Proceedings of the International Conference on Civil, Structural and Transportation Engineering
Ottawa, Ontario, Canada, May 4 – 5, 2015
Paper No. 293

Hydrodynamic Performance Evaluation of Step Floating Breakwaters through Experiment and Artificial Intelligence

Morteza Kolahdoozan, Omidreza Taheri, Hadi Ghasemi
Amirkabir University of Technology/ Department of Civil and Environmental Engineering
424 Hafez Ave, Tehran, Iran
mklhdzan@aut.ac.ir; omidrezataheri@aut.ac.ir; hadighasemi@aut.ac.ir

Abstract- A new type of floating breakwaters (FBs) is introduced by changing the longitudinal section of π-shaped FBs into a stepwise shape. The hydrodynamic performance of so-called step floating breakwaters (SFBs) is evaluated through 144 experiments on SFBs of different types as well as π-shaped FBs. Initially, using the experimental data, the performance of SFBs was evaluated by comparison against π-shaped FBs with similar width and draft depths. The experimental data were then used to develop a model for predicting transmission coefficient of SFBs through Support Vector Machines. The accuracy of this model was assessed through statistical indices like Correlation Coefficient and Root Mean Square Error and was found to be satisfactory. The experimentally obtained data which were further extended using the developed model were utilized for assessing the performance of SFBs when various geometrical and hydrodynamic parameters changed.

***Keywords*:** floating breakwater, transmission coefficient, physical modeling, Support vector machine.

1. Introduction

Floating breakwaters (FBs) have been specially regarded in recent years by marine industry specialists for protecting beaches and marine structures against invasion of short period waves. FBs provide numerous advantages over fixed breakwaters including better compatibility with the environment, mobility and easier installation, lower manufacture and construction costs and enhanced applicability in deep waters and in areas with loose sea bed conditions.

The transmission coefficient (C_t) parameter is usually used for measuring the efficiency of a FB and is calculated through Eq. 1. In this equation H_i and H_t are the heights of incident and transmitted waves respectively.

$$C_t = \frac{H_t}{H_i} \qquad (1)$$

The efficiency of FBs with different shapes has been investigated by many researchers (Brebner and Ofuya, 1968, Fugazza and Natale, 1988, Murali and Mani, 1997, Mastunaga et al., 2002, Liang et al., 2004, Dong et al., 2008, Ozeren et al., 2008, etc) addressing various hydrodynamic conditions. A review of these researches show that the shape of FB can influentially affect its performance. Pontoon FBs are among the standard shapes used for manufacture of these breakwaters. The parameters affecting the performance of Pontoon FBs have been extensively studied in recent years (Sutko and Haden, 1974, Drimer et al., 1991, Tolba, 1998, Koutandos et al., 2005). The results of these studies have revealed that the width and draft depth of Pontoon FBs are too important regarding their efficiency. Further researches on Pontoon FBs have been dedicated to introduction of π-shaped FBs (with increased draft depth), double and multiple FBs (with increased width) and a combination of them while the efficiency of the proposed FBs was compared against Pontoon FBs (Koftis and Prinos, 2006, Gesraha et al., 2006, Abdolali et al., 2011, Pena et al., 2011). These researches unveiled that addition of fins to Pontoon FBs and changing them to π-shaped FBs leads to an efficiency increase. Also, double and multiple FBs have been shown to provide remarkably better performances than single FBs. The manufacture and maintenance costs of these FBs is, however, considerably higher than single FBs.

On the other hand, soft computation techniques such as artificial neural network (ANN), fuzzy logic (FL), supporting vector machine (SVM) and other optimization algorithms have been recently incorporated in engineering problems. Nevertheless, few researches have utilized these techniques for predicting transmission coefficient of FBs. Patil et al. (2011) used adaptive neuro fuzzy inference system (ANFIS) for predicting transmission coefficient of pipe multi-layer FBs. In their study the appropriateness of ANFIS method for predicting transmission coefficient was under consideration. Later on they combined SVM regression and genetic algorithm (GA), for predicting the same parameter (Patil et al., 2012). In their study, the utilization of GA for optimizing the vector machine parameters are examined and base on obtained results it was concluded that the GA-SVM algorithm is useful for the intended purpose.

