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Wave parameters after smooth submerged breakwater

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ABSTRACT

Based on the experimental studies of smooth submerged breakwater in the wave channel, it has been studied how the breakwater impacts on the changes of representative wave periods when the waves cross the breakwater. It has been shown that the reduction of the wave periods has a strong relationship with the wave steepness and relative submersion R_c/H_{m0-i}. Also, the impact of waves crossing the smooth submerged breakwater onto the Rayleigh's distribution of wave heights was investigated.

The influence of short and long waves generated after submerged smooth structure on temporal analysis has been investigated. The Lanczos filter was used for high and low frequency wave removal. It was concluded that long and short waves do not significantly influence the temporal analysis of periods.

The Van der Meer et al. (2000) model for the description of the transmitted spectrum has been improved so it gives better agreement with measurements. It was assumed that transfer of the energy from lower to higher frequencies vanishes linearly with a decrease in the relative submergence $-R_c/H_{m0}$. The energy transferred to higher frequencies is assumed as uniformly distributed between $1.5f_p$ and $3.2f_p$.

1. Introduction

It is usual in the calculation of run up, overtopping, morphological changes and reflection from perforated seawalls to use the characteristic heights and periods of incoming irregular waves. If any mentioned coastal structure is defended by smooth submerged structures, it is important to calculate the modified wave parameters after the submerged breakwater. Considering that low crested structures are mostly permeable (rubble mound), the results of this work cannot be used as general findings, but can contribute to a general knowledge of such structures.

When the waves cross the breakwater, the process of wave breaking and the nonlinear interaction process between the components of the wave spectrum occur. Nonlinear interactions between wave components cause a transfer of wave energy from primary harmonics to higher harmonics of the wave spectrum. The amount of energy transferred depends on the incoming wave parameters, breakwater geometry and water depth. Beji and Battjes (1993) observed wave energy amplifications at high frequencies as waves propagate over a submerged bar in a laboratory experiment. They found that bound harmonics are amplified during the shoaling process and released in the deeper water region after the bar crest. In the process of transition across the breakwater the nonlinear behaviour of waves and a deviation from Gaussian as well as Rayleigh distribution occur. Zou and Peng (2011) found that wave skewness as a primary wave nonlinearity indicator varies across a submerged bar. Their results show that wave skewness decreases slightly above the seaward slope, increases rapidly up to a maximum value above the structure crest, and then decreases above the leeward slope to the value close to incident. Based on the measurements of the surface elevations in the wave channel, this paper proves that, at a certain distance from the breakwater, transmitted surface elevations have Gaussian distribution and wave heights behave according to Rayleigh's distribution (Sections 2 and 3).

The general conclusion of the works of Goda et al. (1974), Tanimoto et al. (1987), Raichlen et al. (1992) is that when the waves cross the breakwater with a low positioned crown, mean spectral wave periods are reduced by 60% in relation to the incoming mean wave periods. Goda et al. (1974) found for emerged breakwater that reduction of mean wave periods depends on relative submergence R_c/H_{m0} and zero freeboard periods are reduced by approximately 30%. The general conclusion is that the transfer of energy to higher harmonics of the wave spectrum causes a transformation of zero crossing and spectral wave periods. Therefore, this study will deal with the impact of breakwater submergence and incident wave parameters on the transformation of wave periods (Section 4).

Hamm and Peronnard (1997) have investigated the influence of high-frequency turbulent fluctuations and low-frequency waves on the accuracy of temporal analysis. They concluded that high-frequency waves could significantly harm the calculation of periods in the nearshore area. Using the same algorithm as Hamm and Peronnard (1997), this work investigates the influence of the short and long waves

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generated when waves cross the submerged bar on the temporal analysis (Section 4).

Van der Meer et al. (2000), conducted tests on emerged smooth breakwaters and reached the conclusion that mean spectral wave period is reduced by up to 40% in relation to the incoming mean wave period. Based on measurements, they developed a very crude model for calculating transmitted energy spectra, where they proposed that 40% of spectrum energy is positioned at frequencies between $1.5f_p$ and $3.5f_p$, and 60% of energy at $f < 1.5f_p$. Van der Meer et al. (2005) confirmed that model experimentally on emerged and submerged structures. The main weakness of this model is that energy transfer to higher harmonics is independent of incident wave parameters or construction geometry. In this work the improvement of the Van der Meer et al. (2000) model was made based on the conclusion that the energy fraction transferred to high frequencies is variable with submergence and reaches the published value 40% (Van der Meer et al., 2000, 2005) when the breakwater crest is around water level. Based on a linear approximation of the value of this fraction and on the assumption that energy is uniformly transferred to the frequency range ($1.5f_p$–$3.2f_p$) a satisfactory description of the mean period reduction over smooth impermeable breakwater is obtained (Section 5). The paper by Briganti et al. (2003) studies the impact of transmission coefficients of wave height on the transfer of energy from lower to higher harmonics. They introduced a parameter named energy density parameter (e.d.p.), which describes how much energy is transferred to higher frequencies in the process of wave transmission. In this work the e.d.p. was used to detect the submergence at which the transition of energy to higher frequencies starts/ends (Section 5).

