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MOORING FORCES IN HORIZONTAL INTERLACED MULTILAYERED FLOATING PIPE BREAKWATER WITH THREE LAYERS

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Abstract: *The paper presents the results of a series of model scale experiments conducted for the study of forces in moorings of horizontal interlaced, multi-layered, moored floating pipe breakwater. The studies are conducted on physical breakwater models having three layers of poly vinyl chloride (PVC) pipes of diameter 25 mm subjected to a wave steepness;* H_i/L *(*H_i *is incident wave height and L is incident wavelength) varying from 0.0138 to 0.0661, relative width, W/L (W is width of breakwater) varying from 0.4 to 2.65 and relative spacing, S/D = 3 (S is horizontal spacing of pipes and D is diameter of pipe). The variation of measured mooring forces on the seaward side are analyzed by plotting non-dimensional graphs depicting* $f_s/\gamma W^2$ *(*f_s *is the force in the mooring per unit length of the breakwater on the sea side, γ is the weight density of sea water) as a function W/L for various values of* H_i/d *(d is the depth of water). The mooring force parameter for sea side (*$f_s/\gamma W^2$*) increases with an increase in wave steepness (*H_i/L*) for a range of* H_i/L *= 0.0138 to 0.0661.*

INTRODUCTION

Invariably, floating breakwaters are conceived either based on the concept of reflecting the wave energy or dissipating wave energy by induced turbulent motion. In recent times, many different types of floating breakwater models have been tested and some have been prototype constructed and their performance assessed. The prime factor in the construction of the floating breakwaters is to make the width of the breakwater (in the direction of wave propagation) greater than one-half the wavelength but preferably as wide as the incident wavelength; else, the breakwater rides over the top of the wave without attenuating the incident wave energy. Further, to be effective, the floating breakwater must be moored in place with both leeward and windward ties; otherwise, it would sag off and ride over the incident wave, a large degree of attenuation of wave heights and less force in the moorings should be the condition to be achieved for optimum design.

The development of floating breakwaters by various investigators has been influenced by several important features - large mass, large moment of inertia, and the combinations of two or more of the concepts of large effective mass or moment of inertia. Most of the literature available indicates that the parameter relative width greatly influences the wave attenuation

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characteristics of the breakwater. The design of a floating breakwater is complicated and is an iterative process due to the interdependency of a number of associated design factors. For example, wave transmission depends on breakwater geometry, mass, and mooring properties. Similarly, mooring forces depend on breakwater geometry and mass. Finally, breakwater structural integrity depends on breakwater geometry, mass, and mooring forces. In the present state of art technology, neither an integrated nor an accepted methodology for the design of floating breakwaters is available. Instead, most designs have been prepared in an ad-hoc manner using one approach for valuation of wave transmission, a separate approach for mooring force determination, and yet another approach for breakwater structural integrity.
Harris and Webber (1968) conducted studies on a model breakwater which consisted of a floating slab of breadth comparable to the length of the wave to be attenuated. It was observed that performance was most sensitive to the area of solid slab per meter length of breakwater, but is sensitive to a lesser degree on overall breadth. Brebner and Ofuya (1968) conducted studies on an ‘A’ frame breakwater to determine wave damping characteristics of a model floating breakwater designed to reduce incident wave heights by processes of wave reflection, wave interference, forced instability of incident waves, and turbulence. Kennedy and Marsalek (1968) devised an empirical equation, and compared results of empirical relation with the experimental results obtained for different conditions. Chen and Weigel (1970) designed three rigid floating breakwaters and added two more later, each making use of a different mechanism or combination of mechanisms of wave energy dissipation and reflection.

Harms (1979) presented design curves for the Goodyear Floating tire breakwater. Two important floating tire breakwater design parameters have been assessed over a practical range of conditions, the breakwater size required for a desired level of wave attenuation and the associated peak mooring force. McCartney (1985) carried out detailed analysis of the various types of floating breakwaters separated into four general categories of box, pontoon, mat, and tethered float. Leach et al. (1985) developed an analytical model to examine the response and efficiency of a rigid, hinged floating breakwater. The theoretical model has been verified experimentally and is used to develop design curves. Based on the experimental and theoretical investigations on the behavior of pontoon type floating breakwaters, Sannasiraj et al. (1998) concluded that theoretical and experimental measurements show good agreement except at the roll resonance frequency.

Murali and Mani (1997) studied conventional floating breakwaters and the feasibility of developing a cage floating breakwater was explored and experiments were conducted to study the performance under wave and wave-current environments. Sundar et al. (2003) studied the hydrodynamic performance characteristics of a floating pipe breakwater (FPBW) model (row of pipes separated by a distance equivalent to the pipe diameter) moored to the flume floor with a slack mooring.

Hegde et al. (2007) conducted experiments on Performance Characteristics of Horizontal interlaced multilayer moored floating pipe breakwaters; A.V Hegde et al. (2008) studied the Mooring Forces in Horizontal Interlaced Moored Floating Pipe Breakwater with Three Layers.

