CHAPTER 2
LITERATURE REVIEW

2.1. General

The present research study deals with the experimental investigation on water surface elevation in the pool, wave reflection from the wall, energy loss and wave forces on the vertical wall defenced by an offshore low-crested rubble mound (LCRB) and semi-circular breakwater (SCLB). An extensive literature review has been carried out; (i) to know the methods and ranges of parameters studied by various investigators on the hydrodynamic behavior of vertical wall structures, offshore low-crested rubble mound and semi-circular breakwaters, and (ii) to bridge the gaps in the information and framing the objectives for the present study.

The concept of using low-crested and submerged breakwaters, as a shore protection structure is not new, but the protection of primary protection structure such as seawall by an offshore rubble mound breakwater, as a defence structure is relatively new. The available literature on the performance of the combined system i.e., vertical wall defenced by low-crested rubble mound (LCRB) is rather scanty and semi-circular breakwater (SCLB) not available, while literature on performance of the low-crested rock structures alone is plenty. Some of the salient features of these reported investigations on the above parameters are reviewed in this chapter.

2.2 Wave Transformation over Low-crested and Submerged Rubble mound Structures.

In many cases of rubble mound structure design, a certain degree of overtopping is acceptable, leading to considerable savings on the quantity of material being used.
Other structures are so low that under daily wave and water level conditions the structure is overtopped. Structures with the crest level around still water level and sometimes far below still water level will always allow wave overtopping and transmission. Low-crested structures have two main design aspects: Stability and the amount of wave transmission. Stability, overtopping and transmission of the rock armoured low-crested rubble mound breakwaters were tested for random waves by Allsop (1983). Damage measurements have been related to stability number and to free board. Stability of the low-crested and submerged breakwaters was described by Van der Meer and Pilarczyk (1990) by analyzing the extensive data sets of the Ahrens (1987), Powell and Allsop (1985), Givler and Sorenson (1987) and Van der Meer (1988) presented practical formulas. They found that for submerged breakwaters significant increase of the stone stability with the increase of the submergence depth. Armor Stability of conventional narrow crested submerged breakwater was examined by Losada and Kobayashi (1992) using a hybrid method based on experimental, numerical and empirical results for solitary waves. They found that significant increase of armor stability with the moderate increase of its submergence.

In present investigation stability of the low-crested or submerged breakwater was not the main focus so we have used the Van der Meer (1987) formulae for the design of the armor unit.

The other design concern was wave transmission or damping action. A number of studies on wave transmission have been published with enough details to make a comparison with other studies useful and possible. Johnson et al.,(1951) performed series of experiments to investigate the damping action of submerged rectangular breakwaters. It was found that a barrier of a given relative height is more effective in
damping steep waves than flat waves. A greater damping effect is obtained when the relative depth is small.

Kabelac (1963) reported the investigations concerning the different shapes of submerged barriers. He reported that the geometrical characteristics like slope of faces, crest width, height of breakwater, etc., are of utmost important in the determination of effectiveness of a submerged breakwater. He also reported that breakwaters with side slopes are better than those with vertical faces and that the dissipation of wave energy with low steepness is determined by crest submersion and the dissipation of steep waves by the crest width.

A comprehensive summary on wave transmission was presented by van der Meer and d’Angremond (1991). They found that wave transmission has a linear relationship between the wave transmission coefficient and the relative crest height. Hall and Seabrook (1998) have developed a design equation for transmission at submerged breakwater using statistical analysis methods. They arrived at this equation from two dimensional and three dimensional physical model settings.

Tanaka (1976) performed monochromatic wave tests that included both submerged and emergent crests as well as a broad range of crest widths. Based on results, he established design curves that give the transmission coefficient as a function of relative submergence and the relative crest width. This definition allows for values greater than unity if wave shoal on a submerged structure. Adams and Sonu (1986) examined wave transmission across a submerged breakwater through three dimensional model tests using random waves. The tests corroborated the trends of Tanaka’s findings within the range of the test parameters and concluded that Tanaka’s
results could serve as a design tool, but be applied with caution as they under predict the transmission coefficients based on the random wave tests.

Nonlinear interaction of water waves with submerged rectangular obstacle has been studied by Massel (1983), Rey et al. (1992), Grue (1992), Ohayama and Nadaoka (1993), Driscoll et al. (1993), Losada (1997). Similar study with a trapezoidal object has been conducted by Beji and Battjes (1993), and Ting and Kim (1994). They found that the incoming waves undergo deformations at the obstacle characterized by harmonic generation. A comparison of results from theory and experiments indicates that inviscid theory cannot accurately reproduce the experimental observations at the lee of the obstacle. The discrepancies between theory and experiment are due to presence of flow separation and energy dissipation, which cannot be modeled by potential theory.

