Wave - Structure Interactions: A Literature Review

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WAVE - STRUCTURE INTERACTIONS: A LITERATURE REVIEW

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Abstract
The purpose of the work is revolved around presenting a literature review applied to wave-structure interactions. During this literature review, three types of breakwaters are presented: Bottom submerged breakwater, submerged plate, and seawalls breakwaters. Further, a numerical method used recently to study wave-structure interactions is presented. Furthermore, a simple analytical model is illustrated. Next, an experimental technique then also is depicted. For more details, this review will focus clearly on submerged bottom breakwater in discussion section for the reason of the importance of this breakwater for many hydrodynamic applications. Finally, valuable remarks will be deducted in the conclusion section.

Keywords:
Wave-structure interactions;
Breakwater;
Submerged plate;
Submerged bottom breakwater.

1 Literature story

Safety and protection of structures in coastal and marine environment are an important challenge in coastal and marine engineering. So, reflection of waves is one of the most persuasive and appropriate solutions to get over problems associated with high extreme waves conditions. Further, the breakwaters are the most commonly used to protect structures from actions of waves and currents. Furthermore, breakwaters are extensively utilized to safeguard coastal settlements in coastal and ocean engineering applications and infrastructure (such as harbors and pipelines), as well as to conserve the coastal environment and resource. Moreover, the investigations associated with wave-structure interactions are depicted into three categories. The first one, scientists or researchers are in interest to study the wave-structure interactions analytically. The second category is in interest to study the interactions between waves and structures in Numerical Wave Tank (NWT). And the third category, are in the interest to study the wave-structure interaction experimentally. In this review, we will discuss three categories of breakwaters: Bottom submerged breakwater, submerged plate breakwater, and the seawalls breakwaters. Further, the discussion section will focus just on submerged bottom breakwater, for the reason of high importance of this kind of breakwater for many industrial applications.

The first category, Fig. 1, is bottom submerged breakwaters, during the last few decades, wave propagation over immersed obstacles has received a lot of attention, are common constructions used to defend coastal regions when total protection from waves is not required. By reflecting the majority of incident waves, these structures minimize wave energy and thereby reduce wave transmission. Bottom submerged breakwaters, such those in harbor entrances and marinas, can efficiently produce calmer regions on their leeward side and can reduce sediment transport capacity. As state-of-the-art, Jeffrey [1] had proposed a rough analytical formula for computing wave transmission and wave action across a submerged rectangular breakwater. Johnson [2] was one of the first researchers conduct results of an experimental investigation on the damping action of submerged rectangular breakwaters. Mei and Black [3] had used the variational approach to investigate the problem of scattering qualities for bottom and surface obstacles. Dattatri [4] conducted a thorough laboratory experiment to assess the performance characteristics of various types and forms of bottom submerged breakwaters. They discovered that the depth of submersion and the width of the breakwater's crest had a significant impact on the performance of submerged breakwaters. Abdul Khader [5] had studied experimentally the effectiveness of submerged breakwaters to dissipate the wave energy. The interaction of waves with a rectangular submerged breakwater of infinite and finite length was studied by Massel [6]. Andrew et al. [7] investigated the propagation of waves over a submerged impermeable obstacle with a rectangular cross section using an experimental and numerical research based on the Boundary Element Method (BEM). EigenFunction Expansion Method (EFEM) within potential flow linear theory was used by Abul-Azm [8] to suggest an analytical solution, to investigate the wave-submerged rectangular breakwater interactions. Hsu [9] has presented a series of experiment measurements to investigate rectangle, cosine, and triangular sand breakwater wave reflections; he concluded that rectangular sand breakwaters produce the most reflection. Cho [10] investigated the wave reflection from rectangular and trapezoidal impermeable by conducting a series of laboratory tests and developing an analytical solution based on the EFEM. The analytical and experimental results were in good agreement, and a trapezoidal-shaped breakwater was suggested for overall good performance. Twu [11] used the EFEM to investigate the wave damping properties of a periodic array of porous bars. It was determined that the porosity effect reduces both reflection and transmission while boosting wave dissipation. Szmidt [12] investigated the interaction of waves with a rectangular breakwater installed at the bottom of a NWT using the finite difference technique (FDM), and calculated the breakwater's efficacy in protecting sea shelf zones from open sea waves. Koley [13] investigated oblique-wave scattering and trapping by bottom-standing porous breakwaters on a sloping bed using an appropriate mix of the EFEM and BEM models. The Bragg reflections for a train of surface water waves from a succession of impermeable submerged bottom breakwaters were studied by Ouyang [14] using a computational solution based on the Regularized Meshless Method (RMM). Senouci [15] proposed a meshless Singular Boundary Method (ISBM) for assessing the hydrodynamic performance of bottom-standing submerged breakwaters in regular waves. Recently, Loukili [16] presented a theoretical approach to study the effect of immersion ratios and the relative lengths of submerged rectangular breakwaters.

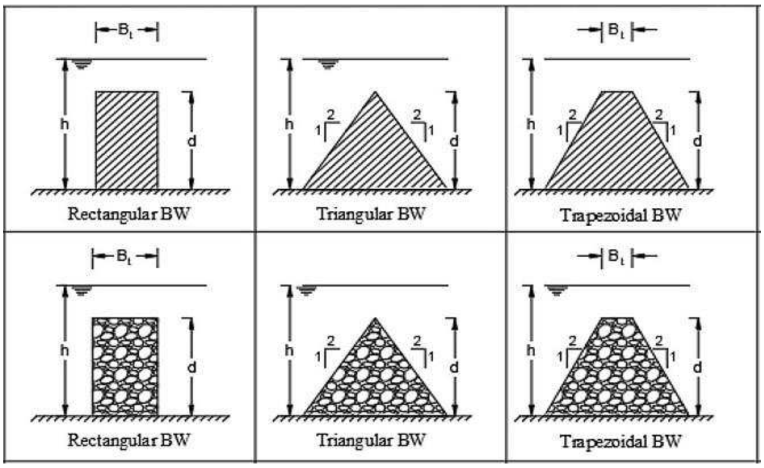


Fig.1: Configuration of bottom submerged breakwater [17].

