Review Article

Review of Indian research on innovative breakwaters

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In this paper, a detailed review of Indian research studies on the development of innovative breakwaters is attempted. Historical studies by Indian researchers and scientists were collected and classified into two broad categories; fixed and floating breakwaters. The first part, Part I, discusses the studies pertaining to different types of fixed breakwaters, whereas, the Part II describes the studies related to floating breakwaters.

[Keywords: Breakwaters, Porous structures, Rubble-mound, Submerged Structures]

Introduction

Breakwaters help us in safe navigation of vessels in and out of harbors and provide clam water area inside harbor boundary for safe loading and unloading of cargo. There is a constant urge for innovation in breakwater systems, to reduce cost, time of construction, to improve efficiency and to satisfy some site specific conditions. The primary requirement of a breakwater is to allow least wave to be transmitted on to its harbor side. However, in many locations, a minimal reflection of incident wave energy is also preferred. Breakwaters are primarily classified as; fixed types, which are seabottom-connected structures and floating types, which float on the surface, held by mooring lines. The special type of breakwaters are generally adopted for specific site requirements and therefore not commonly applied, for example, a pneumatic breakwater, in which air bubble from under water is continuously pumped for reducing wave energy. Under the broad classification of fixed type, breakwaters are further sub-divided into many types, a typical of which is depicted in Fig. 1. Depending upon degree of shelter required and prevailing environment conditions, a particular type of breakwater is chosen for construction.

![Classification of different types of breakwaters.](image-url)
In the process of improving the efficiency of breakwater systems, various Indian researchers have carried out experimental, theoretical and numerical studies to assess hydrodynamic performances of different types of breakwaters. This paper explores past studies on hydrodynamic characteristics of innovative breakwaters from Indian research perspective. Though the main focus of these studies was to find reflection and transmission characteristics of breakwaters, in some studies, dynamic pressures, forces and wave run-up were also estimated. Based on available literatures, innovative breakwaters studies by Indian researchers have been classified into two major types; fixed and floating. The details of fixed and floating type of breakwaters are discussed in Part I and Part II, respectively.

Part I: Fixed type

General

Fixed type of breakwaters belongs to a category where the structures assumed to rigidly fixed, either emerging from seabed or supported on piles. Rubble mound, vertical wall and barrier type of breakwaters fall in this category. The conventional rubble mound breakwaters are most widely adopted breakwater in the world. Depending on the requirement, rubble mound breakwater could be used as a composite type. As wave kinematics are significantly high around still water level, some of vertical wall or barrier type of breakwaters were partially submerged from still water level is adopted, which allowing part of wave energy to transmit to harbor side, for better circulation of water and to minimize reflection. In addition, for aforementioned reasons, barrier types of breakwaters with pre-defined porosity were also used to improve the performance in which porosity of barrier dictates reflection and transmission characteristics of the breakwater system. In order to minimize reflection further, without compromising transmission characteristics, more than one porous barrier were kept with certain distance between them. In this case, spacing between barriers influences reflection characteristics. Barrier types of breakwaters are also used as artificial reefs, in which case, structures emerge from seabed but submerged under still water level. Varieties of innovative fixed types of breakwaters were tested by Indian researchers, through experiments and or numerical techniques, which are discussed in the following sections, in their chronological order.

Innovation in armour blocks

Though the design concepts of a conventional rubble mound breakwaters, need to improve armour layer stability and interlocking capability between individual armour units necessitated research to develop different types of arcomour units. To mention a few, Roopsekhah et al.\(^1\) tested an innovative armour unit resembles a frustum of a cone as armour units of a conventional rubble mound breakwater. Extensive tests were carried out in a laboratory wave flume to assess the stability of these frustum cone blocks. It is reported that interlocking capabilities of frustum blocks are relatively less compared with tetrapods as armour units. In another innovative research in armor blocks Sundar et al.\(^2\) modified Dolos, named as “Kolos” (shown in Fig. 2) were used as armour units for conventional rubble mound breakwaters and tested for its stability through a detailed experimental investigation program. The Kolos are claimed to have overcome the structural weakness of Dolos blocks and stability coefficients were derived through experiments. Further experiments were also carried out on breakwaters with Kolos as armour units to assess various other engineering parameters such as overtopping, run-up and dynamic pressure on crown walls\(^3\) & \(^4\). Beyond the frustum blocks and kolos, there was no research related to innovation of armor block of rubble mound breakwater carried out in India, to the best of knowledge of the author. There is a large scope in this area of research, as the use/application of other core armour layer such as accropod, coreloc, x-block etc. in the constant of breakwater, require payment of significant royalty to the patent companies/organization.

![Frustum cone blocks](a)

![Kolos](b)

Fig. 2—Typical views of armour blocks
Defensive structures

A seawall is a most common defensive structure, generally constructed where the ocean environments is dominating at the coast and make discomfort to the human habitats. However, building a seawall has some inevitable impacts like reflection from these structures cause standing wave which leads to erosion along the face of the wall. Considering this, Mallayachari and Sundar\(^5\) studied reflection characteristics of vertical and sloping permeable seawalls using a theoretical model based on boundary integral method. The effects of porosity, friction factor and wall width on reflection characteristics were investigated. It is reported that model of vertical permeable wall shows oscillatory behavior for reflection to the lower value of friction factor for the entire range of relative wall width (product of wave number and wall width at still water level). However, this oscillatory nature is found completely absent for the case of wall with a slope of 45 degree. Moreover, present model of vertical permeable also exhibits the absence of oscillatory nature for reflection to higher relative wall width when compared with previous study. Whereas, the applicability of present model is limited for the case of linear and non-breaking waves only.

In their further study Mallayachari and Sundar\(^6\)analyzed standing wave pressures on a vertical wall type of breakwaters which is required for safe design and stability of these structures. The time histories of pressures measured from experiments were compared with that obtained from linear theory and third-order solution, for regular and random wave conditions with an emphasis on standing wave pressure due to random waves. It is reported that, for the intermediate water depth condition, linear theory is applicable for the lower steepness, whereas, with the higher wave steepness where non-linearity dominates, the third-order solution yields satisfactory results.

To assess the reflection characteristics of a vertical impermeable wall Sundar and Mallayachari\(^7\) carried out experimental studies in which vertical impermeable wall is defended by a permeable sloped seawall under regular and random wave conditions, shown in Fig. 3. The oscillations of water level inside permeable wall, dynamic pressure and reflected wave characteristics were measured and results were compared with a Green’s identity based theoretical model. It is reported that wave reflections from impermeable wall are reduced by permeable walls and relative wave heights (ratio of incident wave heights to wave heights inside porous barrier) was observed to be increasing with increase in surf similarity parameter. However, the effective reflection coefficient (ratio of area under reflected and incident wave spectra) for sloping permeable wall is about 40% to 60% less than that for impermeable wall, being greater for higher wall slope.