By developing an analytical calculation model, the process of wave transmission and spectral change over a permeable low-crested breakwater is described in the papers of Lamberti et al. (2007) and Zanuttigh and Martinelli (2008). In these works the authors developed an analytical model for emerged low-crested breakwaters able to predict transmitted wave spectrum based only on incident wave conditions and structure geometry. The proposed model is based on a combination of wave transmission through (filtration) and over the structure (overtopping).

This paper represents an extension of an endeavor to develop relatively simple analytical models for the calculation of transmitted spectra. The subject is on (very) large wave transmission, which is an extension of earlier works with emerged and zero freeboard structures.

The objectives of the paper are the following: (1) to show that away from the breakwater, waves behave as a Gaussian process and according to Rayleigh's distribution (independent propagation of components, Sections 2 and 3), (2) to quantify the effect of superharmonics generation, i.e. spectral broadening and mean period reduction (Section 4) and (3) to improve the analytical Van der Meer et al. (2000) model in the area of large wave transmission coefficients (submerged breakwater).

2. Laboratory measurements

Laboratory tests were conducted by piston wave generator using the active wave absorption control system (AWACS). At the end of the channel was the dissipation chamber which gives a maximum reflection coefficient of 0.2 for the longest wavelengths from Table 1. The wave channel width was 1 m, the height was 1.1 m, and the depth of water in the channel was $d_1 = 0.4$ m and $d_2 = 0.446$ m. The submerged breakwater model was made of wood, the crest width being $B = 0.16$ m and the slope 1:2 (Fig. 1). The measurements were performed for two submersions of the wave crown ($R_{c1} = 0.055$ m and $R_{c2} = 0.101$ m) achieved by changing the depth of the water in the channel ($d_1 = 0.4$ m and $d_2 = 0.446$ m). Measurements were performed in conformity with Table 1 for each depth, totaling in 18 measurements. Time duration for an experiment amounts to ~5 min, which is approx. 300 waves per experiment, pursuant to the recommendations from Journée and Massie (2001). The acquisition of the data was performed with a sampling frequency of 40 Hz.

2.1. Data processing

Capacitive gauges G1–G6 were used for measuring surface elevation. The measured data were processed according to two methods: spectral (frequency domain) and zero-crossing (time domain).

According to the spectral principle, spectral wave parameters were established as: H_{m0}, $T_{0,2}$ and T_p (defined in the list of symbols at the end). The incident wave parameters were determined by separating the incoming and the reflected spectrum on the gauges G1–G3, and transmitted wave parameters by separation on the G4–G6 gauges. The Zelt and Skjelbreia (1992) method was used for separating the incident from the reflected spectrum.

The zero-crossing wave parameters H_{max}, $H_{1/10}$, $H_{1/3}$, H_m, H_{rms}, $T_{1/3}$ and T_z have been defined by up-zero crossing method for incident and transmitted surface elevation time series, determined by two approaches:

(a) inverting the FFT of the incident and the transmitted spectrum defined by procedure described in the previous paragraph;
(b) wave record from gauge G1 was assumed to be an incident wave and wave record from G4 a transmitted one. This approach is used to extract Figs. 2b, 7 and 8.

In the temporal domain, surface elevation time series were then processed to remove low-frequency waves using a high-pass filter with a cut-off frequency equal to half the peak incident wave frequency. The next step was the removal of high-frequency waves from the same time series using a low-pass filter with cut-off frequencies of $3.5f_p$ and $1.5f_p$. This way time series for approaches (a) and (b) were obtained and both include: (1) time series without any filtering (no filt),

Table 1
Wave parameters measured in laboratory obtained from Zelt and Skjelbreia's (1992) separation method, the target was the standard JONSWAP spectrum ($g = 3.3$, $s_1 = 0.07$, $s_2 = 0.09$).

$R_{c1} = -0.055$ m							$R_{c2} = -0.10$ m						
Test	Measured incident			Measured transmitted			Test	Measured incident			Measured transmitted		
	H_{m0-i} [m]	$T_{0,2-i}$ [s]	T_{p-i} [s]	H_{m0-t} [m]	$T_{0,2-t}$ [s]	T_{p-t} [s]		H_{m0-i} [m]	$T_{0,2-i}$ [s]	T_{p-i} [s]	H_{m0-t} [m]	$T_{0,2-t}$ [s]	T_{p-t} [s]
1.	0.060	0.66	0.68	0.040	0.65	0.80	10.	0.062	0.66	0.69	0.053	0.69	0.80
2.	0.058	0.72	0.81	0.041	0.65	0.80	11.	0.065	0.72	0.81	0.055	0.72	0.85
3.	0.055	0.85	1.01	0.041	0.69	0.98	12.	0.064	0.85	1.01	0.057	0.80	0.98
4.	0.099	0.81	0.89	0.051	0.73	0.91	13.	0.103	0.81	0.89	0.076	0.80	0.98
5.	0.096	0.92	1.10	0.055	0.77	1.07	14.	0.105	0.92	1.10	0.081	0.85	1.07
6.	0.089	1.15	1.45	0.058	0.85	1.42	15.	0.106	1.15	1.45	0.084	0.93	1.42
7.	0.121	0.89	0.99	0.058	0.79	0.98	16.	0.126	0.89	0.99	0.087	0.85	0.98
8.	0.113	1.01	1.24	0.062	0.82	1.16	17.	0.127	1.01	1.24	0.091	0.89	1.28
9.	0.104	1.32	1.68	0.066	0.95	1.71	18.	0.126	1.32	1.68	0.094	1.01	1.71