The effect of step addition in longitudinal section of π-shaped FBs is studied here. In this regard, hydrodynamic performance of various types of SFBs and π-shaped FBs with similar widths and draft depths was evaluated, initially, using physical modeling method. A model was then developed for predicting transmission coefficient of SFBs using experimentally collected data and SVM method. The developed model was, subsequently, used for investigating the performance of SFBs in wider ranges of parameters than those considered in the experimental program.

2. Methodology

2. 1. Experimental Equipment

The length, width and depth of the flume used in this study are, respectively, equal to 11, 0.3 and 0.4 meters. The flume is made up of Plexiglas sheets with 1 cm thickness. The used flap type wave generator was able to generate regular waves with 1.3 to 3 second periods that were less than 18 cm high. At the end of the flume, a wave absorber made up of porous wooden fibers was installed to prevent wave’s reflection. The water surface level was measured using wave gauges installed around the breakwater. Two wave gauges were installed at the sea side which were responsible for measuring time series and separating incident and reflective waves, while another was used at the beach side for gauging the transmitted waves. Accuracy of these wave gauges was 1mm and sample frequency was up to 100 Hz. Fig. 1 shows the flume and the used equipment from an overall view.

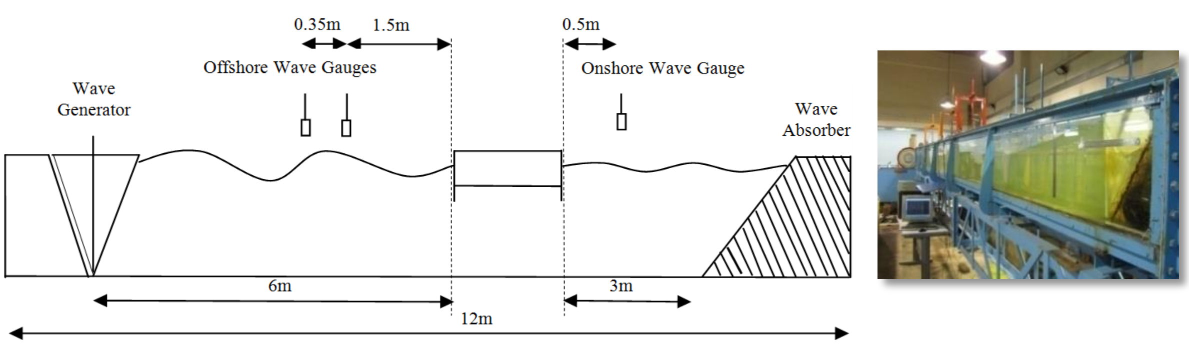


Fig. 1. The overall view of the wave flume; the wave tank (right) and the experimental equipment (left)

2. 2. FB models properties and test conditions

Four different models of SFBs and π-shaped FB with similar widths and draft depths are considered in this study. All models are made up of 6 mm thick Plexiglas sheets and their drafts have been adjusted by placing weights inside them. Geometrical characteristics of different models are illustrated in Fig. 2.

The width and draft depths of all models are selected to be 35 and 14 cm respectively. In order to assess the effect of relative draft (ratio of draft depth to water depth) on the performance of SFBs, all models have been tested in three 30, 25 and 20 cm water depths. Wave periods have been set to vary between 1.3 and 2.2 s and the height of incident waves varied from 2 to 8 cm.

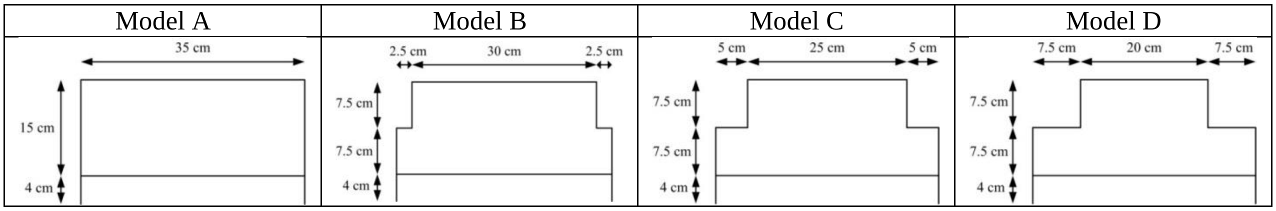


Fig. 2. Characteristics of various floating breakwater models

Manufacturing the SFBs will clearly consume less material than production of π-shaped FBs. The material weight reduction percentage provided by models B, C and D are, respectively, 4%, 7% and 11% in compare with model A.