Majority of the earlier works on wave transmission over low-crested and submerged breakwaters have been concentrated on investigating the transmission coefficient. Goda (1985), Tanimoto et al. (1987), Raichlen et al. (1992) and van der Meer (1990) shows that overtopping/breaking generates more waves and mean period reduces to 0.4-1.0 of the incident mean period. Raichlen (1992) and Lee (1994) shows the peak of the measured spectra of transmitted waves similar to incident spectrum, but with much more energy at the higher frequencies.

In the above studies on the wave transmission on low-crested and submerged breakwaters based on the assumption that wave after transmission travels as a progressive wave to the shore without any vertical wall or any other structure on the lee side of the breakwater. Surface elevation measurements in these studies are for progressive waves on leeside of the breakwater. The present study is different from
these conditions, as the reflective structure is being present immediately or close to lee side of the breakwater.

2.3 Wave forces on Vertical wall defenced by rubble mound breakwater

The major design load for vertical wall is the dynamic pressure due to non-breaking or breaking waves. This method fitted well for the force data of steep waves on vertical walls, whereas, Sainflou (1928) method yielded better results for long period waves of low steepness. Older breaking wave force method of Minikin (1963), which is mentioned in SPM (Shore Protection Manual, 1984) results in very high estimates of wave force. These estimates are too conservative in most cases and results in costly structures.

Goda (1974) proposed design formulae for composite breakwater, which accounts for height of rubble foundation, breaking and non-breaking wave pressures and forces. These formulae were based on laboratory data as well as on theoretical considerations. The wave height, $H_{max}$ was recommended as design wave height. Tanimoto et al. (1976) modified the above formulae for the effect of oblique wave approach. This equation was later modified by others to cover variety of conditions. These formulae provide a unified design approach for estimating the design loads on vertical walls and caissons.

Most of the design methods for vertical/steep walls have been developed for caisson breakwaters, and these methods can also be applied to seawalls or related shoreline structures where the relative wave height/depth conditions are in the appropriate range. It has however always been known that direct wave breaking against a wall, perhaps caused by a steep beach slope or toe mound berm, produce a very intense wave load. Wave impact pressures are much greater than those due to pulsating
waves, and studies in Europe have measured pressures up to or greater than \(40\rho gh_s\).

Predictions of occurrence and magnitude of wave loads are often uncertain.

For many coastal seawalls, and for some breakwaters, the design wave condition may be limited by depth in front of the structure. In these cases the larger waves at the structure will be broken and it is mostly unlikely that wave impact loads will be caused.


Based on a discretized boundary integral relation in conjunction with time marching algorithm Sen, (1992) studied pressures and forces on a vertical wall due to normally incident steep waves. This simulation scheme does not involve any analytical approximation of non-linear free surface boundary conditions.

Minimization of incoming wave energy on the vertical face structures has been of interest in the design of coastal structures. Variety of methods have been in place such as, placing energy dissipation blocks in front of the vertical face structure, making porous vertical face (porous wall breakwater), providing defence barrier seaward of the primary protection structure \(i.e.,\) tandem breakwater system.
Perforated breakwaters placed seaward of a vertical impervious wall have been used extensively to reduce wave motion in front of vertical wall breakwaters since their application was proposed in an early study by Jarlan (1961). An important characteristic of such Jarlan-type breakwaters is that wave energy is dissipated within the front permeable wall by viscous effects. Various modifications to Jarlan-type breakwaters have been proposed involving the combination of permeable barrier and an impermeable back wall, filling the rock core in addition to the above combination.

Richey and Sollitt (1970) studied the wave attenuation characteristics of porous walled breakwater that consist of a wave chamber between seaward permeable wall and back impermeable wall. He concluded that reflection coefficient is more sensitive to changes in porosity. They have given a method for dimensioning the breakwater so its natural frequency can be matched to the incident wave system for best performance. The main hydraulic mechanism is that; (1) incident wave passes through the front face of the breakwater so that reflection is reduced and; (2) the interference of the waves on the front and back of the perforated face and the energy dissipation of the water jets issuing from the wall holes.

Fuggaza and Natale (1992) based on linear wave theory analyzed the wave attenuation produced by the permeable structure and proposed a design formulae that can be used for the optimized hydraulic design of Jarlan-type breakwaters. They demonstrated through the results that Jarlan-type breakwater with a single chamber gives the most effective wave reduction in the range of practical applications.

