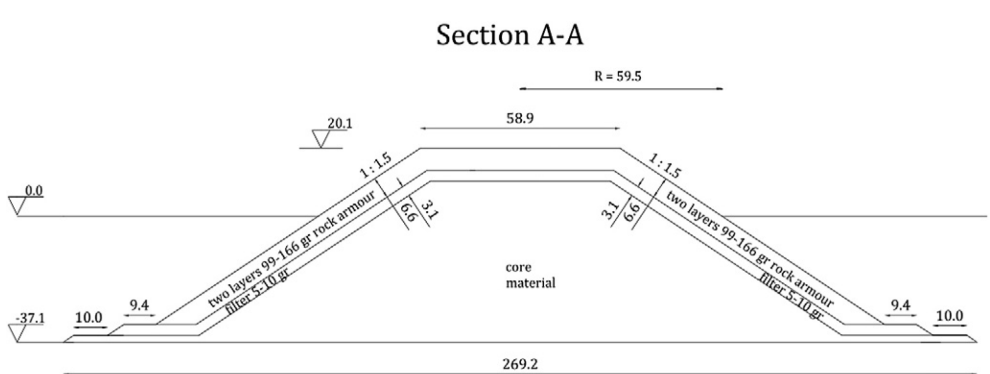

Fig. 2. Roundhead section (measures in centimetres).