The second category, Fig. 2, is he submerged plate breakwater is less dependent on the bottom terrain, and can ensure open scenic views. Further, it permits seawater to freely flow between the sheltered area, preventing stagnation, pollution, and sediment movement while maintaining the natural seabed's overall partition. It's been used as a breakwater in both coastal and offshore areas. It lowers the wave height without obstructing downstream flow. Because of the energy transferred between the various sections of the plate. Patarapanich [18] discovered that the reflection coefficient oscillates with the ratio of the plate length and the wavelength. Subsequently, has explored the reflection and transmission of regular and irregular waves by a submerged plate, both experimentally and numerically [18]. They calculated the occurrence circumstances for the wave's minimal transmission across a submerged plate. Brossard and Chagdali [20] investigated the creation of higher harmonics by waves traveling over a submerged plate. One or two moving probes were employed to separate bound and free harmonic vibrations based on the Doppler shift. Liu [21] used numerical and experimental methods to examine the interaction between non-breaking waves and a submerged horizontal plate. To examine wave transmission and reflection from a submerged plate in the presence of constant currents Lin et al [22] developed a NWT based on potential flow theory. Ning [23] investigated the free higher harmonics caused by a monochromatic wave propagating across a submerged bar via numerical modeling. In the case of weakly nonlinear waves, the amplitude of the *n*-th free harmonic tends to increase in proportion to the *n*-th power of the input wave amplitude, while in the case of strongly nonlinear waves it will approach a constant value. Errifaiy [24] investigated the analytical method to determine the coefficient of reflection throughout the wave-current-plate interactions; the study focuses just on current effect using the evanescent modes model which had a good agreement with the experimental results. Later, Naasse [25] has carried out the same study by investigating the effect of geometrical parameters.

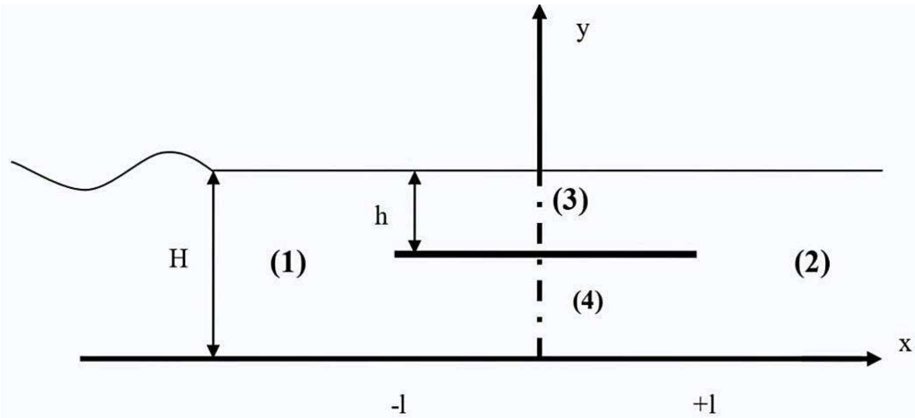
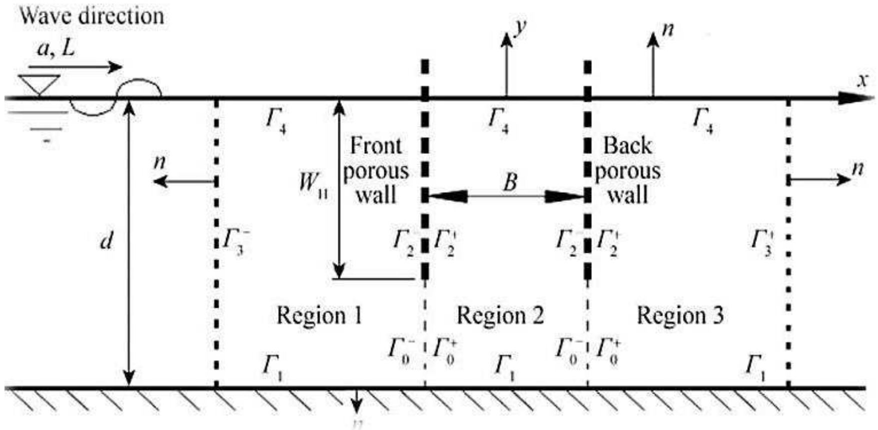
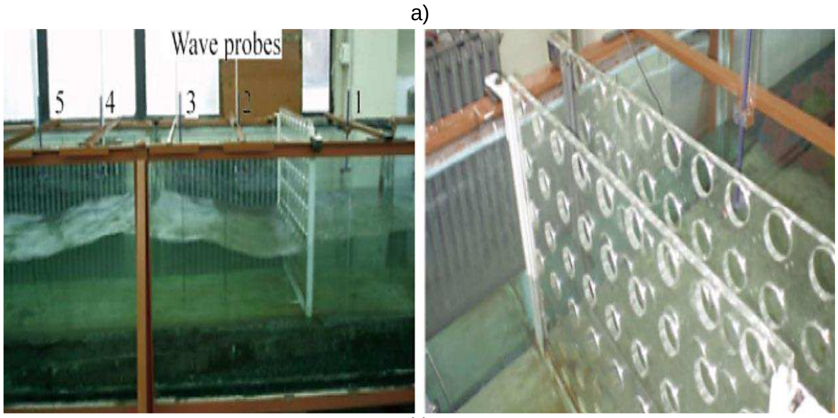


Fig. 2: Configuration of plate submerged breakwater.