Experimental FB models are allow to move in the vertical direction (Heave motion). To provide this freedom, four aluminium rails connected to the flume sides have been used. These rails could restrain the horizontal movement of the models along with its rotation about the longitudinal axis.

2. 3. Support Vector Machine (SVM) method

To assess the performance of SFBs in a more extended range of parameters than that considered in the experiments, the SVM method is utilized. The SVM method is a combination of support vector classification (SVC) and support vector regression (SVR) that provide one of the most accurate and most powerful data mining algorithms. The SVM concept was founded by Vapink (1995). The theoretical basis of the SVM algorithms is formed by statistical learning theory. A superior characteristic of these algorithms is their independence from data dimensions. Besides the strong mathematical reliance on statistical learning theory, successful application of SVMs in scientific and practical fields have been approved.

SVMs are learning systems that use a hypothesis space that is called feature space and contains linear functions with large dimensions. A learner machine is responsible for finding a continuous function with real values that can accurately predict output values in correspondence to each input value. This system is trained using a learning algorithm that relies on optimization theory.

2. 4. Performance Evaluation Method for Models

The performance of the SVM method in predicting transmission coefficient of the models has been evaluated using a number of commonly used statistical indices. The correlation coefficient (CC) and root mean square error (RMSE) are utilized for this purpose which are defined as follows.

$$CC = \frac{\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \overline{X})^2 (Y_i - \overline{Y})^2}} \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2} \tag{3}$$

In above equations, Y and X represent, the predicted and measured transmission coefficient values respectively. while N denotes the number of data available in the collection. $\bar{Y}$ and $\bar{X}$ also denote, the average of predicted and measured transmission coefficient values respectively.

3. Discussion

The results obtained for various studied models are illustrated in Fig. 3. In this figure the variations of transmission coefficients versus H_i/L is shown, with H_i being the height of incident wave and L the wave length. According to the figure, all studied SFBs have shown better performances than π-shaped FBs with similar widths and draft depths. This observation reveals that introduction of steps in longitudinal section of π-shaped FBs leads to an improved performance of FBs in addition to the reduced material used in their manufacturing. This figure also show that models with larger step widths have exhibited better hydrodynamic performances than those with smaller step widths. From above comparison, it can be concluded that increasing steps width will positively affect the hydrodynamic performance of SFBs.

