RECONSTRUCTION OF THE TRASMITTED WAVE SPECTRA BEHIND A SUBMERGED SMOOTH OBSTACLE

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INTRODUCTION

The presence of a submerged obstacle (sand bar or breakwater) induces a reduction of the transmitted wave energy mainly due to wave breaking dissipation. Moreover, the spectral shape behind such obstacles changes from the incoming one. An energy transfer towards higher frequencies, with respect to the peak frequency f_p, is observed due to the non-linear interactions that occur during the passage over the bar for both random (Beji & Battjes, 1993) and regular waves (Losada et al., 1997).

Van der Meer et al. (2000) studied the spectral change behind a low-crested structure. They found that 40% of the energy in the transmitted wave spectra was in the range 1.5f_p-3.5f_p. This energy transfer was assumed to be independent of the incident wave parameters and the breakwater geometry.

In the present work, an experimental campaign was carried out to study the influence of the main wave/geometry parameters in the spectral energy distribution behind a submerged obstacle and to more accurately reconstruct transmitted wave spectra. Such analysis can be useful for the phenomena which are more influenced by the shape of the transmitted wave spectrum, as the evaluation of the wave run-up in the case of protected beaches.

EXPERIMENTAL SET-UP

The experiments were carried out in the wave-flume of Laboratorio di Idraulica e Costruzioni Marittime of Università Politecnica delle Marche (Ancona, IT). The experimental set-up is shown in Figure 1.

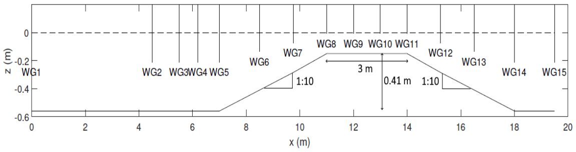

Figure 1 - Experimental set-up of the tested submerged bar.

A smooth submerged trapezoidal bar was constructed, with an upslope and a downslope of 1:10 and a 3m horizontal crest. The height of the horizontal plane section was 0.41m above the flume bottom. The free surface was measured at fifteen stations along the flume (WG1-WG15). The incoming and the transmitted wave spectra are evaluated at WG2 and WG15, respectively. JONSWAP spectra were generated with different peak periods T_p, wave heights H_s and structure freeboards R_c.

RESULTS

First, the analysis of the evolution of the energy density spectrum when waves propagates over the obstacle and the effect of different wave parameters on this transformation were performed. During the passage over the bar, a shift of energy towards higher frequencies occurs, due to the interactions between the harmonic components that generate waves with frequency equal to the sum of the frequencies of the interacting waves. For higher waves, the evolution of the wave spectrum is dominated by wave breaking that dissipates the overall wave energy. The wave period has a strong influence on the nonlinear transformation of waves. Wave breaking causes the distribution of wave energy over a wider range of higher frequencies and favours the generation of low frequency waves in the energy spectra (Figure 2).

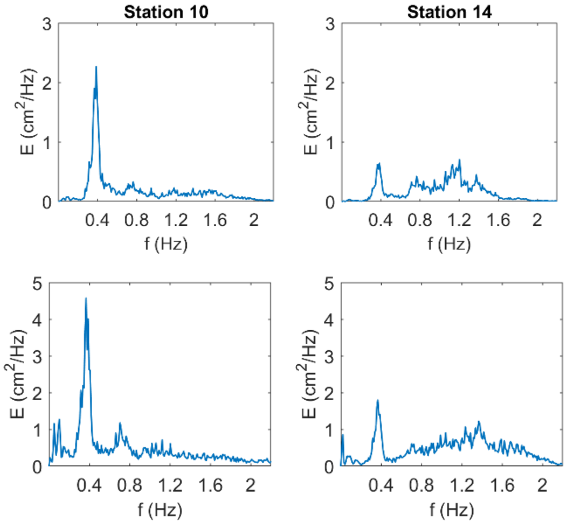

Figure 2 - Wave spectra transformation over and behind the submerged bar for non-breaking wave (upper panels) and breaking wave (lower panels)

In order to study the effect of sea level rise, the propagation of random waves over the submerged bar was also studied by changing the bar submergence. If the submergence increases, the energy is distributed over a shorter range of higher frequencies. However, the effect of the increased submergence is different for nonbreaking and breaking waves. For non-breaking waves the spectral peak of the primary component decreases less in terms of spectral density with the increased water depth and less energy is shifted to higher frequencies because the nonlinear interactions become non resonant. For breaking waves, the intensity of wave breaking is reduced with the increased water depth. Therefore, the dissipation of the primary component is less intense and consequently more energy is available for non-linear couplings between frequencies. As a consequence, the frequencies multiple of the primary show higher spectral peaks at station 14 even if the energy is still distributed over a shorter range at higher frequencies. The submergence of the bar also influences the generation of low frequency waves in the energy spectra. The smallest water depth leads to more severe wave breaking which favours the development of infragravity waves.