The third category is seawalls, Fig.3, are coastal barriers that protect shorelines from the effects of waves and currents. Further, vertical seawalls are preferable because they take up less territory and take less time to build. Strong wave reflections may arise owing to its vertical and impermeable front surface. Further, these structures can be made porous to reduce scouring by attenuating some of the incident wave energy. Furthermore, Oscillations in the water level in front of perforated sea walls can be reduced with slighter effect on coastal waterways. To reduce wave velocity in front of vertical wall breakwaters, seaward of a vertical impermeable wall has been frequently used [26]. Moreover, wave energy is dispersed within the front permeable wall via viscous processes, which is a key feature of Jarlan-type breakwaters. Apart from that, several improvements to Jarlan-style breakwaters have been proposed. In addition, wave energy dissipation is a key characteristic of wave interactions with porous surfaces, and it has been studied by the several authors using linear diffraction theory. Many authors [27-31] have investigated the challenge of a thin permeable breakwater, and generally using numerical solutions based on an eigenfunction expansion method. The coefficients of reflection and transmission of a variety of porous breakwaters, as well as rubble-mound structures, have been compared to experimental data [27, 30, 32], and thin vertical barriers [29, 33] have provided an outstanding overview of hydraulic performance and wave loadings on single and multiple vertical seawalls, and perforated/slotted. They stated that some of the early experimental and analytical research focused on determining the reflection and transmission coefficients of vertical thin walls of various heights in infinite water depth, and porous breakwaters (perforated or slotted) were proposed to lessen wave reflection and transmission from seawalls. Furthermore, the impact of completely or partially perforated/slotted vertical seawalls on reflections and transmissions of waves have been the subject of several experimental and theoretical researches [35-39], according to the findings of these investigations, the porosity of the front wall and the ratio of the wave chamber width to the wavelength are major characteristics associated to wave reflection and transmission, Chioukh [40] recently used the boundary element method to investigate regular wave with perforated thin walls', his investigations revolved around the optimum conditions for high dissipation of wave energy.



a)



b)

Fig. 3: Perforated breakwater: a) scheme, b) experiment [38].

2 Mathematical formulation

In this section, we will present three subsections within the potential theory, where three formulations are presented to study the wave-structure interactions. The first subsection is subjected to the numerical formulation of wave-structure interactions in a NWT using a numerical approach that has been recently used in the literature. For sake of clarity, this method is the improved meshless singular Boundary Method (ISBM). Further, the second subsection stands on presenting the analytical approach (theoretical) within the plane wave model, and the third subsection is subordinate to the experimental model,

2.1 Numerical formulation

Within the hypothesis of fluid motion that is incompressible, inviscid, and irrotational, the problem is formulated within the linear velocity potential theory as:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0, \text{ in the fluid domain II,} \tag{1}$$

$$\frac{\partial\phi}{\partial n}-\frac{\sigma^2}{g}\cdot\phi=0, \text{ at } y = d \text{ (free surface condition } \Gamma_f), \tag{2}$$

$$\frac{\partial\phi}{\partial n}=0, \text{ at } y = 0 \text{ (bottom condition } \Gamma_s), \tag{3}$$

$$\frac{\partial\phi}{\partial n}=0, (x, y)\in \Gamma_{b1}\cup\Gamma_{b2}\cup\Gamma_{b3} \text{ (condition at breakwater } \Gamma_b), \tag{4}$$

where *n* denotes the normal to the boundary pointing out the flow region, $\Gamma_b=\Gamma_{b1}\cup\Gamma_{b2}\cup\Gamma_{b3}$ signifies the total impermeable boundary conditions of the breakwater, see Fig. 4.

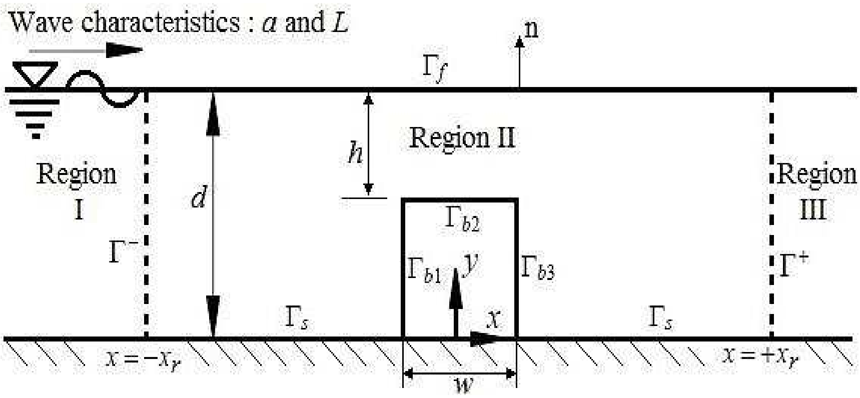


Fig. 4: Configuration of bottom submerged breakwater.

The absorbing boundary conditions at the inflow and outflow regions are written as:

$$\frac{\partial(\phi-\phi_I)}{\partial n} - i \cdot k \cdot (\phi - \phi_I) = 0 \text{ absorbing condition at } x \to -\infty \text{ (boundary } \Gamma^-\text{)}, \quad (5)$$

$$\frac{\partial(\phi)}{\partial n} - i \cdot k \cdot (\phi) = 0 \text{ absorbing condition at } x \to +\infty \text{ (boundary } \Gamma^+\text{)}, \quad (6)$$

where ϕ_I is the incident velocity potential.