The literature survey carried out clearly indicates that the studies on forces in the mooring lines of horizontal interlaced moored floating pipe breakwater (HIMMFPB) model has not been carried out. Hence, the scope of the present paper revolves around the study of forces in the seaward side and leeward side mooring lines of this type of breakwater (HIMMFPB) models in the regular wave flume of the department of Applied Mechanics and Hydraulics of National Institute of Technology Karnataka (NITK), Surathkal, Mangalore, Karnataka, India. The floating breakwater model is fabricated using universally available polyvinyl chloride (PVC) pipes, which are relatively inexpensive, and effortlessly available everywhere. These moored floating breakwaters may be used to create a temporary harbor area for small size boats, to create a tranquil area around an offshore structure, and to mitigate beach erosion during storm weather conditions. The breakwater model considered in the present study dissipates the energy as the sheet of water passes over the floating pipes. It also dissipates energy by wave breaking over the upper surface of the breakwater in between the openings of the pipes through turbulence and eddies. Inertia of the breakwater itself opposes the orbital motion with reflection of small part of the incident wave.

In the present paper, attempts are made to study the performance of horizontal interlaced, multi-layer, moored floating pipe breakwater (HIMMFPB) with respect to sea side mooring forces in the department of Applied Mechanics and Hydraulics at National Institute of Technology Karnataka (N.I.T.K), Surathkal, Mangalore, India. This breakwater model was tested and found to be stable for waves of 18cm (equivalent to 5.4 m wave height in the field on scale 1:30), which is common during the monsoon season off Mangalore coast, India. The breakwater is assumed to be a flexible and intended to be economical as the material involved in its construction is poly vinyl chloride (PVC) pipes, which are relatively inexpensive and easily available compared to other materials used for the construction of the breakwaters.

DIMENSIONAL ANALYSIS

The dimensional analysis is carried out using Buckingham's π theorem. The variables considered under the present investigations are: W, width of the breakwater; d, depth of water; L, wavelength; H_i, incident wave height; H_t ,transmitted wave height; T, wave period; f, force in moorings per unit length of the breakwater; ρ, mass density of sea water; γ, weight density of sea water; and g, acceleration due to gravity. Considering L, H_i, and ρ as repeating variables, the dimensional analysis yields the following non-dimensional π terms: H_t/H_i (transmission coefficient, K_t), W/L, H_i/L, d/W, H_i/d, and $f/\gamma W^2$ where f is the force per unit length of the breakwater model.

BREAKWATER MODEL

A pictorial representation of the breakwater model in plan and section is shown in Figure 1. The breakwater consists of PVC (poly vinyl chloride) pipes of 25 mm diameter. The pipes are placed parallel to each other with spacing S between them in each layer, and the adjacent layers are oriented at right angles to each other so as to form an interlacing of pipes. In the flume, longitudinal pipes are placed along the direction of propagation of waves and transverse pipes are placed and tied perpendicular to longitudinal pipes. The length of the longitudinal pipes defines the width W of the floating breakwater. It is felt that with appropriate number of pipe layers n, spacing of pipes S, and relative breakwater width W/L, it is possible to achieve a considerable and effective attenuation of incident waves.

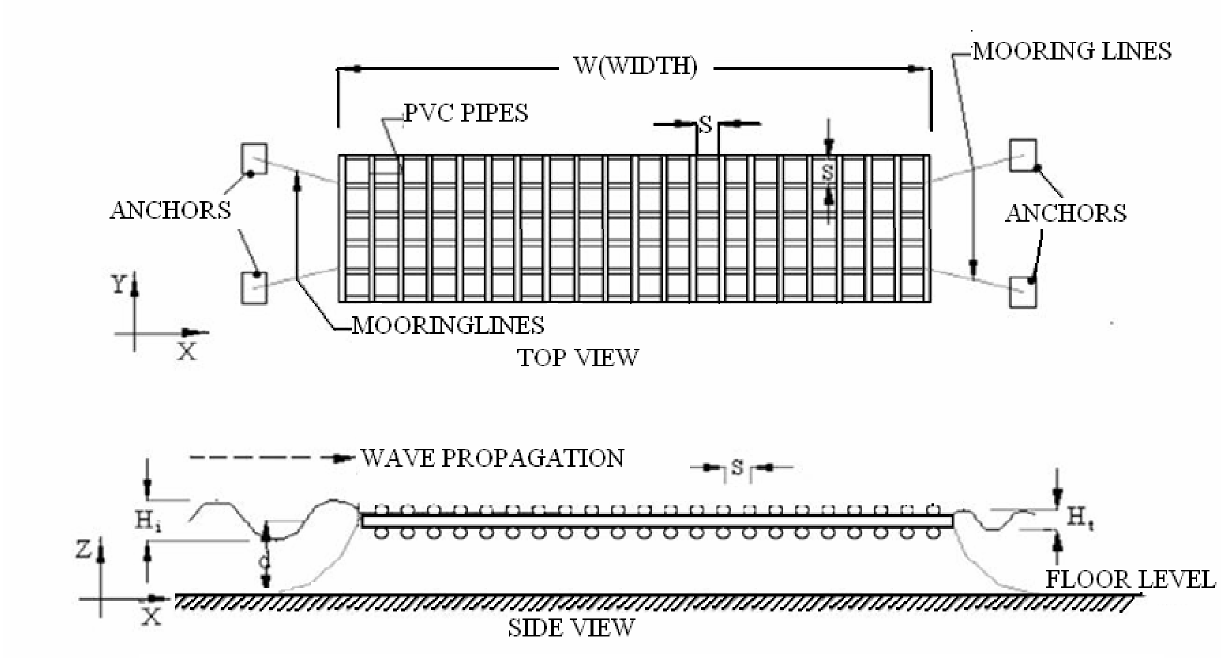

Fig.1. The floating pipe breakwater model setup used in present work

EXPERIMENTS

In the present work, regular waves of different periods and heights as mentioned in Table 1 were generated for W/L ratios of 0.4 to 2.65. The depth of water considered as 500 mm, 450 mm, 400 mm. A spacing to diameter ratio S/D = 3 was adopted. Based on the W/L ratios used, the range of breakwater widths arrived were from 0.77 m to 5.45 m. Waves are generated in bursts of 5 waves only, in order to avoid wave distortion due to reflection and re-reflection from the breakwater structure and the wave paddle. After each burst, wave generation was stopped till tranquility was achieved in the flume. Thereafter, next burst was generated. The breakwater model was placed in the flume at a distance of 28 m from the wave generator flap. (Figure 2).

