Applied Ocean Research 53 (2015) 23–30

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Wave overtopping on reshaping berm breakwaters based on wave momentum flux

Mohammad Navid Moghim [a,*], Razieh Forouzan Boroujeni [b], Mahmoud Mohammad Rezapour Tabari [b]

[a] Department of Civil Engineering, Isfahan University of Technology, P.O. Box 84156, Isfahan, Iran
[b] Department of Civil Engineering, Faculty of Engineering, Shahrekord University, P.O. Box 115, Shahrekord, Iran

ARTICLE INFO

Article history:
Received 12 November 2014
Received in revised form 23 May 2015
Accepted 22 July 2015
Available online 5 August 2015

Keywords:
Wave overtopping
Wave momentum flux
Berm breakwater

ABSTRACT

In this paper, a new wave overtopping formula on reshaping berm breakwaters is derived based on the assumption that the maximum wave momentum flux at the toe of the structure is proportional to the maximum wave run-up and the excess wave run-up overhead the crest of structure can lead to overtop the water over the structure. Wave momentum flux is a physically relevant descriptor of wave forcing having units of force. The first part of Lykke Andersen experimental data were selected randomly for which 80% were used to extend new formula to calculate wave overtopping in reshaping berm breakwaters and 20% were used to validate the generalization accuracy of the new formula as a second part of data. Finally, a comparison is made between predicted overtopping formula by the present study and formulae given by other researchers. The comparison shows that the overtopping predicted by the new formula has a good correlation with the experimental data compare to the other researchers and it can provide an estimation technique that is at least as good as existing formulae for the present experimental data.

.1. Introduction

Breakwaters are the structures constructed to provide protection of the port and harbor facility from dynamic forces of the ocean waves. Berm breakwaters are rubble mound structures initially constructed with a large porous berm above or at still water level at the seaward side. During wave attack, the berm breakwater will typically reshape into an S-shaped profile. Wave forces on individual armor units are smaller for the reshaped berm breakwater than for the non-reshaped breakwater [1]. The berm breakwater concept is basically rather old, but was not used very much until it was "reinvented" in the early 1980s, when a slope protection for an airfield runway extending into the sea in the Aleutian Islands, Alaska was designed [2]. A berm breakwater is usually designed to make an optimum use of the available quarry material and relatively simple construction equipments. The stone gradations will typically be rather wide to get almost 100% utilization of the quarry material [3]. Fig. 1 shows the typical initial and reshaped profiles of the cross section and deformation parameters of a reshaping berm breakwater.

The safety of the coastal regions against flooding largely depends on the performance of the coastal protection structures against wave attacks and storm surges. In the recent years, due to the effects of climate change, the intensity and duration of storms have increased [4]. Therefore, safe design of coastal protections has become more important. Parameters governing the design of coastal structures are divided to hydraulic, structural and Geotechnical parameters. Wave overtopping is one of the main hydraulic parameters of structures. Therefore this parameter must be considered in the design of coastal structures. When run-up level exceeds the crest height, waves overtop the structure. The evaluation of the overtopping discharge is normally related to the evaluation of wave run-up on the structure.

The research on overtopping of some kinds of conventional rubble mound breakwaters and dikes has led to some widely used simple regression models that are based on empirical expressions fitted to hydraulic model test results and there is no method to calculate the wave overtopping base on the physical concept and wave-structure interactions. In this paper, it is tried to find a good estimation of wave overtopping on berm breakwaters with reshaped profile by using the wave momentum flux parameter that is a proper description of the wave forces and wave-structure interactions. The main goal of the recent paper was to prepare an estimation technique that is at least as good as existing formulae

* Corresponding author. Tel.: +98 31 3391 38 41; fax: +98 31 3391 27 00.
E-mail address: moghim@cc.iut.ac.ir (M.N. Moghim).

0141-1187/$ – see front matter
http://dx.doi.org/10.1016/j.apor.2015.07.008

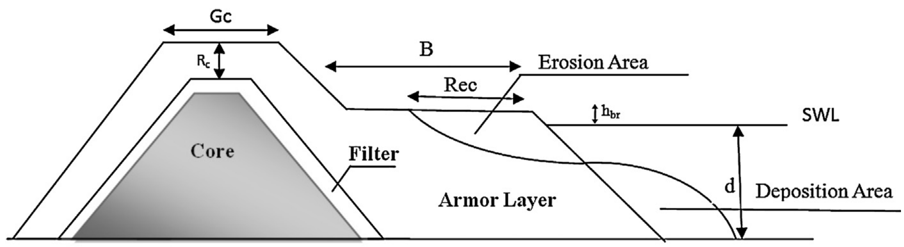

Fig. 1. Definition of cross sectional and deformation parameters of a reshaping berm breakwater.

to predict the wave overtopping in reshaping rubble mound berm breakwaters.

2. Previous work on wave overtopping

Several empirical formulae to calculate wave overtopping on reshaping berm breakwaters have been obtained. In the following these formulae are presented.