The absorbing conditions are treated by transferring the far field potentials at two fictitious positions $x = \pm x_r$, representing respectively the left condition Γ^- and the right condition Γ^+ of the fluid domain. These conditions are expressed as:

$$\phi^- = A^- \cdot \frac{\cosh(k.y)}{\sinh(k.d)} e^{-ik.(x-x_r)} \text{ and } \frac{\partial \phi^-}{\partial n} = -\frac{\partial \phi^-}{\partial x} \quad \text{for } x = -x_r \text{ (at the boundary } \Gamma^-\text{)}, \quad (7)$$

$$\phi^+ = A^+ \cdot \frac{\cosh(k \cdot y)}{\sinh(k.d)} e^{ik \cdot (x-x_r)} \text{ and } \frac{\partial \phi^+}{\partial n} = \frac{\partial \phi^+}{\partial x} \text{ for } x = +x_r \text{ (at boundary } \Gamma^+\text{)}, \quad (8)$$

where A^- and A^+ are unknown coefficients to be calculated. The disturbances are warranted to be out-going waves only [16]. The incident velocity potential is written as:

$$\phi_I = \frac{a \cdot L}{T} \cdot \frac{\cosh(k.y)}{\sinh(k.d)} e^{-ik \cdot (x-x_r)}. \quad (9)$$

The special matching conditions at the interfaces Γ^- and Γ^+ of the flow regions ensure a smooth transfer of the mass flow from one region to the next. Once the potentials ϕ^- and ϕ^+ are calculated by satisfying the radiation boundary conditions of Eqns. (5) and (6), they are matched to those of Eqns. (7) and (8), then the unknown coefficients A^- and A^+ are expressed as [16]:

$$A^- = -(-\frac{a \cdot L}{T}) + . \frac{k}{N_0 . \cosh(k.d)} . \int_0^d \varphi^-(-x_r, y) \cdot \cosh(k \cdot y). dy, \quad (10)$$

$$A^+ = \frac{k}{N_0 . \cosh(k.d)} . \int_0^d \varphi^+(+x_r, y) \cdot \cosh(k \cdot y). dy, \quad (11)$$

where $N_0 = \frac{1}{2}\left(1 + \frac{2k \cdot d}{\sinh(2k \cdot d)}\right)$.

The coefficients of reflection and transmission are expressed as $R = |A_0^-| \frac{T}{a \cdot L}$ and $T_r = |A_0^+| \frac{T}{a.L}$.

2.2 Analytical formulation

The analytical approach to evaluate the reflection and transmission coefficients during the interaction of regular wave-rectangular barrier cited at the bottom of the tank is described in this subsection. Based on matching conditions technic, the reflection and transmission coefficients are calculated theoretically, by expressing the continuity of velocity potential and horizontal velocity at the obstacle's edges, see Fig. 5.

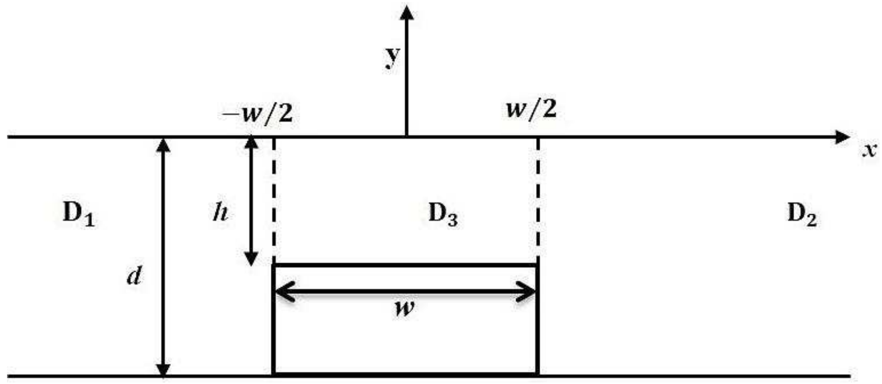


Fig. 5: Configuration of bottom submerged breakwater (for analytical calculation).

The velocity potential at each subdomain is written as:

• at the subdomain D_1: $\phi_1 = \alpha\,[exp\,(-jk(x + w/2)) + Rexp\,(jk(x + w/2))]\,ch\,(k(y + d))$, (12)

• at the subdomain D_2: $\phi_2 = \alpha T, exp\,(-jk(x - w/2))\,ch\,(k(y + d))$, (13)

• at the subdomain D_3: $\phi_3 = \alpha\,[Cexp(-j\sigma x) + Dexp\,(j\sigma x)]\,ch\,(\sigma(y + h)$. (14)

The horizontal velocity and the velocity potential's continuity are defined at $x = -w/2$ and $x = w/2$ as:

• at the position $x = -w/2$:

$$\int_{-h}^{0} \phi_1(-w/2, y) ch\big(\sigma(y+h)\big)\, dy = \int_{-h}^{0} \phi_3(-w/2, y) ch\big(\sigma(y+h)\big)\, dy, \quad (15)$$

$$\int_{-h}^{0} \frac{\phi_1(-w/2,y)}{\partial x} ch\big(k(y+d)\big)\, dy = \int_{-h}^{0} \frac{\partial\phi_3(-w/2,y)}{\partial x} ch\big(k(y+d)\big)\, dy, \quad (16)$$

• at the position $x = w/2$:

$$\int_{-h}^{0} \phi_1(w/2, y) ch\big(\sigma(y+h)\big)\, dy = \int_{-h}^{0} \phi_3(w/2, y) ch\big(\sigma(y+h)\big)\, dy, \quad (17)$$

$$\int_{-h}^{0} \frac{\partial\phi_1(w/2,y)}{\partial x} ch\big(k(y+d)\big)\, dy = \int_{-h}^{0} \frac{\partial\phi_3(w/2,y)}{\partial x} ch\big(k(y+d)\big)\, dy, \quad (18)$$

following the expression of the connection conditions at the positions $x = w/2$ and $x = -w/2$, we get an algebraic system as:

$$\begin{cases} I_1(1+\mathrm{R}) = I_2(Cz + D\bar{z}) \\ I_1 T_r = I_2(C\bar{z} + Dz) \\ kI_3(1-\mathrm{R}) = \sigma I_1(Cz - D\bar{z}) \\ kI_3 T_r = \sigma I_1(C\bar{z} - Dz) \end{cases}, \quad (19)$$