SCALE FACTOR

The floating breakwater model was constructed to suit the prototype maximum wave height of 5.4 m and a maximum water depth of 15 m. A geometrically similar scale of 1:30 was adopted and hence, the range of model wave heights was 60 mm to 180 mm for water depths of 500 mm, 450 mm and 400 mm. Based on this scale ratio, the model to prototype scale factors were obtained using Froude's model law.

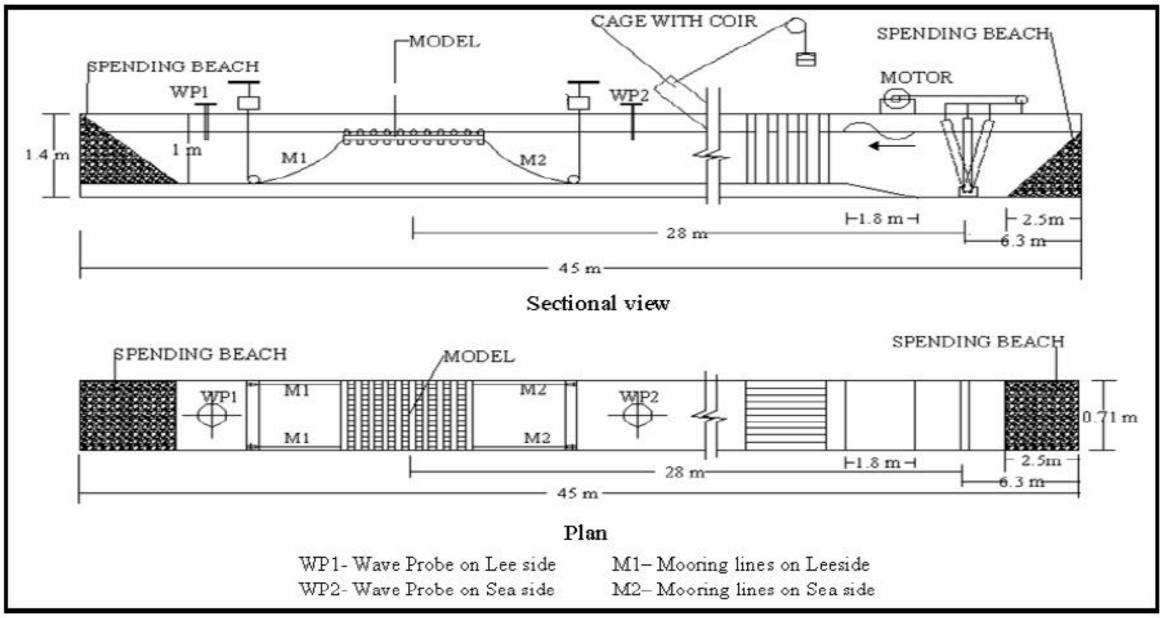

Figure 2. Regular wave flume setup for the present investigation

Table 1. Details of wave-specific and structure-specific parameters considered in the present study

Wave-specific parameters	**Experimental range**
Incident wave height, H_i (mm)	60, 90, 120, 150, 180
Wave period, T (sec)	1.2, 1.4, 1.6, 1.8, 2.0, 2.2
Depth of water, d (mm)	500, 450, 400
Structure-specific parameters	**Experimental range**
Diameter of the pipes, D	25 mm
Ratio of spacing to diameter of pipes, S/D	3
Relative breakwater width, W/L	0.4 to 2.65
Number of layers, n	3

Results and discussion

The variations of dimensionless seaside mooring forces with H_i/L for a range of d/W values are shown in Figures 3 to 9. The variations of dimensionless sea side mooring forces with W/L for a range of H_i/d values are shown in Figures 10 to 12.

In general, the graphs reveal that there is an increase in force parameter with increase in H_i/L and decrease in force parameter with increase in W/L values. This behavior is in agreement with the investigations carried out on floating breakwaters by Mani (1991) and Harms (1979).

Effect of wave steepness on force parameter

In general, as the incident wave steepness increases the force parameter increases. This tendency is obvious since, an increase in wave height relative to wave length causes high energy to impinge on the structure hence; there is an increase in force parameter.