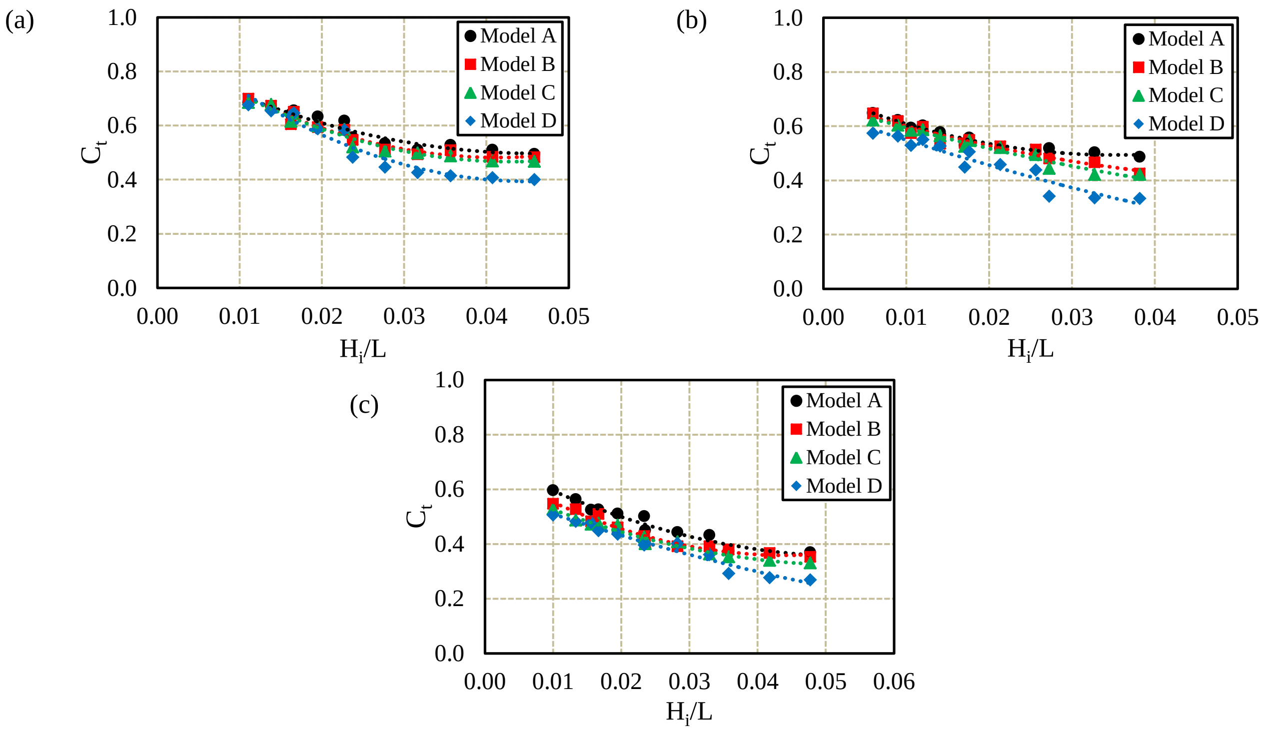


Fig. 3. Comparison of hydrodynamic performance of various experimented models. a) water depth=0.3 b) water depth=0.25 c) water depth=0.2

As previously mentioned, the SVM method has been incorporated, in this study, for predicting the transmission coefficient values beyond the parameter ranges considered in the tests in order to provide more extended performance evaluations. For this purpose, the dimensionless parameters H_i/L (previously described), *B/L* (with *B* being the lower width of the breakwater), *dr/d* (with *dr* being breakwater's draft depth and *d* the water depth) and *S/B* (with *S* being the step width) have been chosen as the input parameters of SVM model and the transmission coefficient parameter (C_t) has been used as the output. Also, 75% of the experimental data have been used for training the models and the remaining 25% have been addressed for evaluating its performance in predicting the transmission coefficient.

In order to train the SVM model, various function kernels such as polynomial, linear and radial basis function (RBF) have been examined and the RBF kernel was found to provide the most accurate predictions. The SVM model has two parameters *C* and *ε* and the RBF kernel function depends on the parameter *γ*. These parameters should be determined by the user and the accuracy of the model is highly sensitive to their values. A search algorithm has been utilized in this study for selecting the values of these parameters so that the value of RMSE index computed based on the measured and predicted values could be minimized. The ultimate values selected for *C*, *ε* and *γ* parameters mentioned above are 100, 0.005 and 0.85 respectively.

After selecting the optimal values for the above parameters, the SVM model was trained using the training data set and its accuracy was assessed using the test data set. Table 1 presents the evaluation parameters of SVM model. Fig. 4 draws a comparison between the transmission coefficient values measured through the tests and those predicted via the proposed model.

Table. 1. Statistical measures for SVM model.