where $I_1 = \int_{-h}^{0} ch\big(k(y+d)\big)\, ch\big(\sigma(y+d)\big) dy$, (20)

$$I_2 = \int_{-h}^{0} ch^2\big(\sigma(y+h)\big) dy, \quad (21)$$

$$I_3 = \int_{-h}^{0} ch^2\big(k(y+d)\big) dy, \quad (22)$$

by combining the set of equations (19), we get

$$Cz = \frac{1}{2}\frac{I_1}{I_2}(1+\mathrm{R}) + \frac{1}{2}\frac{k}{\sigma}\frac{I_3}{I_1}(1-\mathrm{R}), \quad (23)$$

$$D\bar{z} = \frac{1}{2}\frac{I_1}{I_2}(1+\mathrm{R}) - \frac{1}{2}\frac{k}{\sigma}\frac{I_3}{I_1}(1-\mathrm{R}). \quad (24)$$

The formulas (23) and (24) are then injected into the second and fourth equations of the system (19), yielding

$$\frac{I_1}{I_2}T_r = \left[\frac{I_1}{I_2}(1+\mathrm{R}) + \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]\frac{\overline{z^2}}{2} + \left[\frac{I_1}{I_2}(1+\mathrm{R}) - \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]\frac{z^2}{2}, \tag{25}$$

$$\frac{kI_3}{\sigma I_1}T_r = \left[\frac{I_1}{I_2}(1+\mathrm{R}) + \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]\frac{\overline{z^2}}{2} - \left[\frac{I_1}{I_2}(1+\mathrm{R}) - \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]\frac{z^2}{2}, \tag{26}$$

with $z = exp(j\sigma w/2)$, more explicitly,

$$\left(\frac{I_1}{I_2} + \frac{kI_3}{\sigma I_1}\right)T_r = \left[\frac{I_1}{I_2}(1+\mathrm{R}) + \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]\overline{z^2}, \tag{27}$$

$$\left(\frac{I_1}{I_2} - \frac{kI_3}{\sigma I_1}\right)T_r = \left[\frac{I_1}{I_2}(1+\mathrm{R}) - \frac{kI_3}{\sigma I_1}(1-\mathrm{R})\right]z^2, \tag{28}$$

After that, we get a matrix system as $\begin{bmatrix}\mathrm{A} & \mathrm{B}\\ \mathrm{B} & \mathrm{A}\end{bmatrix}\begin{bmatrix}T_r\\ 0\end{bmatrix} = \begin{bmatrix}\overline{z^2} & 0\\ 0 & z^2\end{bmatrix}\begin{bmatrix}\mathrm{A} & \mathrm{B}\\ \mathrm{B} & \mathrm{A}\end{bmatrix}\begin{bmatrix}1\\ \mathrm{R}\end{bmatrix}$. (29)

The formulation of the reflection and transmission coefficients can be obtained as a result of the matrix system's resolution.

$$\mathrm{R} = \frac{z^2 - \overline{z^2}}{\overline{z^2}\mathrm{B}/\mathrm{A} - z^2\mathrm{A}/\mathrm{B}}, \tag{30}$$

$$T_r = \frac{\mathrm{B}/\mathrm{A} - \mathrm{A}/\mathrm{B}}{\overline{z^2}\mathrm{B}/\mathrm{A} - z^2\mathrm{A}/\mathrm{B}}, \tag{31}$$

where $\mathrm{A} = \frac{I_1}{I_2} + \frac{kI_3}{\sigma I_1}$ and $\mathrm{B} = \frac{I_1}{I_2} - \frac{kI_3}{\sigma I_1}$. (32)

2.3 Experimental set up

For wave-structure interactions, the reflection and transmission coefficients are calculated using the node and antinode envelope heights, Fig. 6. A standing wave's envelope height at the antinode is H_i + H_r and the nodal envelope height is H_i - H_r [43, 44]. The refection coefficient is measured by dividing the difference in the heights of the two envelopes by the sum of their heights. It's also possible to demonstrate that the reflection coefficient is equal to $R = H_r/H_i$ where H_i is the reflected wave height and H_r is the incident wave height.

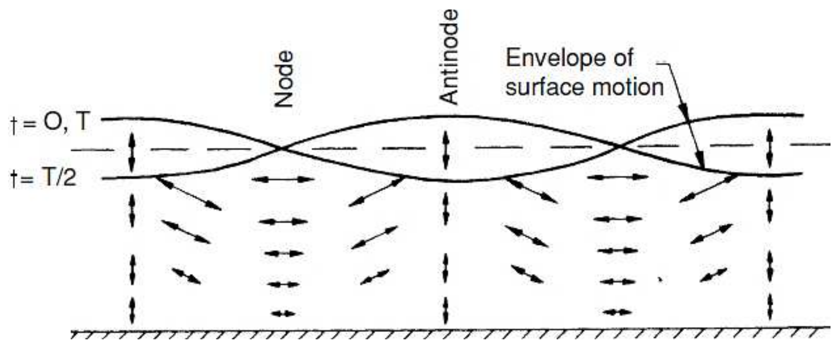
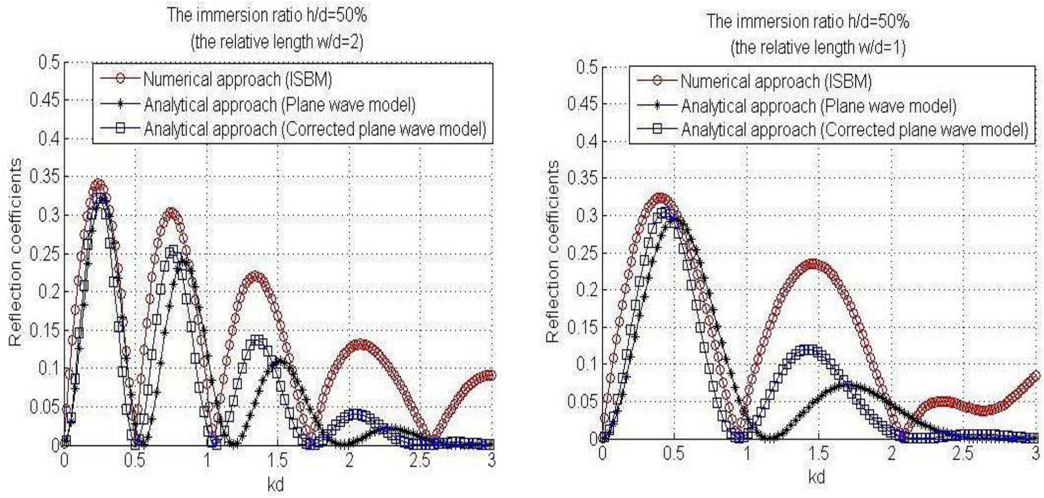