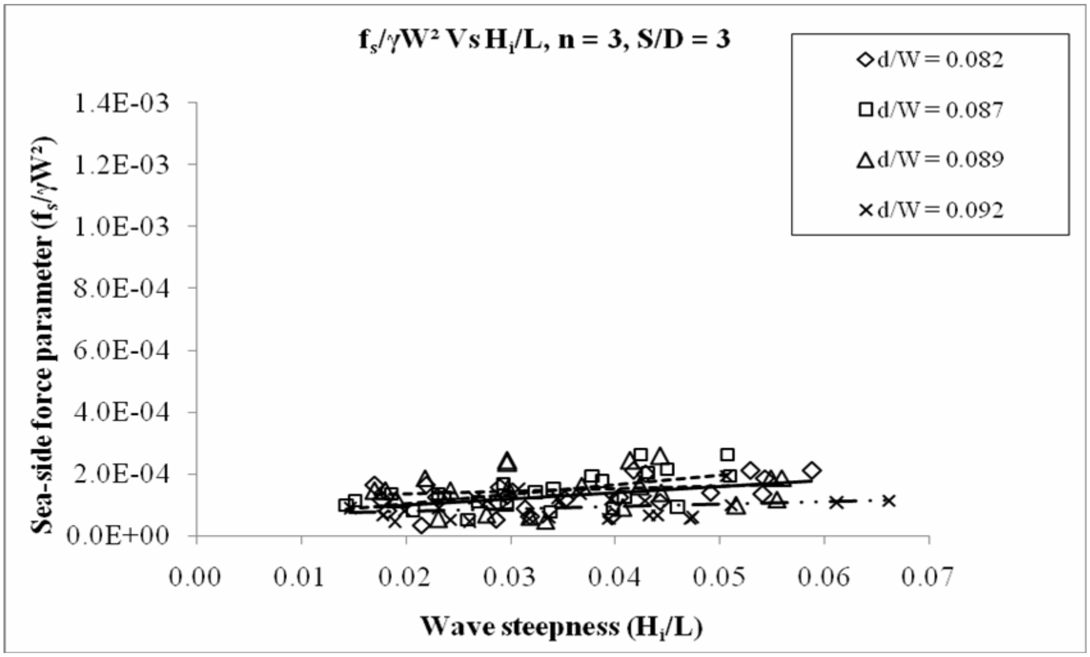

Fig 3. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.082 to 0.092

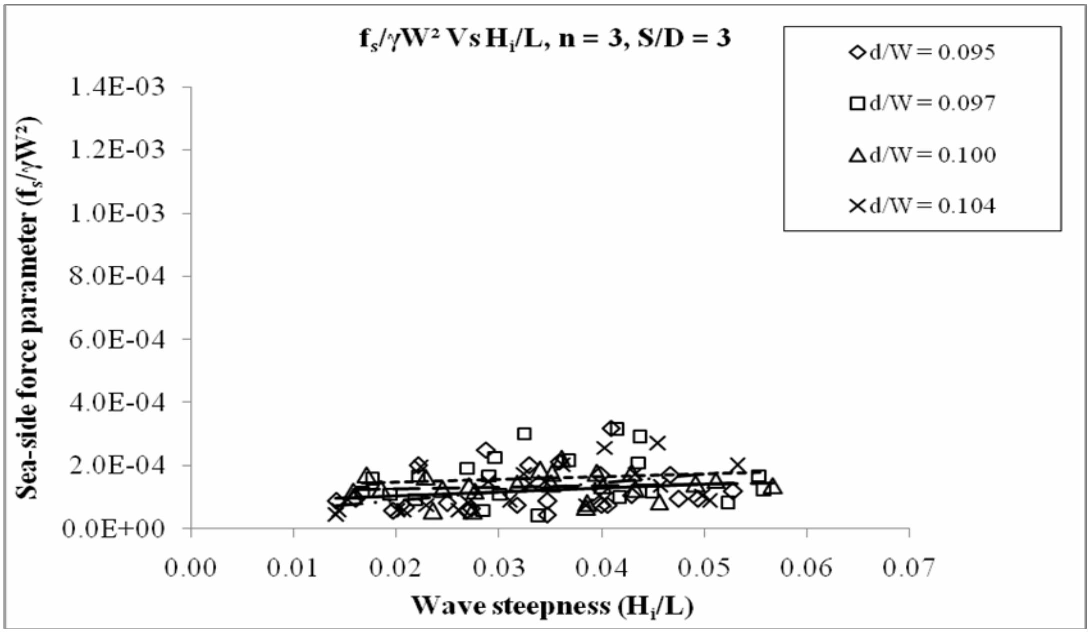

Fig 4. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.095 to 0.104

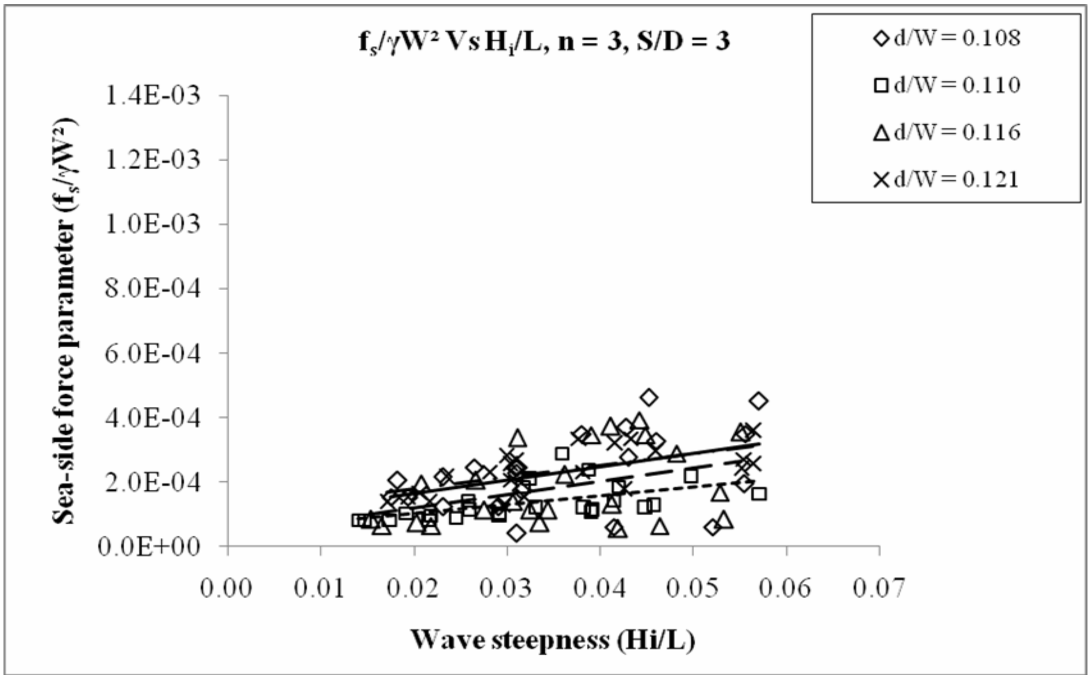