Seawall construction along the coast of India have increased throughout the decades as it was found that the seawall is a reliable solution of protecting human habitat. Despite this, during storms, the impact of waves is dominate, which significantly decreases the life of seawalls. Thus it is necessary to provide support structures along with seawalls which can help to improve the performance as well as life of seawalls. In such cases, a porous structure in-front of seawall could provide necessary protection to seawalls. First of all, the limited research was reported about seawalls as a coastal defense structures in India. With this, the only valuable research was reported in India by Sundar and Mallayachari\(^7\) in which vertical impermeable wall is defensed by permeable sloping wall, which could be considered as seawall defensed by porous structure. Such arrangements can definitely increase the life of seawalls by bring the significant change in reflection, transmission and dissipation of water waves before impacting with seawalls. The wave breaking over the inclined surface, run-up, run-down, wave energy dissipation and reflection through such arrangement is not completely understood from Indian Ocean perspective. There are vast scopes of experimental study in this area including different wave and structural characteristics. However, various numerical efforts have been made by foreigner researchers toward such
arrangements in which porous model were coupled with single or multi-phase flow model, but no evidence has been found regarding similar research in India.

Submerged structures

In situations where the complete protection from the wave is not required, submerged breakwater offers economic solutions. It can effectively use to dissipate wave energy by breaking the waves and generally used as standalone coastal defense structures. Dattatri et al. have a major contribution towards submerged breakwater, where the partial protection from the incident wave is required. The hydrodynamic performance of submerged breakwaters was investigated for different shapes of breakwater: horizontal fixed type, thin vertical wall type, triangular type, rectangular type and trapezoidal type are shown in Fig. 4. The effects of various parameters on the transmission coefficient were investigated. It was concluded that the shape of breakwater does not have any significant influence on the transmission.

A submerged breakwater with their sea-face sloping and vertical face on its shore is effective due to higher sediment trapping efficiency. However, Baba investigated experimentally that the optimum wave damping and maximum sand trapping effect is occurred for submerged breakwater with seaward side slope 1:1.67. Their study is basically for a breakwater with right trapezoid shape (name as "Odessa-type") which involved assessing the effect of top width and height of the breakwater on the wave transmission characteristics. Along with the experimental findings various computational methods used to predict wave transmission on similar type of breakwaters are validated by Baba with laboratory data. Tests result shows the instability of those developed computational methods to over prediction of transmission coefficient, kept with certain distance away from main breakwater (Fig. 5). In an extensive experimental study, Shirlal and Rao considered a submerged rubble mound breakwater (reef) of single layer on seaward of a conventional three-layer rubble mound breakwater, as a tandem breakwater.

A submerged rubble mound, also called as reef breakwater, is well thought of a defensive structure on seaward of any aged breakwater system. This type of arrangement is called as tandem breakwaters, as submerged structures are A parametric study on effect of distance between two breakwaters and height of reef breakwater on reflection, run-up and run-down characteristics had been carried out. It is reported that for non-dimensional breakwater spacing (spacing/water depth) ranges from 3.33 to 4.29, a maximum wave height attenuation of about 25% was observed. The wave run-up and run-down for tandem breakwater is reported to be about 10% to 15% smaller and damage level 20% to 60% less, when compared with that of a single breakwater for tested conditions.

Fig 4 — Configurations of submerged breakwaters

Reef breakwater also plays a significant role in minimizing wave force on structure to its leeward side. Reddy and Neelamani assessed effect of low crested rubble mound breakwater on seaward side of a vertical seawall, to minimize wave forces. The study explored characteristics of waves in energy dissipation zone with respect to relative height of breakwater for a given water depth. It is found that the forces were reportedly less for steeper waves due to depth limited breaking over submerged breakwater, ahead of vertical wall.
A series of submerged porous breakwaters as coastal defense system is modeled by Rambabu and Mani to assess transmission characteristics through submerged breakwater using two-dimensional Green’s formulation, based boundary-value model. The effects of depths of submergence, crest widths, material properties and clear spacing on hydrodynamic characteristics were studied for impermeable trapezoidal, permeable trapezoidal and rectangular breakwater. For achieving minimum transmission coefficient the optimum width ratio (top width of breakwater/depth of water) and clear spacing between two breakwaters is suggested as 0.75 and 2, respectively. Interestingly, it is reported that clear spacing between two submerged breakwaters does not influence transmission of incidents waves.

Although the submerged breakwaters have control over transmission it could also be used as a good wave attenuator and can be significantly controlled by changing top width of reef and spacing between the breakwaters. It is also reported that wave attenuation characteristics, run-up, run-down and stability of tandem breakwater as a function of different geometry of a reef breakwaters located at varying seaward distances. Within tested range of wave conditions, authors had optimized various parameters to obtain reduction in run-up, run-down and optimal damage of main breakwater.

The performance of submerged breakwater was also tested for regular and random wave condition by Reddy et al. In which the combined effect of submerged breakwater and vertical wall on hydrodynamic characteristics of breakwater is discussed. A two-dimensional finite element technique has applied to evaluate the wave forces and wave run-up on the vertical wall. However, the force exerted by the waves on the vertical wall under the action of random incident wave condition is evaluated using linear transfer function approach. It is also reported that the model is applicable for predicting wave forces of low ursell number.

Along with brief discussion over the submerged breakwater, few researches derived the design equation for stable submerged breakwater through experimental findings considering various parameters which significantly affect the transmission of wave through it. Shirlal et al. derived a stability equation, as given below, for breakwater sheltered by a seaward submerged reef through experimental investigation.

\[
\frac{H}{\Delta D_{n50}} = 0.87\sqrt{S}N^{-0.25}P^{-0.4} \quad (1)
\]

Where, \(P = \frac{F_dH_w}{X}\) \( (2)\)

In the above equations, \(F\) is depth of reef submergence, \(H_w\) is depth water wave height, \(d\) is depth of water, \(X\) is length of energy dissipation zone between two structures, \(D_{n50}\) is nominal diameter of armour units, \(S\) is damage level, \(\Delta\) is relative mass density and \(N\) is stability number. As a stand-alone coastal protection structure, Shirlal et al. also tested stability of submerged reef and influence of its varying distance from shore and crest width on wave transmission. Further, Kiran et al., derived design equation for a typical sheltered breakwater through physical model studies, as given below.

