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Sea wave energy transmission behind submerged absorber caissons

Pasquale Filianoti [a,*], Riccardo Piscopo [b]

[a] Dipartimento di Ingegneria Civile, dell'Energia, dell'Ambiente e dei Materiali (DICEAM), University Mediterranea of Reggio Calabria, Loc. Feo di Vito, 89122 Reggio Calabria, Italy
[b] Dipartimento di Meccanica, Matematica e Management (DMMM), Politecnico di Bari, Via Orabona 4-70125 Bari, Italy

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ABSTRACT

The REWEC1 is a submerged caisson breakwater for protecting coasts which remains on the seabed typically 2 or 3 m below the sea surface. The breakwater performs an "active" defence, in that it is able to absorb a share of the incident wave energy.

The work shows an original method to estimate the energy transmission behind the breakwater, considering both the wave reflection and the energy dissipation due to the wave breaking over the breakwater and the wave energy absorption.

Results confirm that the REWEC1 is a good system for protecting coasts. With significant wave heights lower than 2 m, the energy transmission behind the breakwater is limited, thanks to the resonance that maximize the energy absorption by the plant. With higher significant height (> 2 m) the energy transmission behind the breakwater remains limited, thanks to the energy dissipation induced by wave breakings over the roof of caissons.

1. Introduction

Detached breakwaters for coast defence are usually realized by means of rock stones (or concrete blocks) resting on the seabed and having the upper part (crest) which can rise above the mean sea level or to remain below it. Emerged breakwaters present no wave transmission over the structure, whilst frequent overtopping and relatively high wave transmission occurs across low-crested breakwaters. If it is important for recreational and residential coastal developments to minimize the visual intrusion of the structure, fully submerged breakwaters are employed, at the cost of somewhat reduction in the protection supplied to the coast in the lee side. In fact, waves pass over the breakwater with breaking, and higher energy is transmitted over submerged breakwaters than semi-submerged structures.

The effectiveness of a breakwater in attenuating wave energy can be measured by the amount of wave energy that is transmitted past the structure. To this purpose, we will refer to the transmission factor C_T, that is the ratio between the mean wave energy flux transmitted on the landward side of the structure, and the mean wave energy flux of the incident waves on the seaward side of the structure. The bigger the C_T, the smaller the wave attenuation is.

Many numerical modelling and empirical approaches for estimating wave transmission over submerged breakwater have been developed. Several empirical formulas, have been proposed by Tanaka (1976), Ahrens (1987), Van Der Meer (1990), d'Angremond et al. (1996), and Seabrook and Hall (1998). Experimental studies on rigid (impermeable) structures have been carried out also (Dick and Brebner, 1968; Dattatri et al., 1978; Rey et al., 1992; Beji and Battjes, 1993; Stamos et al., 2003; Cho et al., 2004). While numerical prediction of performance of submerged breakwaters have been carried out by Kobayashi and Wurjanto (1989), Rojanakamthorn et al. (1990), Twu et al. (2001), and Rambabu and Mani (2005). This paper investigates the performances of a submerged caisson breakwater embodying a Resonant Wave Energy Converter (REWEC1). The system consists of several caissons in reinforced concrete placed side by side to form a barrier that remains a few meter below the still water level (Boccotti, 2003). Each caisson embodies a device for the energy absorption, which exploits the resonance between incident waves and the water motion in the ducts recovered inside the caisson. In the paper we will estimate the wave energy transmitted in the lee of the breakwater, taking in account the energy reflected towards the open sea by the breakwater, the energy absorbed inside it, and the energy dissipated over its roof.

A theoretical solution for the waves-REWEC1 interaction was achieved by Boccotti (2007) for the emerging breakwater (*i.e.* without energy transmission in the lee side), and it was experimentally verified through a small scale field experiment carried out directly at sea (Boccotti et al., 2007). Here, we calculate the

* Corresponding author. Tel.: +39 0965872954.
E-mail addresses: filianoti@unirc.it (P. Filianoti), riccardo.piscopo@ingpec.eu (R. Piscopo).