Fig 5. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.108 to 0.121

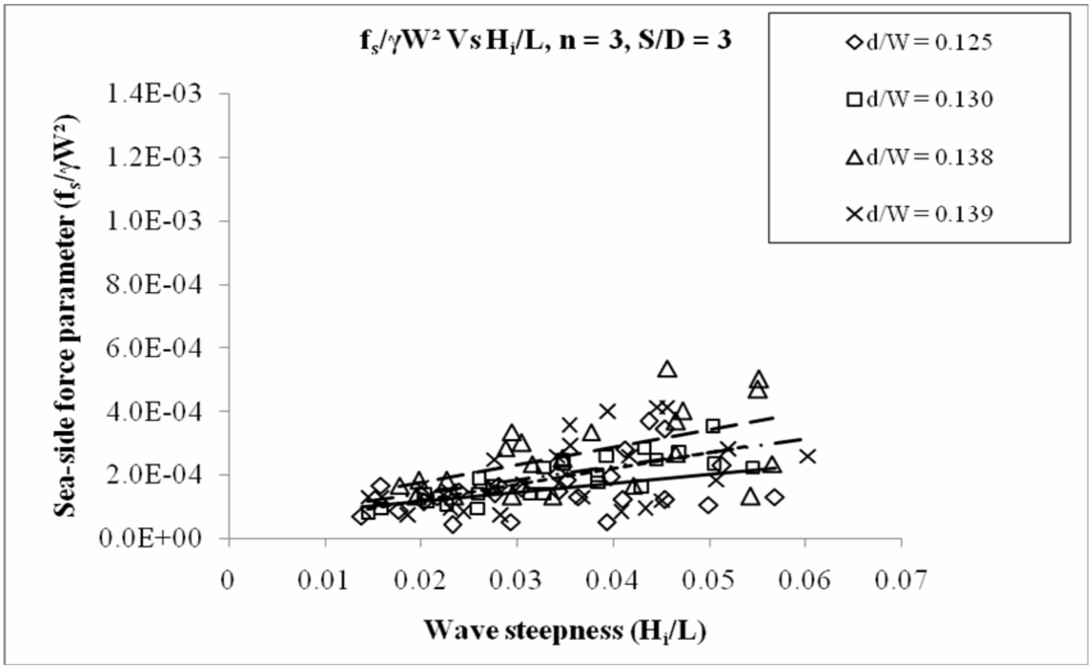

Fig 6. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.125 to 0.139

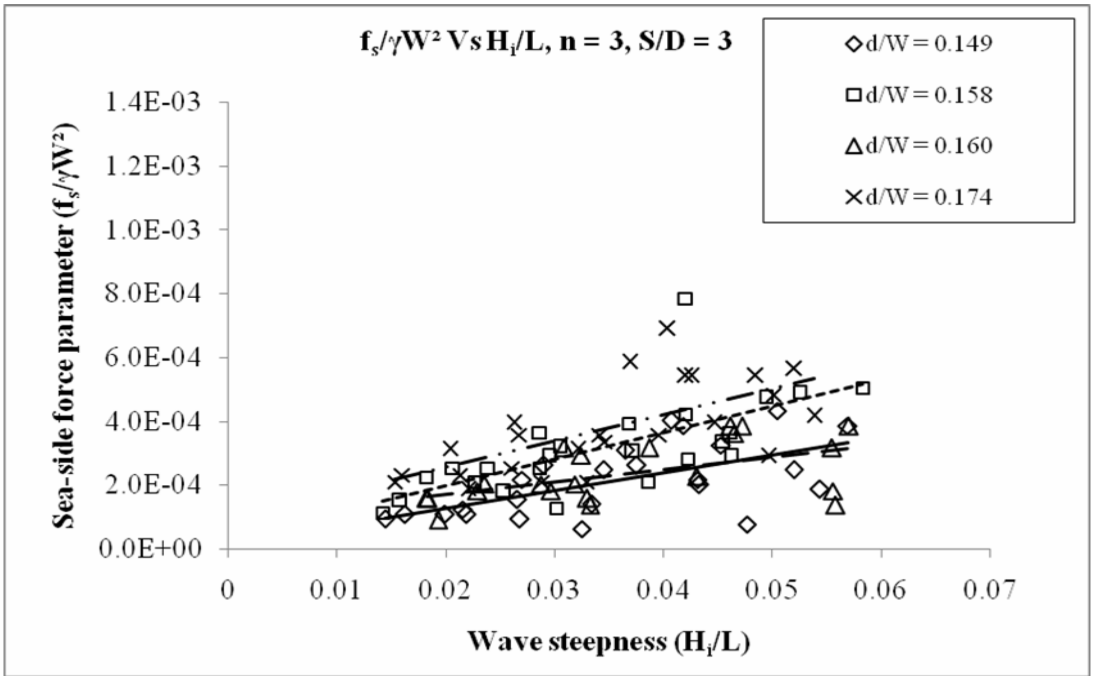

Fig 7. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.149 to 0.174