For submerged breakwaters;

\[
\left[ \frac{h_e}{h} \right] \left[ \frac{D_{n50}}{gT^2} \right] 10^{-3} = 8.9303e^{-0.2841N_s^*} \quad (3)
\]

For reef and sheltered breakwaters;

\[
\frac{S}{\sqrt{T}} = 0.3073x^2 - 0.1812x + 0.0244 \quad (4)
\]

Where, \(x = N_s \left[ \left( \frac{h_e}{h} \right) \left( \frac{H_w}{gT^2} \right) \right]^{0.3} \quad (5)
\]

In which \(\frac{h_e}{h}\) is dimensionless damage, \(T\) is wave period, \(N_s^*\) is spectral stability number and \(H_w\) is deep water wave height, \(B\) is crest width and \(L_0\) is deep water wavelength.

It is also attempted to use a single layer rubble mound reef breakwater as a defensive structure to reduce wave loads on a vertical wall. It is reported that relative height of reef breakwater influences flow pattern with in the pool between reef and vertical wall. The various characteristic phases of flow were also classified as; freely transmitting wave, overtopping, crest dissipation, predominant wave breaking and transmission over breakwater as crest level of reef breakwater reduces form emergent to submerge. In another experimental study, Kudumula and Muni Reddy demonstrated use of perforated semicircular breakwater as reef on seaward of a vertical wall to reduce wave load. It is reported that maximum reduction of wave forces on vertical wall was observed for zero submergence condition and longer pool length.

Very rich Indian literatures are available over submerge breakwater used as a standalone or reef structure. The most common design adopted for submerged breakwaters is trapezoidal type due to their high efficiency, less reflection and less wave load. Almost all the aspects have been covered.
including: breakwater type, crest width, location, depth of submergence, run-up, run-down, stability and performance for all wave characteristics. However, less attention has been paid towards installation of submerged breakwater on a sloping seabed. It is expected that the complicated hydrodynamic will be associate near the submerged breakwater with sloped seabed. Moreover, the wave attenuation characteristic of submerged breakwater can investigate for front slope design, front slope values, material property and porosity. Hereby, the influence of varying parameters on such type of arrangements could be the scope of future work. However, no evidence was found towards numerical simulation of submerged breakwater in Indian literatures, which can control the time and efforts including in experimental investigation.

**Berm breakwaters**

In places, where rocks of huge weight are not available as per requirement of design conditions, provision of a berm, a horizontal slope at an appropriate level on seaward side slope of armour layer, is considered for a conventional rubble mound breakwater. Berm offers reduction in incident wave energy by breaking, thus possibility of reducing weight of individual armour stones. Sometimes, a composite slope of seaward side shall be provided, generally one above and another below berm level. Consideration of more than one berm offer further reduction in wave energy, which however lead to increase in cost and overall base width of breakwater. The schematic diagram of berm breakwater is given in Fig. 6. In an experimental study, Rao et al.\textsuperscript{22} assessed the possibilities of reducing weights of armour stones of a conventional rubble mound breakwater, by introducing a berm on seaward side of breakwater and to use equilibrium reshaping of berm after any storm. It is reported that if the berm width is 60 cm and wave period is about 1.2 s, the 30% reduced armour weight would be stable for design wave height. However, it was understood that reduced armour stone is stable for selected berm width and wave characteristics that dominantly affect overall stability.

Moreover, the berm breakwater with 30% reduced armour stone do not shows the stable profile for all wave characteristics, thus in another experiment, Rao et al.\textsuperscript{23}, estimated runup, rundown and stability of a berm breakwater for reduced armor weight by 20% of armour weight. In addition, it was observed that berm breakwater near still water level is more effective in reducing wave runup.

For a case of berm breakwater, the breaking wave does not strike to the exposed seaside slope, but plunged onto the horizontal part and dissipates energy. So, the basic design criteria are depending on the characterization of berm width. In a basic test Rao et al.\textsuperscript{24} investigated statically stable non-reshaped two layer rubble mound breakwater with a wide width and the influence of wave height, wave period, water depth, and seaward slope on stability, wave runup, and wave rundown of a 20% reduced armour weight berm breakwater were tested. The authors had estimated damage criteria by comparing experimental results obtained for no berm conditions. It is reported that variations in water level above berm influence stability of berm.

Kiran et al.\textsuperscript{25} modified the existing berm breakwater by replacing the armor stone with concrete blocks as an armour unit and investigated its stability experimentally. The stability, runup and rundown of berm breakwater were estimated for different wave climate and stability numbers were reported to be varying from 2.21 to 3.63 for the tested wave conditions. Further, Prashanth et al.\textsuperscript{26} studied wave run-up and run-down characteristics of a berm breakwater with concrete cubes as armour units. Experiments were conducted with reduced weight of armour units than that of required as per standard design formula. Various berm widths, water depths and percentage reduction in weight of armour unit were considered for experimental tests. It is reported that berm width significantly influences run-up characteristics, which decreases with increase in berm width.

In another experiment, Manu et al.\textsuperscript{27}, reported physical model study on stability of concrete armoured units on tandem and berm breakwater. For the case of tandem breakwater run-up, rundown, transmission and breakwater damage is estimated for two different seaward distances of reef. The comprehensive study shows that when the reef is placed far for main breakwater the overall performance of reef breakwater is good for above mention parameters. Whereas, in case of berm breakwater, its height and width were
considered as characteristics factor for reducing breakwater damage. Study shows that stability of berm breakwater is significantly influenced by storm duration.

Many physical models were developed and experiments were carried out to design a safe and stable berm breakwater, which is very dedicated to space require, time consuming and expensive. To avoid these draw backs of experimental work, Mandal et al.\textsuperscript{28} approached soft computing models: artificial neural network, support vector machine and adaptive neuro fuzzy inference system to predict the damage levels and proved the efficiency of the models, which basically used data obtained from experimental stability tests on berm-breakwater. These models enable the consideration of wave period, wave steepness, breakwater slope and wave height in predicting damage levels.

The berm breakwater is advantageous compared to conventional breakwater in both the cases; technically and economically. For the long term stability, berm breakwater reshape into a statically stable profile. However, the main armor layer in berm breakwater is designed for berm reshaping to achieve such stable profile. As per the author’s knowledge, there is no definite design procedure for berm breakwaters. So, the innovation in berm could be development of stability equation for different type of berm breakwater. However, the cost optimization study can perform while maintaining the same or improved level of stability. Moreover, the numerical simulation for reshaping of berm breakwater can be perform for observing flow field in and on breakwater slope with different structural aspects as permeability, stone gradation, stability of toe and scour protection and probabilistic analysis.

