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Armor stability of hardly (or partly) reshaping berm breakwaters

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ABSTRACT

This paper deals with stability of hardly (or partly) reshaping berm breakwaters. A simple physical argument is used to derive a new stability formula based on the assumption that the maximum wave force causing damage of armor layer is proportional to the maximum wave momentum flux near the structure toe. The main goal of the present paper is to provide an estimation technique based on this physical principle to predict the deformation of the front slope in terms of the eroded area. The proposed method is verified by comparison with model test data. It is found that by using the maximum wave momentum flux approach the damage to the front slope (eroded area) can be very well predicted. Moreover, a simple method to estimate the eroded area based on measured or calculated berm recession (*Rec*) and depth of intersection of reshaped and initial profile (h_f) is presented. The performance of the simple method based on measured data of *Rec* and h_f is better than the presented stability equation based on wave momentum flux parameter. When using the best prediction formulae for recession and depth of intersection the simple method and the momentum flux stability equation provide similar uncertainty.

1. Introduction

Berm breakwaters have successfully been constructed to protect harbors from rough seas. They have been introduced in the early 1980s as mass armored reshaping structures. Lately the design philosophy has changed to multi-layered less reshaping structures (Icelandic type). The design philosophy of berm breakwaters aims at optimizing the structure with respect to wave load, possible yield from an armor stone quarry, available equipment for construction and the function of the breakwater.

Berm breakwaters are divided into different categories based on the reshaping and on the construction method. PIANC (2003) gave a classification based only on reshaping behavior. Sigurdarson and van der Meer (2012) introduced a new classification of berm breakwaters based on the structural behavior, such as hardly reshaping, partly reshaping, and fully reshaping when exposed to design waves.

The initial idea of the berm breakwater was to construct the berm with simple construction equipment from one wide armor stone class (mass armored). Due to the construction method a seaward slope angle close to the natural angle of repose (about 1:1.25) was typically used. The mass armored berm breakwaters are constructed with a berm that is allowed to reshape into an S-shape profile (Fig. 1). The most relevant damage parameter for these structures is the recession of the berm (*Rec*).

However, during the structural lifetime the reshaping process might cause high stone velocities leading to breakage and abrasion of individual stones and thereby reduced stability. The question is therefore to which degree reshaping can be allowed based on the ability of the stones to withstand crushing and/or abrasion when rolling or sliding on the structure (stone quality). However, another important issue with fully reshaping structures is that a significant longshore transport can occur in oblique waves. For these reasons dynamically stable berm breakwaters with frequent stone movements have to be avoided.

The Icelandic berm breakwater concept have several stone classes with the largest stones placed in the top part of the berm where they add most to the overall stability (Fig. 2). It leads to a very stable but also more complicated cross-section. In the Icelandic berm breakwaters slopes of 1:1.25 and 1:1.3 were used up to the middle of the 90s, but since then the front slope has mainly been 1:1.5 as it is significantly more stable than the very steep slopes. The Icelandic berm breakwaters have been designed as hardly (or partly) reshaping structures with a quite narrow berm. It has been successfully constructed at several locations throughout the world. The initial damage to berm breakwaters designed as hardly or partly reshaping is not well characterized by berm recession (*Rec*) as the reshaping might develop similar damage in conventional rubble mounds, cf. Fig. 2.

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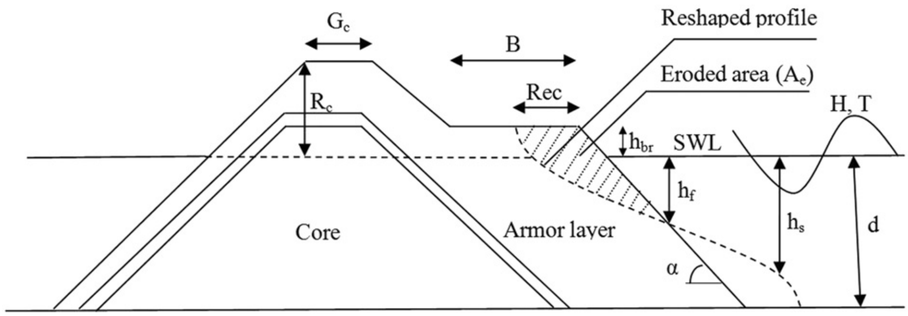

Fig. 1. Illustration of front slope erosion in reshaping berm breakwater.