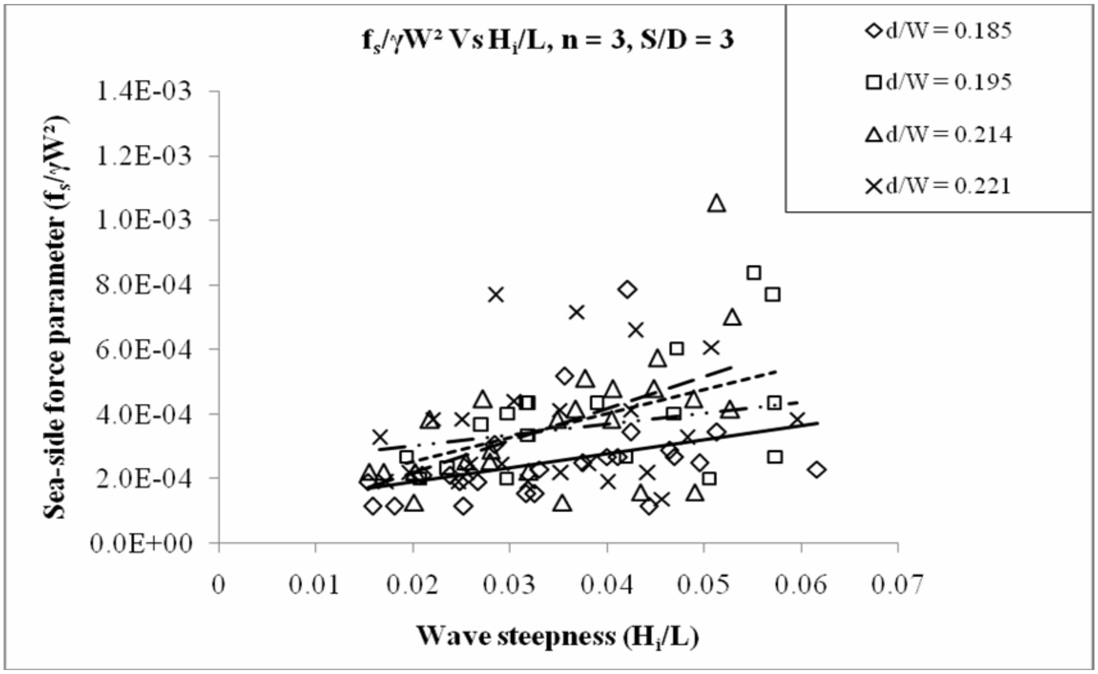

Fig 8. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.185 to 0.221

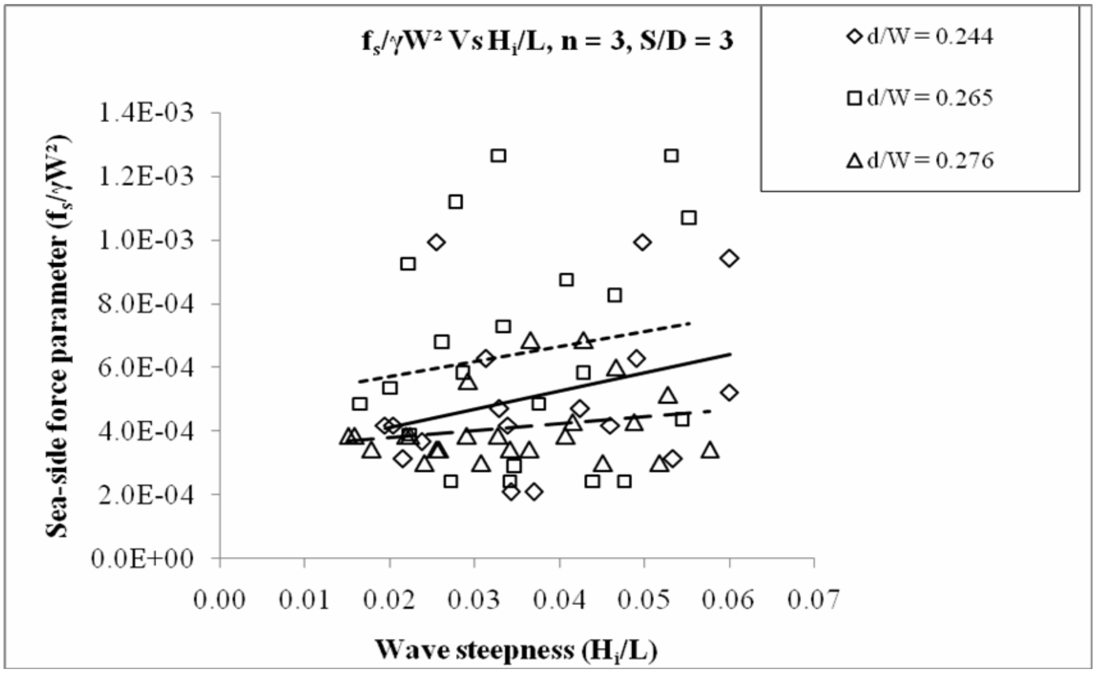

Fig 9. Variation of $f_s/\gamma W^2$ with H_i/L for n = 3, S/D = 3 for d/W = 0.244 to 0.276