Barrier/screen type of breakwaters

Thin barriers, impermeable or permeable, supported with piles can be used as breakwaters, in places where soil conditions are week to take loads of conventional rubble mound breakwaters. In places, where circulation of flow is expected in and out of the harbour basin, these barriers may be constructed up to partial water depth. These barrier also called as free-surface or open breakwaters. Generally, barriers types of breakwaters are adopted in places where wave height and period are relatively less. The schematic diagram of some barriers and their most common arrangements are given in Fig. 7.

In Indian context, hydrodynamic characteristics of barrier type of breakwaters have extensively been studied through various mathematical models. Wave reflection and transmission characteristics of a submerged fixed vertical barrier for obliquely incident wave were studied by Mandal and Goswami\textsuperscript{29}, for different value of incident wave angle and wave number. However, Mandal and Kundu\textsuperscript{30} reported a number of mathematical methods to solve water wave scattering by vertical barrier. These methods involve expansion, integral equation, reduction and complex variable methods. The authors had discussed the advantages and limitations of each method. Further, Mandal and Kundu\textsuperscript{31} reported hydrodynamic characteristics of a thin vertical barrier with a gap by using approximate solution...
submergences. Later, the water wave scattering from vertical plate of full length was reported by Bharathi et al.\textsuperscript{35} using perturbation technique. Later, Shaoo and Chakrabarti\textsuperscript{36} presented a mathematical model of partially immerge vertical wave-maker problems for typical cases. The solutions were achieved through converting boundary value problem into a set of dual integral equations by utilizing the well-known property of mixed boundary condition. In addition, problem of nearly vertical partially submerged wave maker problem is also considered along with more other cases.

Solutions for wave-structure interaction problem is also derived for thin barrier where the thickness of barrier is neglected compared to water wave length\textsuperscript{37, 38, 39, & 40}. Mandal and Basu\textsuperscript{41} used Green’s integral to investigate reflection coefficients of thin barriers in two superposed fluid regions. It is noted that closed form solution of the diffraction problem exists for normal incident wave train and deep water case. For the case of oblique incident wave train, problem cannot be solved in closed form, although the reflection and transmission coefficient can be obtained approximately. Based on Galerkin approximate method, Mandal and Das\textsuperscript{42} obtained the reflection and transmission coefficients for a submerged thin vertical plate subjected to oblique incident waves. Later, using the same technique, Banerjea et al.\textsuperscript{43} estimated the reflection coefficients of submerged single and twin thin wall with a gap under oblique wave conditions. Das et al.\textsuperscript{44} extended the concept to double thin barriers with gap (Fig. 9) for three different cases: partially immersed, partially submerged and fully submerged to estimate the reflection and transmission coefficients. According to study, total reflection occurs only for the partially immersed barrier, whereas, total transmission occurs for all the three configurations. The study concluded that consideration of two barriers in submerged test case increases reflection coefficient for certain wave frequencies. However, Chakrabarthi et al.\textsuperscript{45} had demonstrated application of unified analysis to solve the multiple integral equations of fully submerged and partially immerged barrier by converting them into a single Cauchy-type singular integral equation.

Kundu and Saha\textsuperscript{46} used perturbation technique to analysis water wave scattering problem of a thin plane barrier which is vertical and partially immersed barrier, inclined at special angles called a slender barrier. The first order correlation to the reflection and transmission coefficient of a submerged slender barrier, in deep water is the main finding of present research.

Furthermore, it was observed that the correlation to the transmission vanishes for a submerged nearly vertical plate which does not vanish for submerged slender barrier. A very next, Banerjea and Kar\textsuperscript{47} investigated first order correlation to reflection and transmission coefficient of a thin barrier with a gap through Green’s integral theorem and simplified pertubational analysis. The application of developed numerical method is adopted for some explicit shape of the barrier whose results then compared with the corresponding problem of vertical wall in next stage.

In general, the reflection of surface gravity wave occurs due to irregular bottom which act as obstacles to propagating waves. The mechanism of wave getting reflected through irregular bottom is wave-induced mass transport forms sand ripples of some wavelength which produce strong reflected waves. Mandal and Gayen\textsuperscript{48} mathematically solved wave scattering off bottom undulations along with addition effect of a partially immersed thin vertical barrier. A simplified perturbation analysis is used to obtain first-order reflection and transmission coefficients for sinusoidal shape functions that define undulations.

Mandal and Chakrabarthi\textsuperscript{49} presented a detailed description of mathematical concept of Galerkin’s method of approximate solutions for water wave problems, specifically wave thin barrier interaction problems. The comparison of single-term Galerkin’s and multi-term Galerkin’s approximation for single and double thin vertical barrier of four different configurations is discussed briefly. In addition, the basic functions for standard test cases are highlighted along with a short review of earlier literatures pertaining to Galerkin’s method for water wave problems.

Past decades, the problem of water wave scattering for thin vertical barriers of various configurations and its modification have been studied extensively. Less attention has been paid
towards the water wave scattering through thick obstacle in the direction of flow. Mirdula et al. studied the wave scattering of thick vertical barrier of rectangular cross section in water of uniform finite depth. The study considered four different geometrical configurations of the barrier; surface-piercing, partially immersed, bottom-standing and submerged, to estimate the reflection characteristics of the obstacle, using multi-term Galerkin’s approximations. Again, Mirdula studied wave scattering by a thick submerged rectangular wall with a gap in finite depth water, using multi-term Galerkin’s approximations involving ultra-spherical Gegenbauer polynomials. Mridula extended their work to study the wave scattering from the thick rectangular slotted barrier for an arbitrary number of slots with unequal slot length as well as unequal length of the wetted portions of above mentioned barriers.

Sahoo et al. considered four different configurations of permeable barriers; surface piercing; submerged; barrier with gap; and bottom touching, to estimate reflection coefficients, different shapes of elements are also investigated and the same are compared with that of circular elements. In another experimental study, hydrodynamic performance of a slotted screen of four different porosities with circular elements in regular and random wave fields, are investigated. The numerical predictions and experimental results are reported to be in agreement. Using a Boussinesq equation based numerical model, Balaji attempted to study reflection and transmission coefficient of twin porous barriers. The oscillation of waves between the two porous barriers were measured and reported to be containing partial sub-harmonic resonance, when spacing between barriers to wave length ratio \(B/L\) is of order of 0.2, leading to minimal reflection of incident waves. The wave elevation between barriers when projected in phase plane, revealed more than one periodic attractor, as can be seen in Fig. 10, indicating the presence of multi-frequency oscillations. In addition, magnitude of phase portrait appear larger for \(B/L\approx0.2\), when compared to other \(B/L\) ratio, exhibiting presence of higher wave elevations inside the chamber, due to partial resonance.

