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Mathematical study for analyzing caisson breakwater supported by two rows of piles

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ABSTRACT

The hydrodynamic characteristics of the semi immersed caissons suspending by two rows of piles is experimentally and mathematically studied under normal regular waves. The effect of different wave and structural parameters is investigated e.g. the incident wave length and height, the caisson width and draft and the supporting piles diameter and spacing. The mathematical model based on an eigenfunction expansion method is developed to determine the hydrodynamic characteristics of such structures. In order to examine the validity of the mathematical model, the mathematical results are compared with different experimental and mathematical results. Comparison between experiments and predictions shows that the mathematical model provides a good estimate of the wave transmission, reflection, and energy dissipation coefficients when the lower pile part friction factor is $f_p = 1.0$. The proposed mathematical model gives a reasonable efficiency when compared with the mathematical and experimental results of other similar breakwater models.

1. Introduction

Rubble mound breakwaters are widely used around the world to protect harbors and shorelines from wave attack. Caisson breakwaters may be adopted, when sufficient quantity and good quality rubbles are not available. The both breakwater types are expensive in deeper waters and hence, special type of breakwaters can be invented. This type requires less concrete per unit run, but at the same time, capable of transmitting less wave energy. Since in deeper waters, most of the wave energy is concentrated near the water surface, a structure, which can be effectively intercept and dissipate or reflect this energy, is required.

The partially immersed caisson breakwater helps in dissipating the energy of the sea incident wave and protects shorelines from erosion and wave attack. This type of breakwaters possess desirable features such that maintaining adequate flow exchange between the partially enclosed water body and the open sea and experience slightly less total hydrodynamics force compared with vertical solid breakwater. This type of breakwater minimizes pollution aspects near shores because it permits for exchanging the water mass.

The present investigation has been carried out with the following objectives:

1. To develop a simple mathematical model for estimating the wave transmission, reflection and energy dissipation characteristics due to the proposed structure.
2. To investigate experimentally the same characteristics for different wave and structural parameters.

The study of wave hydrodynamics (wave transmission, reflection and energy dissipation) due to this structure is the key information necessary to understand the hydrodynamic performance of this structure as a special breakwater. The information about wave transmission is essential to select the structure configuration (caisson and supporting piles dimensions and spacing) for a prevailing wave climate once the permissible range of transmission is decided for the protected areas. The wave reflection characteristics are necessary to understand the wave climate at the seaside of the structure; hence the crest level of the structure can be determined.

2. Literature review

The functional performance of the caisson breakwater is evaluated by examining the wave hydrodynamics (wave reflection, transmission and energy dissipation). There is very little material available on the proposed breakwater. There are many experimental and mathematical models were made for determining the efficiency of models similar to the proposed model e.g. one or multiple rows of

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List of notations

The following symbols are used in this paper :

A_n^a, A_n^s	complex coefficients
a	half width of the caisson
B	caisson width
B_n^a, B_n^s	complex coefficients
C_m	added mass coefficient
D	caisson draft
D_n^a, D_n^s	complex coefficients
d	piles diameter
E_i	energy of incident waves
E_r	energy of reflected waves
E_t	energy of transmitted waves;
F_h	excreting horizontal wave force
F_v	excreting vertical wave force
f_p	piles friction factor
G	clear distance between piles
G_1	clear distance between piles in the first row
G_2	clear distance between piles in the second row
G_p	permeability parameter
$G^{\backslash}$	permeability parameter per unit width
g	acceleration of gravity
H_i	incident wave height
H_r	reflected wave height
H_t	transmitted wave height
h	water depth at the breakwater site
k	incident wave number at breakwater site
k_d	energy dissipation coefficient
k_n, k_m	wave number of different wave modes
k_r	reflection coefficient
k_t	transmission coefficient
L	wave length at breakwater site
N	evanescent wave mode number
P	wave pressure
s	inertia coefficient
T	wave period
$X_n(z)$	horizontal eigenfunctions
x, z	two dimensional axis
$Z_n(z)$	vertical eigenfunctions
$\alpha_{n,m}$, $\alpha_{0,m}$	parameters
$\alpha_{n,l}$, $\alpha_{0,l}$	parameters
$\delta_{0,1}$	kroneker delta
ε_p	piles porosity
Φ_p	total flow velocity potential
ϕ_1, ϕ_3	seaward and shoreward velocity potential
ϕ_2	flow velocity potential under breakwater
$\eta(x)$	water elevation at distance x
ω	angular wave frequency

widely or closely spaced piles supporting semi-immersed thin or wide bodies.