2.1. TAW

It might be expected that the overtopping discharge on reshaped berm breakwater profiles should be well predicted by the overtopping formula of Van der Meer and Janssen [5] developed for dikes. This formula were later slightly modified and presented by TAW [6] which was also reported in EurOtop manual [7] as the following for berm breakwaters:

$$\frac{q}{\sqrt{gH_{mo}^3}} = \min \begin{cases} \dfrac{0.067}{\sqrt{\tan\alpha}}\gamma_b\xi_0 \exp\left(-4.75\dfrac{R_c}{H_{mo}}\dfrac{1}{\xi_0\gamma_b\gamma_f\gamma_\beta\gamma_v}\right) \\ 0.2\exp\left(-2.6\dfrac{R_c}{H_{mo}}\dfrac{1}{\gamma_f\gamma_\beta}\right) \end{cases} \quad (1)$$

TAW [6] gives the overtopping discharge at the outer crest line, and it is assumed that this overtopping also reaches the rear of the crest, which is a very rough assumption. In this equation q is the mean overtopping discharge per meter structure width ($m^3/s/m$), R_c is the crest freeboard which is the vertical distance from SWL to the crest, H_{mo} is the significant wave height based on frequency domain analysis, g is the acceleration due to gravity, ξ_0 is the breaker parameter ($\xi_o = \tan\alpha/\sqrt{S_{mo}} = \tan\alpha/(gT_m^2)$), T_m is the wave period, α is the slope angle, γ_b is the reduction factor for a berm, γ_v is the reduction factor for a vertical or nearly vertical crown wall, γ_f is the reduction factor for roughness and permeability and γ_β is the reduction factor for wave direction [6].

2.2. CLASH NN-model

CLASH project was developed a neural network model to calculate wave overtopping [8]. The neural network model must be regarded as state of the art in estimating average overtopping discharges, as it is based on approximately 10,000 overtopping tests with all kinds of structures without considering the effect of stone diameter and reshaped profile parameter on wave overtopping. The reliability of this model is very much dependent on the amount of available data for the specific structure in the training process of the neural network. Consequently, very accurate estimations are given for most conventional rubble mound breakwaters, but much less reliable for complex geometries with fewer available data, as berm breakwaters and etc. [8].

2.3. Lykke Andersen

Lykke Andersen carried out experiments to obtain a semi-empirical equation to estimate the wave overtopping on homogeneous rubble mound berm breakwaters. He considered the effect of parameters such as sea state conditions, storm duration (number of wave attack), armor stone diameter and water depth in his equation and proposed the following formula to calculate wave overtopping [9]:

$$\frac{q}{\sqrt{gH_{mo}^3}} = 1.79\times10^{-5}\left(f_{Ho}^{1.34}+9.22\right)S_{op}^{-2.52}\exp\left(-5.36\left(\frac{R_c}{H_{mo}}\right)^{0.92} -0.61\left(\frac{G_c}{H_{mo}}\right)^{1.39} - 0.55h_{b*}^{1.48}\left(\frac{B}{H_{mo}}\right)^{1.39}\right) \quad (2)$$

where S_{op} is the deep water peak wave steepness, G_c is the width of armor in front of eventual crest element, B is the berm width, h_{br} is the water depth above berm elevation (negative if berm is elevated above SWL), $H_0 = H_{mo}/\Delta D_{n,50}$, $T_0 = \sqrt{g/D_{n,50}}T_{0,1}$, $T_{0,1}$ is the mean wave period based on frequency domain analysis, and

$$h_{b*} = \begin{cases} \dfrac{3H_{mo}-h_{br}}{3H_{mo}+R_c} & \text{for} \quad h_{br} < 3H_{mo} \\ 0 & \text{for} \quad h_{br} \geq 3H_{mo} \end{cases} \quad (3)$$

$$f_{Ho} = \begin{cases} 19.8\exp\left(-\dfrac{7.08}{H_0}\right)S_{0m}^{-0.5} & \text{for} \quad T_0 \geq T_0^* \\ 0.05H_0T_0 + 10.5 & \text{for} \quad T_0 < T_0^* \end{cases} \quad (4)$$

$$T_0^* = \frac{19.8\exp(-7.08/H_o)S_{om}^{-0.5} - 10.5}{0.05H_0} \quad (5)$$

2.4. Sigurdarson and Van der Meer

Sigurdarson and Van der Meer introduced the general overtopping formula for steep smooth and rough slopes that they can also represent overtopping of berm breakwaters with similar reliability. Summarizing, overtopping for berm breakwaters can be calculated by [10]:

$$\frac{q}{\sqrt{gH_{mo}^3}} = 0.2\exp\left(-2.6\frac{R_c}{H_{mo}\gamma_{BB}\gamma_\beta}\right) \quad (6)$$

With:

(7)$\gamma_{BB} = 0.68 - 4.5S_{op} - 0.05\frac{B}{H_s}$ for HR and PR

$$\gamma_{BB} = 0.68 - 9.0S_{op} \quad \text{for FR} \quad (8)$$

γ_{BB} is a factor based on a new classification of berm breakwaters to take into account the structural behavior of berm breakwaters. Based on Table 1 three degrees of reshaping are defined [10]:

- Hardly reshaping berm breakwater, HR.
- Partly reshaping berm breakwater, PR.
- Fully reshaping berm breakwater, FR.