In Indian context, some studies have been performed considering fluid of different layered. These distinguish of layers could be because of density difference of fresh river water and ocean water, sediment dissolved and temperature gradient. The hydrodynamic characteristic of dynamic pressures and surface elevations through a mathematical boundary-value problem, as functions of angle of wave attack and different barrier porosities. The importance of porous-effect-parameter for controlling reflection coefficient for above mentioned configurations of barrier is discussed in detailed. According to study, the dissipation of incident wave can be control by adjusting the vertical position of barrier along with porous-effect-parameter. For bottom-standing barrier type, the authors have observed three-dimensional variations of surface elevations, which are attributed to superimposing of incident and phase-shifted reflected waves.

Balaji and Sundar applied boundary integral based Green’s identity method to study wave transformation characteristics of slotted screens, consisting of horizontal wave intercepting elements. The effects of size and shape of individual elements, porosity, and relative depth of submergence of wave screen on its transmission characteristics are investigated. In addition, wave attenuation characteristics of structures depends on the free surface interaction and fluid interface. As a result the reflection and transmission coefficients, wave elevations, wave load on the structures will be vary in compared to single layer fluid and need to be analyzed. Manam and Sahoo numerically approximated the reflection and transmission coefficient of a porous structure for a two-layered fluid medium through simplifying the analytical equation and expressing them in term of Bessel function. The study also involved in estimation of surface elevations at the surface and the interface, along with the amplitude of the force acting on the structure. Later on, Suresh and Sahoo estimated the reflection and transmission coefficients, dynamic force and response of a flexible porous breakwater in a two-layer fluid system. The authors have obtained wave reflection and transmission for both fluid layers and reported that location of fluid interface, density ratio (ratio of density of two-layered), porosity and structural rigidity influence performance.

Balaji et al. estimated reflection characteristics and dynamic pressures exerted on an impermeable wall on leeward side of permeable wave screens due to action of regular waves through theoretical and experimental investigations. The breakwater model consists of two wave attenuating chambers, formed by placing horizontal slotted wave screens consisting of equally spaced circular wave-intercepting
elements. A theoretical model, based on the eigen-function expansion theory for linear waves, is also developed for prediction of reflection characteristics. It is reported that wave reflections are relatively less for dimensionless spacing (width of chamber to wave length, $B/L$) in the range of 0.1-0.4. In another set of experiments, the authors have tested reflection characteristics of a multi-chamber absorber system, which was proposed to be used as an end-flume wave absorber for one of the test facilities.

![Phase portraits of wave elevation measured inside the chamber.](image1)

The porosities of the screens are gradually decreased towards vertical impermeable wall, as can be seen in Fig.11 and reflection coefficients are reported to be less than 0.3 for wide range of wave conditions. Theoretical predictions obtained for multi-chamber system is reported to be in good agreement with experimental results.

![Cross sectional view of wave absorber.](image2)

In an extensively study, Krishnakumar et al.\textsuperscript{59} experimentally tested variety of wave screens, made of wave intercepting elements, by varying the configurations (Fig. 12). The effect of depth of submergence of the seaward side screens on the reflection and transmission characteristics were reported. In addition, set of design formulae were suggested through experimental results for single and double screens to estimate reflection and transmission coefficients. In another study, by the authors, Krishnakumar et al.\textsuperscript{60}, it is reported that dynamic pressures and forces, due to multi-directional wave conditions, on single and double wave screen reduces as against uni-directional waves and reduction is observed to be dominant for lower values of directional spreading index.

![Model setup for double slotted barriers.](image3)

In Indian literatures, good contribution has been reported for the vertical wall type breakwaters which includes; thin barrier, thick barrier, immerge, submerge and bottom sitting. From Indian contrast, most of the studies have been performed considering seabed is flat, except that Mandal and Gayen\textsuperscript{61} who considered the irregular bottom. The study can extend to investigate the influence of several parameters on the hydrodynamic of vertical type barrier placed at irregular bottom of seabed. However, limited research has been reported for water wave scattering in two layer fluids. Hereby, no evidence has been found regarding oblique water
wave scattering in two layer fluid. Moreover, the effect of current in two layer fluid is yet to be remained a scope of future research. In addition for Indian context, no evidence of any numerical model has been found to analyze wave-structure interaction in two layer fluid.

**Other type of breakwaters**

Apart from the standard types of fixed vertical barriers, the horizontal fixed plat is a good wave attenuator long with the control over reflection and transmission of incident wave. In general, most of the kinetic wave energy concentrates near the surface which can effectively control by floating breakwater to give temporary protection to beach from erosion or some meaning full advantages. Several innovative types of breakwaters have been tested by various Indian researchers, which are discussed in this section. Sundar and Dakshinamoorthy\(^\text{62}\) experimentally investigated the hydrodynamic characteristics of fixed plate breakwater model. Experiments were carried out with various depth of submergence of the models to estimate the reflection and transmission of waves. It is reported that the horizontal fixed breakwater effectively attenuated the incident waves than a vertical breakwater for a similar relative depth of submergence. When compared to floating type of breakwaters, fixed type reported to perform effectively. Neelamani and Reddy\(^\text{63}\) experimentally investigated the reflection and transmission characteristics of a fixed horizontal plate, in deep water conditions for wide range of various parameters. It is reported that minimum wave transmission obtained when the plate is kept at the still water level, however the loss of wave energy due to breaking was reported to be maximum when the plate was slightly below the still water level.

Mani and Jayakumar\(^\text{64}\) reported experimental investigation on the transmission characteristics of suspended pipe breakwater. It is concluded that the present model is capable to reduce incident wave height up to 50% when the gap to diameter ratio is 0.22 and draft to water depth ratio is 0.46. The study also estimated the cost effectiveness of the suspended pipe breakwaters against conventional pile supported ones.

Mallayachari and Sundar\(^\text{65}\) developed a two-dimensional boundary integral model to predict wave reflection and transmission characteristics of submerged obstacles of rectangular, trapezoidal and half-cylinder shapes, as shown in Fig. 13. It is reported that reflection coefficients show oscillating characteristics with respect to relative water depth, for all tested shapes and more pronounced by rectangular body.