2. Stability classification of berm breakwaters

The main governing dimensionless parameter in relation to the stability of berm breakwaters are the following:

$$H_o = \frac{H_s}{\Delta D_{n,50}} \text{ (The stability number)} \tag{1}$$

$$T_o = T_m \sqrt{\frac{g}{D_{n50}}} \text{ (The stability number)} \tag{2}$$

where, H_s = incident significant wave height, Δ = relative buoyant density ($\Delta = \frac{\rho_a}{\rho_w} - 1$), ρ_a = density of stone, ρ_w = density of water, D_{n50} = median stone diameter ($D_{n50} = (\frac{M_{50}}{\rho_a})^{1/3}$), g = gravitational acceleration, M_{50} = median stone mass and T_m = mean wave period.

Table 1 shows the new classification for berm breakwaters, including indicative values for the stability number ($H_o = Hs/\Delta D_{n50}$), the damage parameter ($S_d = A_e/D_{n50}^2$) related to the eroded area (A_e) and the berm recession (Rec/D_{n50}). These values are given for a 100-year wave condition. For wave conditions with smaller return periods the values will be smaller and consequently, for more severe wave conditions, like overload tests, the values may be larger (Sigurdarson and van der Meer, 2012).

3. Existing stability assessment tools for berm breakwaters

Several researchers have given methods and formulae to assess the stability of berm breakwaters. The most common approach has been to describe the stability by the berm recession (*Rec*) which is a key parameter describing the deformation of fully reshaping berm breakwaters (Fig. 1). Failure of a fully reshaping berm breakwater is typically defined as *Rec* > *B*, where *B* is the berm width (PIANC, 2003).

Different experimental and numerical models have previously been applied to estimate the stability of berm breakwaters, e.g., Van der Meer (1988, 1990, 1992), Hall and Kao (1991), Norton and Holmes (1992), Van Gent (1995, 1996), Tørum (1998), Tørum et al. (2003, 2012), Sigurdarson et al. (2008), Lykke Andersen and Burcharth (2009), Moghim et al. (2011), Moghim and Alizadeh (2014), Lykke Andersen et al. (2012, 2014). Two formulae given for calculating the berm recession to investigate the stability of berm breakwater are given in Appendix A. The initial damage to hardly (or partly) berm breakwaters is in some cases quite different to what is predicted by the usually applied recession formulae. Moreover, the recession formulae typically have quite large scatter in the area with initiation of damage.

Stability assessment of hardly (or partly) reshaping berm breakwaters might alternatively be assessed by the methods for conventional rubble mound breakwaters, e.g., Van der Meer (1988, 1990, 1992) and Melby and Hughes (2003). One thing that should be noticed on this regard is that these methods are developed only for statically stable straight slopes without a berm. As the berm is typically very permeable and berm level is much lower than the crest of conventional structures, it might be important to include the effect of berm height (h_{br}) and find a new stability relation for hardly (or partly) reshaping berm breakwaters. Also the front slope of berm breakwaters is in many cases steeper than in conventional structures. Therefore, the structure hydraulic interaction has to be considered when applying these formulae to berm breakwaters.

The proposed methods for conventional rubble mound breakwaters by Van der Meer (1988, 1990, 1992) and Melby and Hughes (2003) are presented in the following.

3.1. Van der Meer (1988)

The Van der Meer (1988) rock armor formula for static stability breakwater and non-overtopped conventional rubble mound structures reads:

For plunging waves ($\xi_{om} < \xi_{om,cr}$):

$$\frac{H_s}{\Delta D_{n50}} = 6.2 p^{0.18} \xi_{om}^{-0.5} \left(S_d / \sqrt{N} \right)^{0.2}. \tag{3}$$

For surging waves ($\xi_{om} > \xi_{om,cr}$):

$$\frac{H_s}{\Delta D_{n50}} = 1.0 p^{-0.13} \xi_{om}^{p} \sqrt{\cot\alpha} \left(S_d / \sqrt{N} \right)^{0.2}. \tag{4}$$

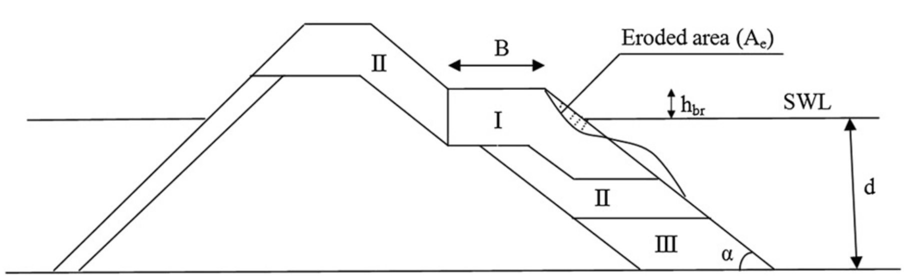

Fig. 2. Illustration of front slope erosion in Icelandic berm breakwater (hardly or partly reshaping berm).