	CC	RMSE
Training data	0.9758	0.0218
Testing data	0.9586	0.0285

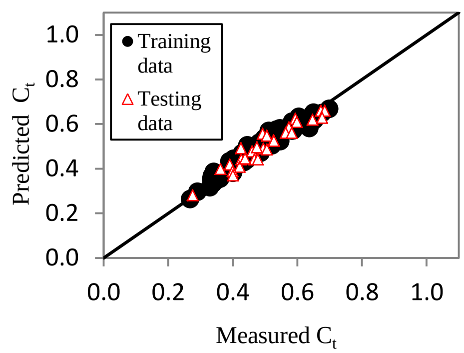
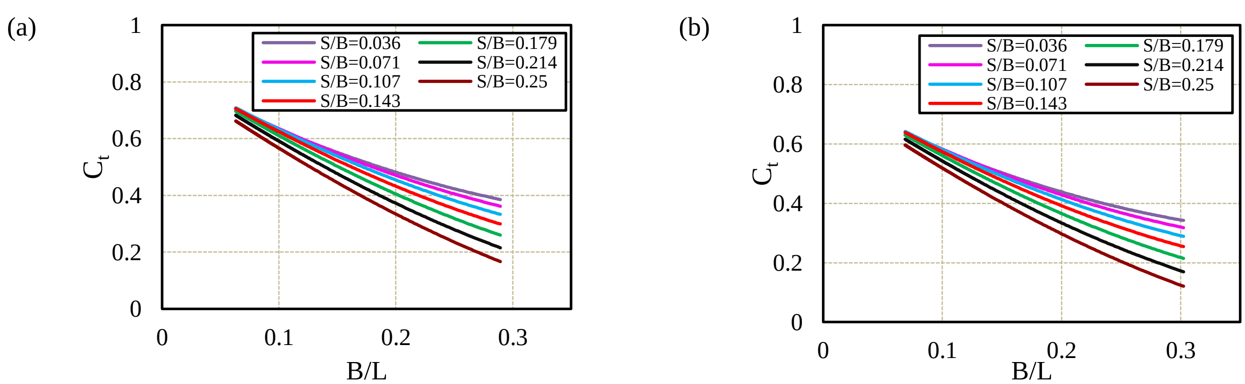


Fig. 4. Comparison of predicted and measured C_t for SVM model.

The results depicted in Fig. 4 and tabulated in Table 1 approve the superiority of the predictions performed by the developed model as the comparison between predicted and measured data suggests. This model is, therefore, said to be suitably capable of predicting the transmission coefficient of SFBs and is employed for extending the experimental observations. Figures 5, 6 and 7 present these data and are used for evaluating the performance of SFBs in a more extended range of parameters.

Fig. 5 depicts the variations in transmission coefficient of SFBs versus the values of the *B/L* parameter.



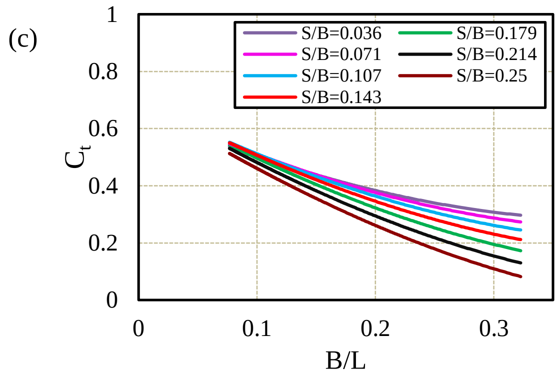


Fig. 5. The effect of B/L parameter on transmission coefficient of SFBs in different S/B values.
a) dr/d=0.47 b) dr/d=0.56 c) dr/d=0.7

The various curves shown in this figure are related to different values of the *S/B* parameter. According to this figure, the transmission coefficient of SFBs decreases as the *B/L* parameter increases. In addition, an increase to the *S/B* parameter has led to an improvement to the SFBs performance. The degree of this improvement is not, however, constant and increases with increase of *B/L* parameter. The figure's curves also show that changing the *dr/d* parameter does not noticeably affect the distance between different branches. Therefore, it can also be concluded that increasing the *S/B* parameter is more effective in larger *dr/d* values according to the larger performance improvement percentage provided.

The graphs depicted in Fig. 6 show the changes in transmission coefficient of SFBs against *dr/d* parameter.