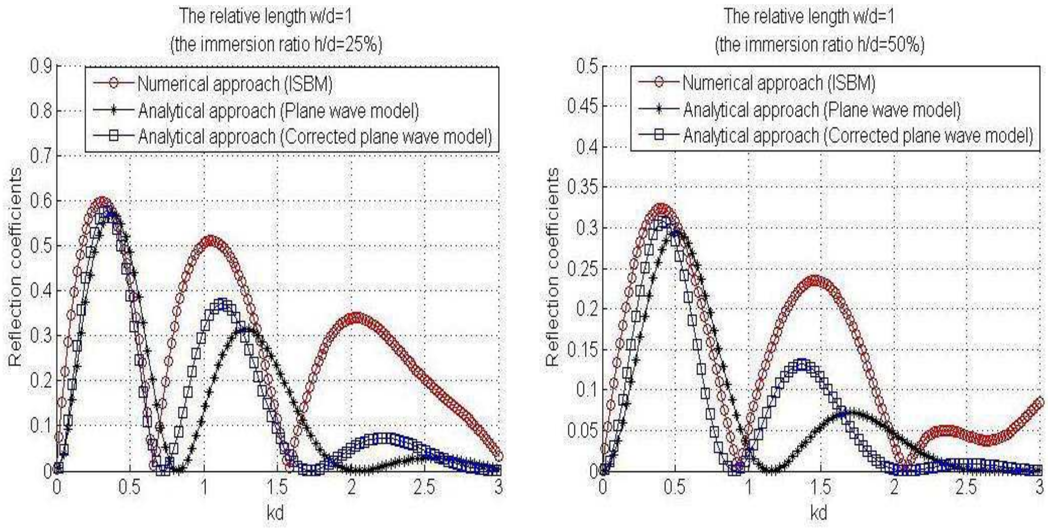
Fig. 6: Standing wave and surface profile envelope.

3 Discussions

After introducing a literature review applied to wave-structure interactions, and presenting the numerical, analytical, and experimental approaches often used to study the reflection and transmission coefficients. The goal of this section is to review the efficiency of the numerical and analytical approaches. Further, a comparison of numerical, analytical, and improved version of analytical approach are investigated. For more details, the improved version of the analytical model is improved by adding 5 % to the relative length and subtracting 4 % [16]. Furthermore, the comparison has covered different hydrodynamics parameters. Namely, this study is investigated for different immersion ratios and the relative lengths.



a)



b)

Fig. 7: Reflection coefficients for: a) different relative length, b) different immersion.

The outcomes of the Fig. 7 show an acceptable agreement between the improved version of the analytical and numerical approaches. This assertion can prove the efficiency of the improved version of the analytical model. Moreover, the advantage of the improved version of the analytical model is that very simple to implement and to manipulate.

For more review around the submerged bottom breakwater, two tables are incorporated in this literature review, for the goal to compare the efficiency of different bottom submerged breakwaters.

Further, the Table 1 is dedicated to different impermeable bottom submerged breakwaters, and Table 2 is depicted to show the efficiency of permeable submerged breakwaters.

Table 1: Maximum value of reflection and transmission for various impermeable structures [17].

h/d		Rectangle		Triangle		Trapezoidal	
		K_R	K_T	K_R	K_T	K_R	K_T
0.8	Max	0.612	0.996	0.487	0.996	0.573	0.990
	Kh	0.700	0.050	0.500	0.050	0.400	0.050
0.6	Max	0.357	0.999	0.290	0.999	0.350	0.998
	Kh	0.850	0.050	0.650	0.050	0.550	0.050
0.4	Max	0.182	1.000	0.149	1.000	0.193	1.000
	Kh	0.950	0.005	0.850	0.050	0.700	0.050

Table 2: Maximum values of reflection and transmission for various permeable structures [17].

h/d		Rectangle		Triangle		Trapezoidal	
		K_R	K_T	K_R	K_T	K_R	K_T
0.8	Max	0.222	0.983	0.273	0.975	0.311	0.961
	Kh	0.900	0.050	0.500	0.050	0.450	0.050
0.6	Max	0.155	0.990	0.185	0.990	0.221	0.984
	Kh	0.950	0.050	0.650	0.050	0.550	0.050
0.4	Max	0.092	0.995	0.103	0.996	0.135	0.994
	Kh	1.000	0.050	0.850	0.050	0.700	0.050

The reflection and transmission coefficients associated with different submerged bottom breakwaters are clearly assessed in the Table 1 and 2. Three bottom submerged breakwater are assessed. Namely, rectangle triangle, and trapezoidal breakwaters are studied for two cases: permeable and impermeable structures. For sake of details, Tables 1 and 2 show that the reflection coefficients of rectangular submerged breakwater is the most important then triangular and trapezoidal submerged breakwater in the case of permeable breakwater. On other hand, the Trapezoidal bottom submerged breakwater is the most important then triangular and rectangular.