Isaacson et al. (2000) presented a theoretical analysis and an associated numerical model to assess the performance of a breakwater consisting of a perforated front wall, an impermeable back wall, and a rock-filled core. They have compared the reflection
coefficient with Mallayachari and Sundar (1994) for limited data. Isaacson et al. (2000) found that addition of the rock fill reduces the flow through the perforated breakwater and thus the energy dissipation, so that reflection coefficient increases slightly, but the wave force on the impermeable back wall is reduced significantly. It was suggested that for design of the breakwater the relative width should be greater than one. On the similar lines Hu et al. (2002) presented a two dimensional analytical study on the reflection and transmission of linear water waves propagating past a submerged horizontal plate and though a vertical wall and found that breakwater system can effectively reduce the transmitted waves, especially for long incident waves. They have also calculated the wave forces on back permeable vertical wall.

Concept of conventional breakwater and a submerged reef breakwater operating in tandem has been designed by Cox and Clark (1991) for small-craft harbor. Tandem breakwater system found to cost significantly less than a single structure designed to meet the same operating criteria. Because of the depth limiting behavior of the reef, the tandem design posses a lower design risk for extreme events. They found that for very shallow reef conditions, the wave response appears much different; transmission cannot be adequately predicted by linear transmission theory unlike the higher reef conditions in spite of breaking.

There is not much study on the present topic except the experimental work by Gonzalez Madrigal et al. (1990) on reduction of wave forces on vertical breakwater defenced by a submerged breakwater. Mallayachari and Sundar (1994) measured the dynamic pressures on vertical wall fronted by submerged breakwater. Christie Schacht et al. (2001) investigated the seabed reaction and pore pressures due to the water waves with the submerged breakwater, vertical wall and sandy seabed. Their
results indicate that the pore pressure beneath the submerged breakwater is greater than that at the toe.

Based on the monitoring results of a submerged breakwater and resulted model studies in an attempt to reduce beach erosion and wave impact on a protective seawall, Dean et al., (1997) reported that breakwater modifies both the wave and current fields depending on the crest elevation relative to the still water level. And also observed that the volume of water flow over the breakwater is only secondarily affected by the offshore location of the breakwater, however, long-shore currents vary inversely with this distance.

Cox and Clark, (1991) used the tandem breakwater system to restrict the transmitted wave heights to the designed storm wave height on the main breakwater. The observed that tandem breakwater offer significantly reduced design risk since high-return-period events are also reduced to a more manageable level. For partial barrier of any configuration, irrespective of the porosity and flexibility, full reflection always occurs when the distance between the end-wall and the barrier is an integer multiple of half-wave length and hence overturning and moment will vanish (Yip et al., 2002).

Hajime Mase et al., (2004) studied the characteristics of random wave run-up on models of seawalls. They concluded that Rayleigh distribution provides a generally satisfactory representation of random run-up. The predicted model based on the imaginary slope and associated curves, derived from regular waves, gives an approximate upper limit to the measured mean of all run-ups from random waves.
The experimental and numerical investigations on the performance of an offshore submerged breakwater in reducing the wave forces and wave run-up on vertical all were presented in Muni Reddy and Neelamani (2005) and Muni Reddy et al., (2007).

Hong-Bin Chen et al., (2007) presented the experimental results of wave transformation between a submerged permeable breakwater and a sea wall including the variations of wave profile, piling-up of water and the wave run-up. The results show that the wave height transformation behind the submerged breakwater varies in spatial due the transmitted wave being reflected from the seawall.

Yong-Sik Cho (2011) studied the wave set-up between the submerged rectangular impermeable breakwater and rubble mound breakwater and run-up and run-down on the rubble mound breakwater. Carevic, Dalibor et al., (2011) studied through laboratory experiments, the wave load reduction on perforated sea wall defenced by smooth submerged breakwater and reported that wave heights could reduce up to 50% and force reduction on the front wall up to 12-25% in joint action.

Ching-piao Tsai et al., (2012) investigated wave transformation and wave set-up between a submerged permeable breakwater and a seawall. Modified time-dependent mild-slope equations, which involve parameters of the porous medium, were used to calculate the wave height transformation and the mean water level change around a submerged breakwater. Higher wave set-up occurs if the nodal or pseudo-nodal point appears near the submerged breakwater. We also examined the influence of the porosity and friction factor of the submerged permeable breakwater on wave transformation and set-up.

Cox and Clark (1992) built a breakwater defenced by seaward submerged reef structure for protecting a marina harbor at Hammond, Indiana and conducted set of
tests by varying reef submergence, crest width, porosity, spacing etc. and concluded that it could offer significantly reduced design risk and efficient functioning.

2.4 Wave Transformation over Low-crested Semi-circular Submerged Breakwaters.

Due to the advances in the design and construction techniques, new types of breakwaters are being introduced. The semicircular breakwater (SBW) is one such type. The semicircular breakwater was first studied in Japan in the early of the 1990s, and was built at Miyazaki Port in 1993. Small wave force, good stability and low cost are main advantages of this type.