2.1. Semi-immersed thin barriers

The efficiency of the thin semi-immersed wall was experimentally and mathematically studied by many researchers. Ursell (1947), Weigel (1960), Reddy and Neelamani (1992), Heikal (1997), and Koraim (2005) carried out experimental studies to determine the efficiency of this type. Lui and Abbaspour (1982) developed mathematical model using the boundary integral equation method for analyzing the interaction between the water wave and the thin vertical barriers. Losada et al. (1992), Abul-Azm (1993), Heikal (1997), and Sahoo et al. (2000) developed mathematical models using the eigenfunction expansion method to determine the efficiency of the thin vertical breakwaters.

2.2. Semi-immersed rectangular fixed or floating breakwaters

Many experimental and developed mathematical models were carried out for protecting shorelines from wave action by floating breakwaters using different breakwater shapes. Carr (1952), Macagno (1953), Wiegel (1964), Sutko and Haden (1974), Mc-Cartney (1985), Mani (1991), Murali and Mani (1997), Tolba (1998), Heikal (2004), Koutandos et al. (2005), Koraim (2005), El-Sharabasy (2011) and Zidan et al. (2012) carried out experimental studies to determine the efficiency of partially immersed or floating bodies. Mathematical studies for determining the performance of the floating breakwaters were studied by Fugazza and Natale (1988), Gesrahab (1995), Tolba (1998), Abul-Azm and Gesrahab (2000), Williams et al. (2000), Koutandos et al. (2002), Koutandos et al. (2004), Gesrahab (2004), Koraim (2005), Behzad and Akbari (2007), Dong et al. (2008) and Rageh and Koraim (2010a).

Rageh and Koraim (2010a) studied mathematically and experimentally the hydrodynamic characteristics of fixed semi-immersed caisson used as breakwater. The mathematical breakwater efficiency was calculated using the eigenfunction expansion method. The results were presented as function of the transmission, the reflection and the wave energy loss coefficients for different wave and structure parameters. El-Sharabasy (2011) and Zidan et al. (2012) examined experimentally the hydrodynamic interaction of regular waves with fixed, semi-immersed single and double rectangular bodies in intermediate and deep water. The influence of incident wave characteristics and certain geometric characteristics on the breakwater efficiency were examined. This efficiency was presented as a function of the transmission and reflection coefficients.

2.3. Suspended structures on piles

The performance of suspended structures on piles was studied by different authors. Neelamani and Rajendran (2002a, 2002b) and Neelamani and Vedagiri (2002) studied the wave transmission, reflection and energy dissipation characteristics of T-type, ⊥-type and partially immersed twin vertical barriers using physical models. Regular and random waves with wide ranges of wave heights and periods were investigated. Sundar and Subbarao (2002, 2003)carried out experimental studies on the quadrant front face pile supported breakwaters. The breakwater was consisted of superstructure with quadrant solid front face at the seaside and vertical solid face at the shore side supported on closely spaced piles. Neelamani and Gayathri (2006) investigated experimentally the wave transmission and reflection characteristics and wave-induced pressures on single surface plate and twin plate barriers supported on piles. They used a wide range of wave heights and periods in regular and random waves.

Gunaydın and Kabdasli (2006, 2007) investigated experimentally the performance of solid and perforated Π-type and U-type breakwaters under regular and irregular waves. Different wave groups were generated over these breakwaters, and the transmission, reflection and energy-dissipation characteristics were determined. Suh et al. (2006, 2007) and Ji and Suh (2010) studied experimentally and mathematically the hydrodynamic characteristics of a single and multi-curtain–wall–pile breakwater. The upper part of this structure is a vertical solid wall and the lower part consists of an array of