4 Conclusions and remarks

In this research paper, a literature review is presented for wave-structure interactions. Further, this literature review covered three categories of breakwaters structure: bottom submerged breakwater, submerged plate breakwater, and seawalls breakwater.

During our investigations, we remark that the study of bottom immersed breakwater in the case of wave-current interactions is still laky. Further, the experimental, theoretical, and numerical study applied to wave-bottom immersed breakwater in the presence of current is strongly required.

On other way, submerged plate breakwater is studied experimentally, theoretically, and numerically. Moreover, the wave-plate-current interactions are further studied recently by Errifaiy [24], but the experimental and numerical investigations are also still also laky. However, the theoretical investigations of wave-plate-current interactions are limited just to the current with the same direction as the propagation of the incident regular wave. Furthermore, a series of plates are also required to be investigated.

In addition, the numerical simulation using sponge layer boundary condition is mostly used, and then it is not efficient for several actual cases like truncated domains. For this reason, the Generating Absorbing Boundary Conditions (GABCs) [41, 42] is strongly recommended to investigate easily the wave-current-structure interaction where the wave and current are coplanar, and opposite.

Finally, this literature review shows that seawalls breakwaters are strongly recommended when total protection from waves is required.

As perspective, we endeavor to study the reflection and transmission coefficients using a simple analytical model to simulate the interaction of water waves with the obstacle cited at the free [45, 46] for different hydrodynamics parameters.

Acknowledgment

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References

[1] JEFFREYS, H.: Note on the offshore bar problems and reflection from a bar. Great Britain Ministry of Supply, Wave Report No. 3, 1944.
[2] JOHNSON, J. W. – FUCNS, R. A. – MOVASOR, J. R.: The damping action of submerged breakwaters. Transaction American Geophysical Union, Vol. 32, 1951, pp. 704-718.
[3] MEI, C. – BLACK, J.: Scattering of surface waves by rectangular obstacles in waters of finite depth. J. Fluid Mech. Vol. 38, 1969, pp. 499-511.
[4] DATTATRI, J. – RAMAN, H. – SHANKAR, N. J.: Performance characteristics of submerged breakwaters. Proceedings of the 6th International Conference on Coastal Engineering. ASCE1978, Hamburg, Germany.

[5] BDULKHADER, M. H. – RAL S. P.: A study of submerged breakwaters. Journal of Hydraulic Research, Vol. 18, 1980, pp. 113-121.
[6] MASSEL, S.: Harmonic generation by waves propagating over a submerged step. Coast. Eng., Vol. 7, 1983, pp. 357-380.
[7] DRISCOLL, A. – DALRYMPLE, R. – GRILLI, S.: Harmonic generation and transmission past a submerged rectangular obstacle. Coast. Eng., 1992, pp. 1142-1152.
[8] ABUL-AZM, A. G.: Diffraction through wide submerged breakwaters under oblique waves. Ocean Engineering, Vol. 21, 1994, pp. 683-706.
[9] HSU, T. W. – CHANG, H. K. – HSIEH, C. M.: Bragg reflection of waves by different shapes of artificial bars. China Ocean Engineering, Vol. 16 (3), 2002, pp. 21-30.
[10] CHO, Y. S. – LEE, J. I. – KIM, Y. T.: Experimental study of strong reflection of regular water waves over submerged breakwaters in tandem. Ocean Engineering, Vol. 31, 2004, pp. 1325-1335.
[11] TWU, S. W. – LIU, C. C.: Interaction of non-breaking regular waves with a periodic array of artificial porous bars. Coastal Engineering, Vol. 51, 2004, pp. 223-236.
[12] SZMIDT, K.: Finite difference analysis of surface wave scattering by underwater rectangular obstacles. Arch. Hydro-Eng. Environ. Mech., Vol. 57, 2010, pp. 179-198.
[13] KOLEY, S. – BEHERA, H. – SAHOO, T.: Oblique wave trapping by porous structures near a wall. Journal of Engineering Mechanics, Vol. 141, Iss. 3, 2015.
[14] OUYANG, H. T. – CHEN, K. H. – TSAI, C. M.: Wave characteristics of Bragg reflections from a train of submerged bottom breakwaters. Journal of Hydro-Environment Research, Vol. 11, 2016, pp. 91-100.
[15] SENOUCI, F. – CHIOUKH, N. – DRIS, M .E. A.: Performance Evaluation of Bottom-Standing Submerged Breakwaters in Regular Waves Using the Meshless Singular Boundary Method. Journal of Ocean University of China, Vol. 18, 2019, pp. 823-833.
[16] LOUKILI, M. – DUTYKH, D. – NADJIB, C. – NING, D. – KOTRASOVA, K.: Analytical and Numerical Investigations Applied to Study the Reflections and Transmissions of a Rectangular Breakwater Placed at the Bottom of a Wave Tank. Geosciences, Vol. 11, 2021, 17 p.
[17] SHIVAKUMAR, P. – KARMAKAR, D.: Performance evaluation of submerged breakwater using Multi-Domain Boundary Element Method. Applied Ocean Research, Vol. 114, 2021, 15 p.
[18] PATARAPANICH, M.: Forces and moment on a horizontal plate due to wave scattering, Coastal Engineering, Vol. 8, 1984, pp. 279-301.
[19] PATARAPANICH, M. – CHEONG, H. F.: Reflection and transmission characteristics of regular and random waves from a submerged horizontal plate. Coastal Engineering, Vol. 13, 1989, pp. 161-182.
[20] BROSSARD, J. – CHAGDALI, M.: Experimental investigation of the harmonic generation by waves over a submerged plate. Coastal Engineering, Vol. 42, 2001, pp. 277-290.
[21] LIU, C. – HUANG, Z. – KEAT TAN, S.: Nonlinear scattering of non-breaking waves by a submerged horizontal plate: experiments and simulations, Ocean Engineering, Vol. 36, 2009, pp. 1332-1345.
[22] LIN, H. – NING, D. – ZOU, Q. – TENG, B. – CHEN, L.: Current effects on nonlinear wave scattering by a submerged plate. J Waterway Port, Coastal, Ocean Engineering, Vol. 140, Iss. 5, 2014, pp. 1-12.
[23] NING, D. Z. – ZHUO, X. L. – CHEN, L. F. – TENG, B.: Nonlinear numerical investigation on higher harmonics at lee side of a submerged bar. Abstract and Applied Analysis, Vol. 2012, 2012, 13 p.
[24] ERRIFAIY, M. – NAASSE, S. – CHAHINE, C.: Analytical determination of the reflection coefficient by the evanescent modes model during the wave–Current–horizontal plate interaction. Comptes Rendus Mécanique, Vol. 344, 2016, pp. 479-486.
[25] NAASSE, S. – ERRIFAIY, M. – CHAKIB, C.: Analytical study of the effect of the geometrical parameters during the interaction of regular wavehorizontal plate-current. Acta Oceanologica Sinica, Vol. 38, 2019, pp.10-20.
[26] JARLAN, J. E.: A perforated vertical wall breakwater. Dock and Harbour Authority, Chapman & Hall, London, Vol. 41, 1961, pp. 394-398.
[27] SOLLITT, C. K. – CROSS, R. H.: Wave transmission through permeable breakwaters. Proc., 13th Coastal Engineering Conf., Vol. 3, Iss. July 10-14, 1972, pp. 1827-1846.
[28] DALRYMPLE, R. A. – LOSADA, M. A. – MARTIN, P. A.: Reflection and transmission from porous structures under oblique wave attack. J. Fluid Mech., Vol. 224, 1991, pp. 625-644.
[29] HAGIWARA, K.: Analysis of upright structure for wave dissipation using integral equation. Proc., 19th Coastal Engineering Conf., Vol. 3, 1984, pp. 2810-2826.