The transfer of energy to higher frequencies is mainly influenced by the structure submergence and by the peak period. On the other hand, the incident wave height has a smaller effect. Therefore, we have found that the amount of energy transferred to frequencies higher than 1.5f_p is well related to a non-dimensional parameter which is a function of the ratio between the structure submergence *Rc* and the wavelength associated to the peak period L_p and the ratio between the water depth h at the structure toe and the incident wave height $H_{m0,i}$ (see Figure 3). This non-dimensional parameter is also well correlated with the transmitted energy at frequencies higher than 2.5fp and 3.5fp.

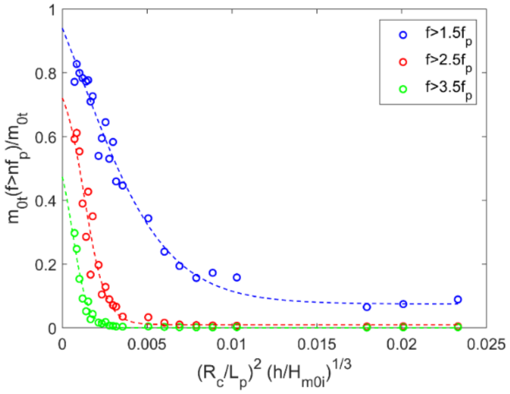

Figure 3 - Ratio of energy transferred to frequencies higher than 1.5f_p or 2.5f_p or 3.5 f_p vs a non-dimensional parameter.

Therefore, the ratio between the energy of the spectrum at frequencies higher than 1.1 times the peak frequency [$m_0(f>1.1f_p)$] and the total energy of the spectrum (m_0) is used to reconstruct the spectral shape. This ratio can be represented by a hyperbolic tangent function. The equations for the coefficients depend on f/f_p and are obtained by a step-by-step data fitting.

The maximum frequency for the calculation is chosen equal to 5.5f_p. From the area of the spectrum at each frequency interval we can reconstruct the transmitted spectrum.

From experimental data, Equation 1 was found to accurately describe the transmitted spectrum:

$$\frac{m_{0t}(f>1.1f_p)}{m_{0t}} = A + B\,tanh\left(C\left|\frac{L_p}{R_c}\right|^2\left(\frac{H_{m0i}}{h}\right)^{1/3} - D\right) \qquad (1)$$

where the coefficients depend on f/f_p.

In Figure 4 the present method and the method of van der Meer et al. (2000) are applied to two wave conditions. Both methods give appreciable results for shorter waves (panel *a*). When the wavelength further increases (panel *b*), the new approach is able to more adequately represent the transmitted wave spectrum.

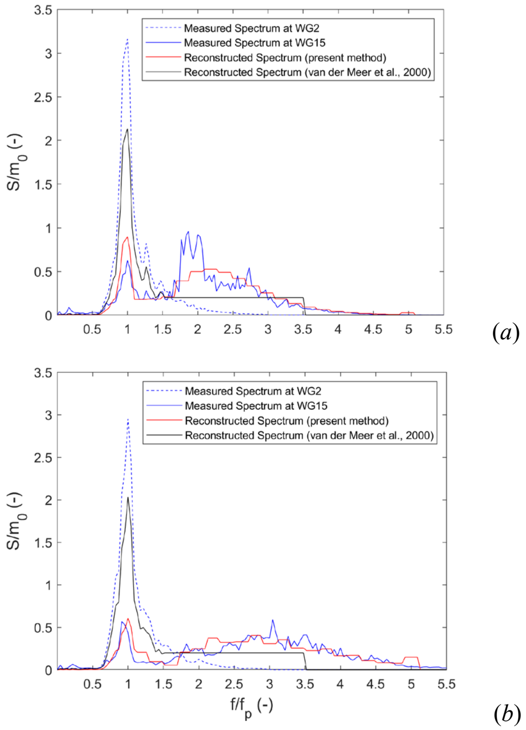

Figure 4 - Comparison between the measured normalized spectrum S/m_0 (blue line) and the spectra obtained by the present method (red line) and by the van der Meer et al. (2000)'s method (black line). R_c=-0.10m, H_s=5cm, T_p=2.0s (panel *a*) and T_p=2.5s (panel *b*).

Further analysis is required to extend the validity of the method to account for the generation of long waves in the transmitted spectrum and to extend the method to different geometries and roughness.

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