Laboratory experimental data and practical observation show that: no overturning moment is induced for wave force in the structure surface and it passes through the center of the circle. The lateral wave force is smaller than that on a vertical breakwater with the same height. As a result, the stability against sliding is increased while the construction cost is reduces. This type being a hollow structure, it is suitable for soft soil foundation because of small and almost uniformly distributed vertical force acting on foundation. Owing to prefabricated structure, rough sea areas can use it to withstand the large breakwater immediately after installation.

The other characteristic is that it may be not the same time for the maximum horizontal wave force and the wave crest (trough) propagating over the breakwater top, and the maximum horizontal wave force generally generates at the time of the minimum sliding coefficient inducing. Therefore, it is proposed to calculate the wave force at the state of crucial sliding condition.
Sasajima et al., (1994) have reported the results obtained on the measured pressures and forces on the rear wave dissipating type SBW constructed at Miyazaki port in Japan. The variation of measured highest 1/3 wave pressure, pressure at the time of maximum force and maximum wave pressure at different elevations along the wall have been compared with the modified theoretical formulation of Goda (1974). Sundar and Raghu (1997) from their model tests on an impermeable type SBW subjected to regular waves concluded that the reflection coefficient, Kr varied from 0.5 to 0.9 for waves with steepness. The results also indicated that the variation of Kr with H/L is less than its variation with d/L.

Bottom-seated breakwaters are traditionally built to provide sea defence and coastal protection. These structures are generally massive in size, associated with large scales in construction materials, effort and cost. The development of large breakwater schemes may trigger some effects on neighboring coastal environment, e.g. large amount of wave reflection. Waves reflected from the breakwater may pose navigational hazard to small vessels, toe’s scour and even explosive clapotis in front of the structure.

On the whole, the majority of the free surface breakwaters reduce the energy transmitted to the leeside of the structures by wave reflection. In many cases, the effect of wave reflection in front of the breakwater is regarded as a potential risk to the sea navigation. The present investigation is motivated by the need to develop a free surface breakwater that could meet functional, economic and safety requirements.

Although several experimental and theoretical studies have been reported in the literature on the performance characteristics of cylindrical and quadrant front face free surface breakwaters, to the knowledge of the authors, the performance of the
perforated semicircular breakwater (which could be supported on piles or jacket structures) located near the free surface has not yet been investigated. In the present work, a model of a perforated semicircular low-crested free surface breakwater (SCLB) has been constructed and tested under various wave conditions.

The transmission coefficient decrease with increase in percentage of perforations which is due to fact that, provision of perforation dissipates more energy by creating turbulence and the curvature of the structure and decrease with increase in water depth due to a fact that, the effect of the structures on the propagating waves will be less pronounced, since relative depth of submergence is more (Dinakaran et al., 2008).

2.5 Importance of the Present Study

- The information on transmission over the low-crested breakwaters is useful in deciding the crest level of the vertical wall and the sedimentation characteristics in the pool if the system is designed for coastal protection and management. The above information is also useful if the system is designed for rehabilitation measures.

- Information on reflection from the vertical wall and the pool response characteristics useful if the system is contemplating for converting the existing damaged vertical wall as small fishing harbors or marinas. A quantitative assessment of the reduction in transmission and reflection will help in decision making for the investment on low-crested breakwaters.
• Knowledge of wave force acting on wall is important for designing the structural dimensions of the wall and the design of foundation for the wall. A qualitative assessment on force reduction due to the presence of the low-crested breakwater especially for an existing partly damaged structure will help for assessment of structural life extension in the presence of breakwater. For new seawalls with breakwater, the risk of damage is reduced due to reduced wave loads on seawalls.

2.6 Objectives and Scope of the present study

Based on the above critical review of literature, it is observed that the research in the area of wave interaction with vertical wall defenced by an offshore low-crested barrier is scarce, which is a significant gap in the knowledge on hydrodynamics of vertical wall and porous defence barrier. Hence, the primary objective of the present research work is to carryout extensive experimental studies on the hydrodynamic characteristics of combined system of vertical wall and an offshore low-crested breakwater. The results of the investigations can be used both for the design of rehabilitation system and new seawalls with defence barrier on its seaside.

• To investigate experimentally the hydrodynamic performance of a system of vertical wall defenced by an offshore low-crested rubble mound and semi-circular breakwater by measuring
  o dynamic forces on the seawall and reflection from the wall
  o water surface oscillations in the pool between two structures
  o performance evaluation of the Low crested rubble mound and semi-circular perforated breakwaters in terms of energy loss
To investigate the effect of parameters such as
  - depth of submergence of an offshore low-crested breakwater
  - crest width of the low-crested breakwater
  - pool length (location of the low-crested breakwater from the wall) and
  - water depth at the location of low-crested breakwater
  - porosity of the semi-circular low-crested breakwater