[30] YU, X. P.: Diffraction of water waves by porous breakwaters. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 121, Iss. 6, 1995, pp. 275-282.

[31] ISAACSON, M. – BALDWIN, J. – ALLYN, N. – COWDELL, S.: Design of a perforated breakwater. Proc., Ports ’98 Conf 1998a, Vol. 2, pp. 1189-1198.

[32] SULISZ, W.: Wave reflection and transmission at permeable breakwaters of arbitrary cross section. Coastal Engineering, Vol. 9, 1985, pp. 371-386.

[33] ISAACSON, M. – PREMASIRI, S. – YANG, G.: Wave interactions with a vertical slotted barrier. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 124, 1998, pp. 118-126.

[34] HUANG, Z. H. – LI, Y. C – LIU, Y.: Hydraulic performance and wave loadings of perforated/slotted coastal structures: A review. Ocean Engineering, Vol. 38, 2011, pp. 1031-1053.

[35] DAS, P. – DOLAI, D. P. – MANDAL, B. N.: Oblique wave diffraction by parallel thin vertical barriers with gaps. Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 123, 1997, pp. 163-171.

[36] BERGMANN, H. – OUMERACI, H.: Hydraulic performance of perforated structures. Proceedings of the 5th International Conference on Coastal and Port Engineering in Development Countries, COPEDEC, 1999, pp. 1340-1349.

[37] HUANG, Z. H.: Wave interaction with one or two rows of closely spaced rectangular cylinders. Ocean Engineering, Vol. 34, 2007, pp. 1584-1591.

[38] LIU, Y. – XIE, L. Q. – ZHANG, Z. H.: The wave motion over a submerged Jarlan-type perforated breakwater. Acta Oceanologica Sinica, Vol. 33, 2014, pp. 96-102.

[39] HUANG, Z. H. – LI, Y. C. – LIU, Y.: Hydraulic performance and wave loadings of perforated/slotted coastal structures: A review. Ocean Engineering, Vol. 38, 2011, pp. 1031-1053.

[40] NADJI, C. – KARIM, O. – YALÇIN, Y. – BENAMEUR, H. – ESIN, Ç.: Meshless Method for Analysis of Permeable Breakwaters in the Proximity of a Vertical Wall. China Ocean Engineering, Vol. 33, 2019, pp. 148-159.

[41] LOUKILI, M. – DUTYKH, D. – KOTRASOVA, K. – NING, D.: Numerical Stability Investigations of the Method of Fundamental Solutions Applied to Wave-Current Interactions Using Generating-Absorbing Boundary Conditions. Symmetry, Vol. 13, Iss. 7, 2021, 9 p.

[42] LOUKILI, M. – KOTRASOVA, K. – BOUAINE, A.: A Generating - Absorbing Boundary Condition Applied to Wave - Current Interactions Using the Method of Fundamental Solutions. Civil and Environmental Engineering, Vol. 17, Iss. 2, 2021, pp. 343-352.

[43] LOUKILI, M. – KOTRASOVA, K. – MOUHID, M.: Computerized Decision Aid Applied to Meshless Method for the Use Case: Wave-Structure Interactions. International Conference on Decision Aid Sciences and Application, DASA, 2020, pp. 33-36.

[44] BROSSARD, J. – PERRET, G. – BLONCE, L. – DIEDHIOU, A.: Higher harmonics induced by a submerged horizontal plate and a submerged rectangular step in a wave flume. Coastal Engineering, Vol. 56, 2009, pp. 11-22.

[45] MASOUDI, E, – GAN, L.: Diffraction waves on general two-legged rectangular floating breakwaters. Ocean Engineering, Vol. 235, 2021, 9 p.

[46] MASOUDI, E.: Hydrodynamic Characteristics of Inverse T-Type Floating Breakwaters. International Journal of Maritime Technology, Vol. 11, 2019, pp. 13-20.

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