Ever since semicircular breakwater is successfully built in Miyazaki Port, Japan, the breakwater system has been tested under various conditions to improve its hydrodynamic performance. Sundar and Ragu\(^\text{66}\) reported dynamic pressures exerted and run-up characteristics on semicircular breakwater (Fig. 14) at five different elevations under random wave experimental condition. It was reported that the shape of dynamic pressure spectra is slightly broader than corresponding incident wave spectrum.

![Schematic diagram of semi-circular breakwater](image)

Rao and Rao\(^\text{67}\) and Rao et al.\(^\text{68}\) investigated the performance of single row of suspended cylinder (non-perforated and perforated, Fig. 15) by measuring the wave reflection of incident waves. It was found that reflection coefficient is significantly influenced by submergence, relative water depth and wave steepness. The size of pipes, percentage of perforation, size of perforation and staggering of piles were reported to less influencing the hydrodynamic characteristics. Interestingly, transmission through two rows of pile breakwater is observed minimum when the non-dimensional clear spacing between them is 1, for both the cases of perforated and non-perforated. Later on, Rao et al.\(^\text{69}\) extended their study to measure reflection and transmission characteristics for two rows of perforated hollow piles and reported that the clear spacing between piles significantly affect the reflection performances.
Neelamani and Rajendran experimentally investigated the hydrodynamic characteristics of ‘T’ type breakwater (Fig. 16) under regular and random wave conditions. It is reported that a minimum transmission coefficient obtained for a condition of horizontal barrier of the T type breakwater, immersed to about 7% below the still water level. The breakwater is reported to very efficient in dissipating incident wave energy to a maximum extent of about 65%.

Neelamani and Rajendran tested hydrodynamic performance of ‘┴’ type breakwater under same structural and wave conditions as that of Neelamani and Rajendran. The schematic view of the breakwater is shown in Fig. 17. Interestingly the transmission characteristics of incident wave energy were reported to be as same as Neelamani and Rajendran. However, reflection decreases and energy loss increases with increased wave steepness, especially when top tip of vertical barrier of breakwater is kept at still water level. It is also reported that ‘T’ type breakwater are more effective than ‘┴’ type, by 20 to 30% in terms of hydrodynamic performance.

Neelamani and Vedagiri investigated the performance of partially immersed twin vertical barriers (Fig. 18) for nine different immersions. The wave fluctuation between the barriers is emphasis in regular and random wave experiments. An experimental result showed that, transmission coefficient reduces significantly with increase of relative water depth. However, it is found that twin barrier is better in reducing transmission coefficient and increasing in energy dissipation in random wave experiments than the regular wave experiments.
Fig 18—Schematic view of twin wall breakwater.

Sundar and Rao\textsuperscript{73} investigated the hydrodynamic performance of a pile supported quadrant face breakwater. The effect of spacing between piles on dynamic pressures exerted along quadrant face (Fig. 19) and reflection characteristics under regular waves were studied. In another set of experimental study, the authors have presented hydrodynamic performance characteristics of the breakwater under random wave condition\textsuperscript{74}. It is reported that reflection coefficient for random waves is 10 to 15\% higher than that obtained to test regular waves for all submergence depth of the quadrant front face.

Fig. 19—Schematic sectional view of breakwater.

Dhinakaran et al.\textsuperscript{75} reported dynamic pressures and forces on seaside perforated semicircular breakwater with two different porosities and also compared with that obtained for an impermeable semicircular breakwater. Later, the effects of porosity on seaward and rear side, rubble mound heights on which the semicircular breakwater was kept, depth of submergence on the hydrodynamic characteristics, pressures and forces were studied, in detail, by various authors\textsuperscript{76, 77, 78, 80, 81 & 82}.

Usha and Gayatri\textsuperscript{83} developed an analytical model, based on linear wave theory, to investigate the reflection and transmission of a twin plate breakwater system. The twin plate breakwater consisted of a horizontal plate at the still water surface and an identical submerged plate below that. The performance of twin plate breakwater was compared with surface plate, submerged plate and group of submerged plate in later stage and found that twin plate breakwater is more effective. However, study is limited for two-dimensional case only and could be extended for three-dimensional problem along with the effect of wave height. Neelamani and Gayathri\textsuperscript{84} extensively studied the performance of single and twin plate barriers under the action of regular and random waves in physical model tests. It is reported that the performance of twin plate system is similar to a single plate for certain spacing between plates.

Laju et al.\textsuperscript{85} presented the new concept of skirt type breakwater (Fig. 20) and its hydrodynamic performance through numerical and experimental investigations.

Fig. 20—Schematic diagram of skirt breakwater

It was reported that the transmission of waves depends on the maximum submergence of either the front or rear skirt, whereas, the reflection depends on the submergence of the front skirt. In another study, Laju et al.\textsuperscript{86} investigated effect of single and double row of skirt breakwater on reflection and transmission coefficient as well as oscillation of water surface in between two rows of skirt breakwater through eigen function based theoretical model.

Sankarbabu et al.\textsuperscript{87} presented the theoretically determined hydrodynamic characteristics of dual cylindrical caisson breakwater formed by a row of caissons each of which consisting of a porous outer cylinder circumscribing an impermeable inner cylinder. It was reported that, increase in porosity of the outer caisson resulted in decrease in wave reflection and increase in wave
transmission. The size of inner cylinder reported to play a significant role, an increase in its size result in an increase in wave reflection and transmission.

Rao et al.\textsuperscript{88} carried out physical model studies to evaluate the wave transmission characteristics of a submerged plate breakwater of different orientation (Fig. 21), by varying inclinations and submergence. The effect of wave steepness, relative depth, relative submergence and angle of inclination on the hydrodynamic performance was studied. It is reported that submerged plate with angle of inclination 60 degree is more effective to reduce wave height about 40% than other angles.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig21.png}
\caption{Various plate orientations tested.}
\end{figure}

Mani\textsuperscript{89} modified a pile supported breakwater of Mani and Jayakumar\textsuperscript{64} into a zigzag pile supported breakwater to improve hydrodynamic efficiency (Fig. 22). Experiments are conducted to estimate reflection, transmission and forces on the porous screen. In addition, the author has attempted to measure the wave elevation in between zigzag. This study revealed that wave attenuation does not changed compared to conventional pile breakwater but a significant reduction in reflection coefficient was observed due to the presence of porous screen and zigzag position of piles. The reflection and transmission coefficients, obtained from the experiments were compared with that of obtained from a theoretical model.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig22.png}
\caption{Zigzag pile supported breakwater}
\end{figure}