The variations of force parameter with wave steepness, with d/W as a parameter are shown in Figures 3 to 9 for the sea side mooring forces. There is an increase in sea side mooring force parameter with an increase in H_i/L. An increase in wave height relative to wavelength causes high energy to impinge on the structure and hence there is an increase in force parameter. The graphs also indicate the influence of d/W on force parameter. The force parameter increases as d/W increases. The probable reason for this behavior is as W increases relative to d, the breakwater width is such that the presence of both the crest and the trough of the wave on the breakwater leading to lower forces on the moorings. Further, it is observed that for d/W = 0.082 maximum force parameter attained was 2.11E-04 and for d/W = 0.276, the maximum force parameter was 6.88E-04. Hence, it clearly indicates the influence of d/W on $f_s/\gamma W^2$.

Effect of relative breakwater width on force parameter

Relative width (W/L) of the breakwater plays a significant role on force parameter. As the relative breakwater width increases the force parameter decreases because for higher W/L values, the wavelength is lower than the breakwater width, leading to the presence of both crest and trough resulting in lower force in mooring lines.

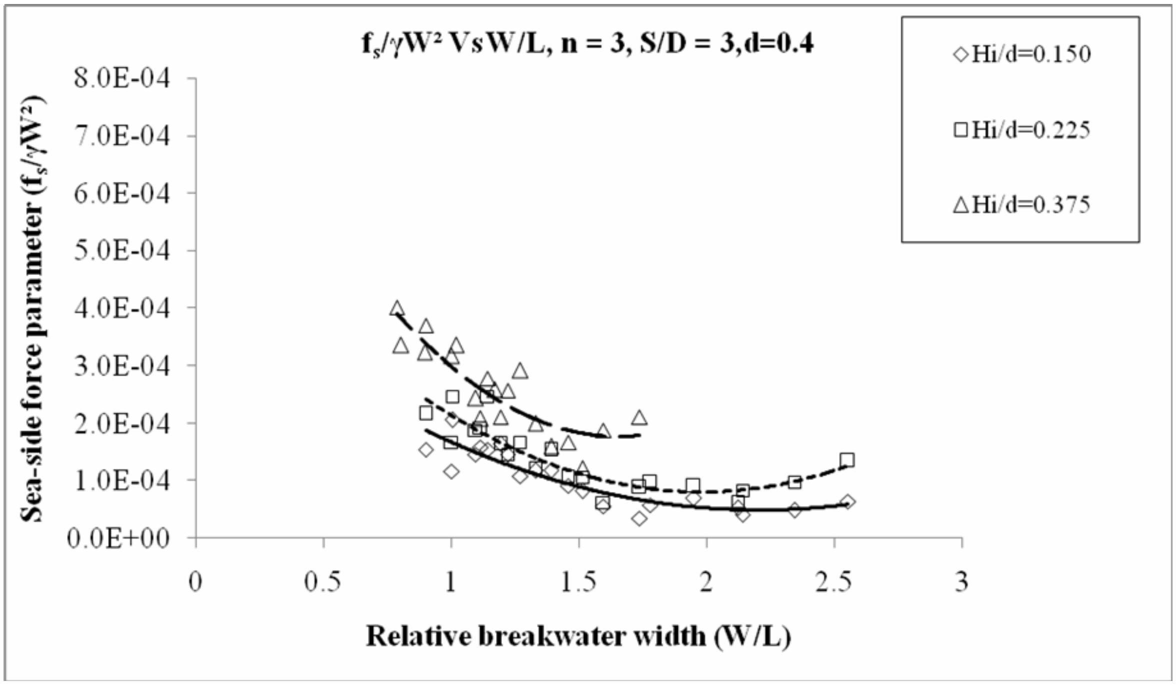

Fig 10. Variation of $f_s/\gamma W^2$ with W/L for n = 3, S/D = 3 for H_i/d = 0.150 to 0.375