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Notation

a	barrier height
A, A'	differential equation coefficient
b	barrier depth
c	height of the plenum
c'	level of the ceiling of the air room below the mean water level
C_g	linear group speed
C_A	absorption factor
C_D	diffraction factor
C_L	dissipation factor
C_R	reflection factor
C_T	transmission factor
d	water depth
D	mean power dissipated per unit horizontal area
E_h	power spectrum of the energy per unit weight
$E_{\Delta p}$	power spectrum of the fluctuating pressure Δp
E	mean energy density
f	friction coefficient
F, F'	differential equation coefficient
F	mean energy flux
F_{L0}	mean energy flux per unit span dissipated over the breakwater roof due to wave breaking
F_{T0}	mean energy flux per unit span transmitted in the lee of the breakwater in ideal flow conditions
F_W	mean energy flux per unit span of incident waves
g	acceleration of gravity
G	Green's function
$G(\omega)$	frequency response function
H	total head
H_m	maximum wave height above which all waves are considered broken
H_{rms}	r.m.s. value of wave height
H_s	significant wave height
I	source strength distribution function
K_{ad}	turbulent flow mean energy losses/laminar flow mean energy losses
$K_{i/o}$	minor losses coefficient
l	length of the vertical duct (including half height of opening duct-plenum)
L	wave length
m	polytropic exponent
N	number of elemental wave components
p	probability
p_a	absolute pressure in the plenum
p_{atm}	atmospheric pressure
Q, Q'	differential equation coefficient
P_{ass}	mean absorbed power
Q_b	fraction of breaking waves
R	hydraulic radius
s	curvilinear abscissa along the streamline
$T*$	time lag of the first local minimum of $\psi(T)$
T_p	peak period of the spectrum of pressure head waves
u	velocity amplitude
$U_{1/3}$	threshold being exceeded by 1/3 wave heights of velocity fluctuations
v	water mean velocity
v_w	water velocity in the vertical duct
Y	hydraulic losses
α	tunable parameter that controls the intensity of the dissipation
Δp_B	pressure fluctuation of waves on the upper opening of the vertical duct
Δp_W	pressure fluctuation of incident waves
ε	phase angle
$\Phi = \Phi_S + \Phi_W$	total velocity potential
Φ_S	velocity potential of scattered waves
Φ_W	velocity potential of incident waves
Γ	immersed surface of the solid body (caisson)
η_{ph}	fluctuating pressure head
ψ	cross-correlation function
ω	frequency
$\overline{\omega}$	mean spectral frequency of the random wave field
σ_v	standard deviation
ζ	height of the air pocket
ζ_0	still water value of ζ

reflected energy by solving the problem of the waves scattered by a rigid submerged body. The velocity potential of scattered waves is calculated in the framework of linear waves using the boundary element method (BEM).

Many factors affect the wave energy dissipation involved in the interaction between waves and submerged breakwaters. The most relevant ones are wave breaking, bottom friction and percolation through the porous structure. The influence of porosity was investigated by many authors using different approaches. Massel and Mei C.C. (1977) developed an analytical theory for random waves impinging on a dissipative breakwater, reducing the random-wave scattering problems to simple harmonic ones whose solutions are known, through the linearization of quadratic loss at the breakwater. Losada et al. (1996) presented a model based on linear superimposition and eigenfunction expansion to evaluate random wave transformation on/within rectangular breakwaters, taking into account the influence of structure geometry, porous material properties and oblique random incident waves. Gu and Wang H. (1992) developed a BEM model based on the linearized porous flow equation, to simulate the wave energy dissipation within submerged breakwaters. Mizutani et al. (1998) proposed a BEM-FEM model modified to simulate the flow inside the porous media and the wave deformation outside it. Koutandos et al. (2006) investigated numerically the effect of permeability on breaking over submerged porous breakwaters with a 2DV numerical approach, revealing that turbulence kinetic energy intensity in the case of lower permeabilities is much lower than in the case of higher permeabilities. Ting and Kim (1994) compared measured experimental data to the theoretical predictions of a linear inviscid model, with the aim to investigate flow separation effects induced by periodic waves travelling over a submerged rectangular obstacle. Iwata et al. (1996) discussed experimentally and numerically the breaking limit and post-breaking wave deformation due to submerged structures.

Being the REWEC1 a smooth (non-porous) structure, the breaking of waves passing over the roof of the structure plays the most relevant role among dissipative phenomena occurring outside the caisson. A common approach to the modelling of wave breaking in the near-shore is to parameterize the breaking process to account for its macro-scale effects. Many of such parametric models are based on the work of Battjes and Janssen (1978), and have been developed and calibrated for beaches (Thornton and Guza, 1983; Baldock et al., 1998). In Johnson (2006), to simulate the wave energy dissipation over submerged breakwater, it was adapted the model of Battjes and Janssen (1978), and it was calibrated against laboratory measurements for submerged breakwaters. The encouraging agreement between the numerical model and the empirical equations proposed in d'Angremond et al. (1996) and