Through a laboratory study, Shirlal\textsuperscript{90} investigated wave transmission characteristics of a submerged serrated inclined plate breakwater (Fig. 23). The serrations are made of squares fixed on an inclined plate in two different configurations; zigzag and parallel. It is reported that serrations reduce reflection characteristics when compared to a smooth plate. However, lowest transmission is observed for 60 degree inclined plate with square zigzag serrated. Special types breakwaters are usually made to serve special purpose and it do not follow any standard design procedures.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig23.png}
\caption{Schematic view of serrated plate breakwater}
\end{figure}

Specially, these breakwater play an important role in supportive structure which provide assesses to main breakwater. After continuous existence, these breakwaters convert into a standard breakwater. From Indian contrast good contribution was reported towards these type of breakwaters and expected to be continued for special cases.
PART 2: Floating type

General

Conventional breakwaters like rubble mound breakwaters are widely used, but incurring more cost and more time of construction. Floating breakwaters have proved to be economic compared to conventional bottom connected breakwaters, in mild wave conditions. Floating breakwaters are advantageous, when the foundation at a specific site is poor for fixed breakwater, in deeper water depths, where the construction of the fixed type of breakwaters becomes uneconomical, minimum interference for fish migrations and flow circulations is desired and also where the mobility of breakwater is important. The primary requirement of any breakwater system is to allow minimum wave energy to be transmitted on to its harbor side. The floating breakwaters are broadly classified as; pontoon or box, plate, mat and tethered types. Under these broad classifications, various other forms have been developed with modifications and alterations in their configurations and geometry. With continuous efforts taken to improvise the efficiency of floating breakwater system, various Indian researchers have carried out experimental, theoretical and numerical studies to assess the hydrodynamic performances of the same. This part explores the various studies on floating breakwaters from Indian innovative research perspective. Though the main focus of these studies is to find reflection and transmission characteristics, forces and motion responses of the floating breakwater were also investigated in some of these studies.

Pontoon types

Pontoon or box shapes are one of the oldest forms of floating breakwaters to be studied. Pontoon can offer a platform for the berthing activities and hence have proved to be a better choice for marinas and small craft harbours. Indian researchers have taken efforts to modify the basic form of pontoon into various innovative shapes to improve the wave attenuation characteristics. The different forms of box or pontoon type breakwaters are described in the following sections.

In early Nineties, Mani91 designed a Y-frame floating breakwater (Fig. 24) and measured the efficiency of this breakwater in terms of reflection and transmission of waves. It is reported that fixing a row of pipes with certain length and interval at the bottom of a trapezoidal float helps in reducing the wave transmission.

Murali and Mani92 investigated the performance of cage floating breakwater (Fig. 25) by experimentally measuring the reflection and transmission characteristics and water surface elevation within the cage under wave and wave-current conditions. Results of this study showed that, transmission of wave can be reduced below 50% of incident wave height with gap ratio of 0.22, relative depth of 0.46 and ratio of pontoon width to clear spacing is 1 and a maximum initial tension corresponds to 22.5% of the total displacement of pontoon. Though the stiffness of the mooring lines does not modify the

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Fig. 24—Cross sectional view of Y-Frame breakwater.

Fig. 25—Schematic views of floating cage breakwater.
performance of the breakwater, use of mooring lines was suggested to have sufficient stiffness.

Sannasiraj et al.\(^{93}\) numerically studied the hydrodynamics of long floating structures in directional sea. A rectangular long pontoon (Fig. 26) was considered in this study, which can be used as a floating breakwater, and the diffraction, radiation and motion responses were estimated using a finite element method. It is reported that for mean directions of the waves, other than the normal wave directions, the motion responses reduces.

Sannasiraj et al.\(^{94}\) investigated the behavior of pontoon floating breakwater and the effect of mooring configurations on transmission coefficient through numerical and experimental investigations. Motion responses and mooring forces of three different mooring configurations (Fig. 27) were analyzed. According to the study, the transmission coefficient is not significantly affected by mooring configurations but higher transmission coefficient is observed for floating breakwater with cross mooring, as the cross mooring leads to a resonant response near the roll natural frequency. The cross mooring was suggested to be inefficient compared to other two configurations.

Sannasiraj et al.\(^{95}\) extended the use of finite element based numerical model to study the hydrodynamics of twin long floating structures, under oblique wave conditions.

The effect of mean wave direction, directional homogeneity on hydrodynamics and the motion response in sway, heave and roll model were reported. The force ratio and the response ratio are evaluated numerically for frequency-independent and frequency-dependent cosine power type spreading functions.

Syed and Mani\(^ {96} \& \ 97\) presented a theoretical model for three pontoon floating breakwater acting as a single unit (Fig. 28) and it's performance was estimated in terms of reflection and transmission. Results of the study revealed that, width between pontoons significantly influence the reflection and transmission characteristics. It was found that a gap ratio of 0.5 gives an optimum band width of frequencies for floating breakwater operation. Further, the breakwater system was analysed with a numerical approach. The diffraction and scattering potentials were obtained by solving boundary element problem using Green's integral method. The solution from numerical model includes forces act on pontoon system, oscillations in the interspaces and reflection coefficient.

![Fig. 27—Definition sketch of mooring configurations.](image)

![Fig. 26—Definition sketch of problem.](image)

![Fig. 28—Definition sketch of three-pontoon breakwater.](image)
Combined use of floating breakwater as a wave energy converting device, Rapaka et al.\textsuperscript{98} tested a floating multi-resonant oscillating column wave energy device, as shown in Fig. 29, for its hydrodynamic characteristics in a laboratory investigation. The motion responses and mooring forces were presented for different mooring line configurations and variety of wave conditions. The effects of mooring line configurations and water depth conditions on the performance were evaluated.

Murali et al.\textsuperscript{99} modified the existing cage floating breakwater of Murali and Mani\textsuperscript{100} by introducing rigidly connected pontoons having a row of cylinders attached beneath. The experiments were conducted under regular and random wave conditions to understand the hydrodynamics by measuring reflection, transmission, energy-loss and motion response characteristics.

Plate types

These types of floating breakwaters consist of a plate structure floating at the surface level to attenuate the wave energy. Sundar and Dakshinamoorthy\textsuperscript{62} experimentally investigated the hydrodynamic characteristics of floating plate breakwater models and the results are compared with that obtained for fixed breakwater model. Experiments were carried out with various depth of submergence of the floating and fixed models to estimate the reflection and transmission of waves. It was reported that the horizontal fixed breakwater effectively attenuated the incident waves than a vertical breakwater for a similar relative depth of submergence. When compared to floating type of breakwaters, fixed type reported to perform effectively.