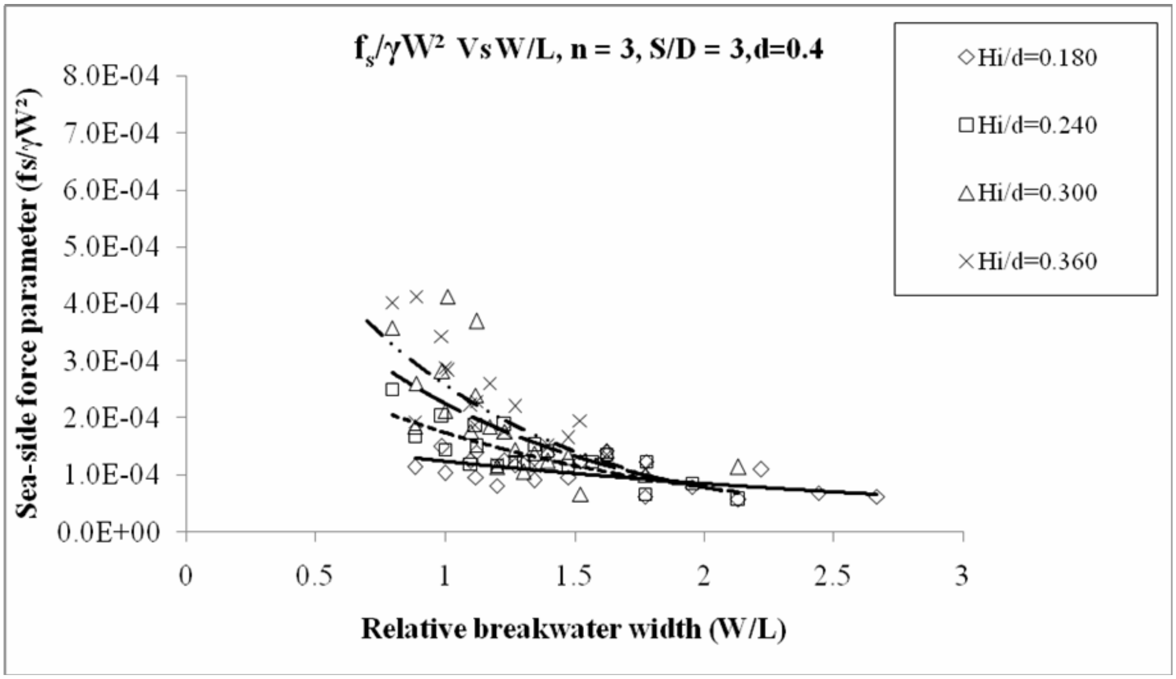

Fig 11. Variation of $f_s/\gamma W^2$ with W/L for n = 3, S/D = 3 for H_i/d = 0.180 to 0.360

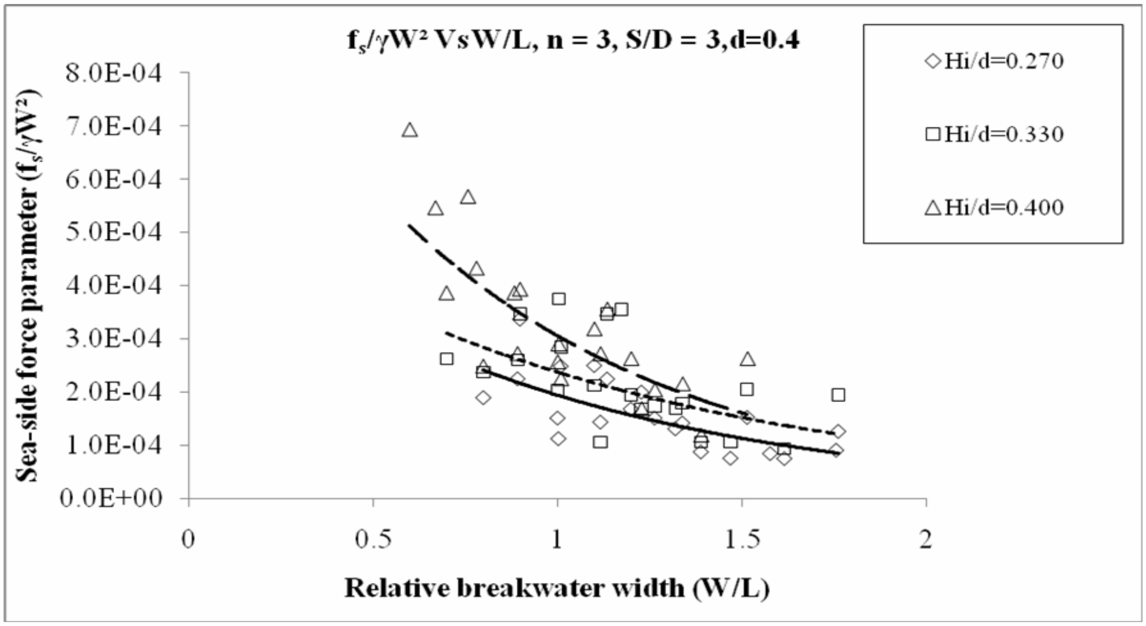

Fig 12. Variation of $f_s/\gamma W^2$ with W/L for n = 3, S/D = 3 for H_i/d = 0.270 to 0.40

Figures 10 to 12 show the variation of force parameter with relative breakwater width (W/L) and H_i/d as parameter for sea side mooring forces. The graphs show that decrease in force parameter with increase in W/L up to W/L = 2.65. The probable reason for this behavior is that for a smaller W/L value, the wavelength is longer than the breakwater width leading to the presence of either the crest or the trough resulting in higher force in mooring lines as there is no counter balancing of force implied by the crest or the trough. As W/L increases, the wave length is shorter or equal to breakwater width leading to the presence of both crest and trough of the wave leading to decrease in forces in the moorings. The graphs also reveal that as H_i/d increases an increase in the value of $f_s/\gamma W^2$ is observed. Further, it is observed that for H_i/d = 0.150 maximum force parameter attained was 2.06E-04 and for H_i/d = 0.400 maximum force parameter was 6.93E-04. Hence, it clearly indicates the influence of H_i/d on $f_s/\gamma W^2$.

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