Arunachalam and Raman\textsuperscript{101} attempted to experimentally investigate the performance of perforated horizontal floating plate breakwater (Fig. 30) for different wave steepness, relative lengths of breakwater and relative depths of draft.

Their study concluded that the transmission coefficient depends on wave steepness and relative length of breakwater, whereas it is less influenced by relative draft. It was found that mooring forces increase with increase in wave steepness and increase in relative draft.

Murali et al.\textsuperscript{99} modified the existing cage floating breakwater of Murali and Mani\textsuperscript{100} by introducing rigidly connected pontoons having a row of cylinders attached beneath. The experiments were conducted under regular and random wave conditions to understand the hydrodynamics by measuring reflection, transmission, energy-loss and motion response characteristics.

Sundar et al.\textsuperscript{102} investigated the performance characteristics of moored plain and perforated plate type of breakwaters with various porosity of horizontal plate, draft, initial mooring tension and wave conditions. The reflection, transmission of waves, motion responses and mooring forces were measured and reported as function of relative width of the floating breakwater. Further, Sundar et al.\textsuperscript{103} introduced a bottom skirt (short vertical thin barrier) at the mid-section of the moored floating plate breakwater, to assess the effect of various skirt depth on the reflection, transmission characteristics, motion response of the floating breakwater, mooring forces and dynamic pressure distribution along the depth of skirt. The skirt breakwater was then rigidly fixed and the experiments were repeated and the results were compared. The reflection of waves was more for fixed plate breakwater, whereas transmission of waves was less, when compared to floating type. The dynamic pressures exerted on the skirt were higher for the fixed plate breakwaters.

Maiti and Mandal\textsuperscript{104} presented a mathematical model for water wave scattering by a thin elastic floating plate in which, the ocean bed is considered as porous material, as shown in Fig. 31. The method of Eigen function expansion was used in the mathematical analysis to estimate the reflection and transmission from elastic plate for different values of porous bed conditions and edge conditions of plate. The edge condition of the plate involved a free edge, a simply supported edge and a built in edge condition and observed that a free edge condition have a prominent effect on the reflection and transmission coefficients.
Pipe types

These type breakwaters consist of connected pipes in different orientation, mostly floats at the surface level. Sundar et al.\textsuperscript{105} investigated the hydrodynamic performance characteristics of a moored floating breakwater (Fig. 32), made of row of horizontally placed pipes, and separated by a distance equivalent to the pipe diameter, through experimental study. The effect of different diameter and their positions on the reflection and transmission of waves, motion responses and mooring forces are examined and reported. The depth of submergence to depth of water ratio of 0.15 is found out to be most efficient to reduce the coefficient of reflection by about 30% and also reduction in the mooring forces on leeward and seaward sides by 60%.

Hegde et al.\textsuperscript{106} studied the performance characteristics of horizontally interlaced multi-layer moored floating pipe breakwater (Fig. 33). Transmission coefficient reported to reduce with the increase in the relative breakwater width for all relative wave heights. Maximum wave attenuation of about 40.5% achieved for relative breakwater width of 1.0 and relative wave height of 0.3. The performance of the floating breakwater was found to be better for configurations with relative width more than 0.7.

Hegde et al.\textsuperscript{107} experimentally measured the mooring forces on a horizontal interlaced moored floating pipe breakwater extending the previous study on the same structure. The forces on the seaward side mooring were observed to increase with the increase in the wave steepness for water depth to width of breakwater ratio values ranging between 0.081 to 0.276 and decreases when wave steepness increases up to 1.3. The wave attenuation and forces in the mooring were found to be lower for relative spacing of 4 than that of 2.

Mandal et al.\textsuperscript{108} used Artificial Neural Network (ANN) model for the prediction of wave transmission from multi-layer floating breakwater. The model was applied for the floating breakwater with 5 different layers of pipes with spacing to diameter ratio of 2, 3, 4 and 5. Two different ANN models were studied one for spacing to diameter ratio and other to study over range of spacing of pipes and its effects. The study showed that the correlation coefficient of ANN depends on the pipe spacing ratio. The increase in the pipe spacing ratio leads to increase in the correlation coefficient.

Vishwanath et al.\textsuperscript{109} reported a physical model study to measure the mooring forces of horizontal interlaced multi-layered floating pipe breakwater and the effect of relative breakwater width, relative wave height and wave steepness on the forces in mooring. The study also showed the peak mooring forces and found maximum for relative spacing 2, wave steepness of 0.420, relative wave height of 0.4 and relative width of 1.2.

Patil et al.\textsuperscript{110} studied the Neuro-fuzzy based approach for prediction of transmission characteristics of a horizontally interlaced multilayer moored pipe floating breakwater. The adaptive neuro-fuzzy interface system has been trained using the physical model based data, obtained from the previous study\textsuperscript{106}. The input parameters that influence the coefficient of transmission were found to be spacing to diameter...
ratio, wave steepness, relative width of the floating breakwater and incident wave relative to water depth. This model claimed to outperform ANN models in predicting transmission coefficients.

A genetic algorithm based support vector machine (SVM) was proposed by Patil et al.\textsuperscript{111} to predict wave transmission characteristics of horizontally interlaced multi-layer moored floating pipe breakwater. The model was trained and tested using the experimental data obtained from an experimental study (Fig. 34). The forecasting performance of model reported to be influenced by the choice of its kernel function, and setting of kernel and SVM parameters. The performance of this model in predicting the reflection characteristics was claimed to be superior than ANN and adaptive neuro-fuzzy interface system.

Further, Hoolihalli and Hegde\textsuperscript{112} reported the wave transmission characteristics of a horizontal interlaced multi-layer moored floating pipe breakwater. Effects of wave steepness and relative breakwater width on the wave reflection and transmission were reported. Patil et al.\textsuperscript{113} reported the performance of moored floating pipe breakwater based on intelligent computing, using the results of earlier physical model studies.

**Summary**

This study involves in comprehensive collection of various historical research studies carried out by Indian scientists and academicians on the understanding of innovative fixed and floating type breakwaters. Overall, the review of the past literatures revealed that the research interest lies in improving the hydrodynamic performances of variety of breakwater types. Interestingly, majority of the studies involved in the experimental investigations. A notable mathematical solution was used to understand the performance characteristics of the innovative breakwaters. However, response characteristics of the floating breakwaters are rather scanty in mathematical modeling. This paper aimed to disseminate the readers the various types of fixed and floating breakwaters tested by the Indian researchers.

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