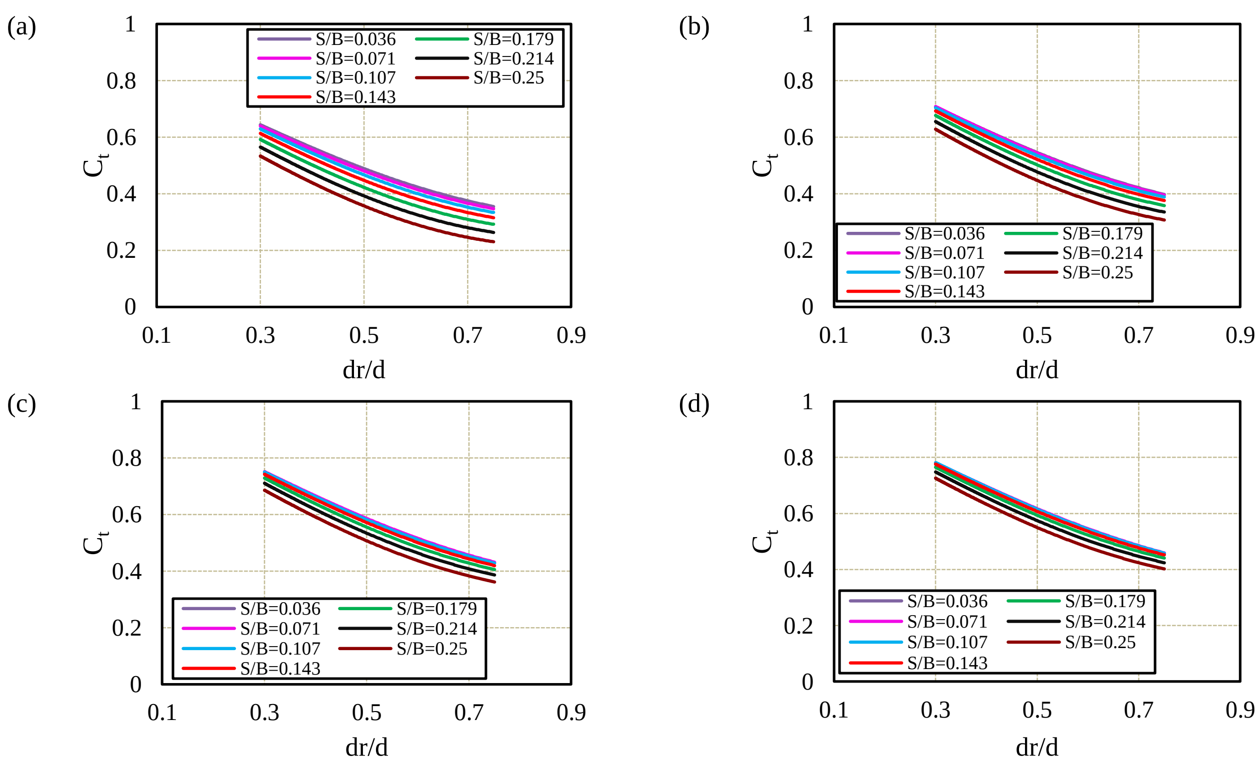


Fig. 6. The effect of dr/d parameter on transmission coefficient of SFBs in different S/B values.
a) T=1.3 b) T=1.6 c) T=1.9 d) T=2.2

The various branches present in this figure show different values of *S/B* parameter. According to this figure, an increase in the *dr/d* leads to reduction of transmission coefficient of SFBs. Again, elevation of the *S/B* parameter results in an improvement to the performance of SFBs. According to this figure, the distance between various branches remains almost unchanged by changing the value of the *dr/d* parameter leading to the conclusion that the effect of *S/B* parameter is more pronounced in larger values of *dr/d* parameter. Ultimately, comparing the various graphs presented in Fig. 6, it can be stated that increasing the period of incident waves causes the different graphs to get closer which in turn decreases the effect of *S/B* parameter.

The graphs presented in Fig. 7 illustrate the hydrodynamic performance of SFBs when characteristics of the incident waves change. This figure's graphs depict the changes in transmission coefficient of SFBs due to changes in the period (*T*) of waves. The various branches presented in this figure are related to different heights of incident waves (H_i). According to the graphs in this figure, with reduction of incident waves' period and increase of their height, the transmission coefficient of SFBs is decreased. Comparison of different graphs reveal that, with increase of *S/B* parameter, the graphs' slopes are elevated and the distance between them is remained nearly constant. Therefore, reducing the period and increasing the height of incident waves yields in a performance improvement of SFBs whose percentage is elevated with increase of *S/B* ratio. In other words, the effect of *S/B* parameter is more pronounced in case of waves with shorter periods and larger heights.

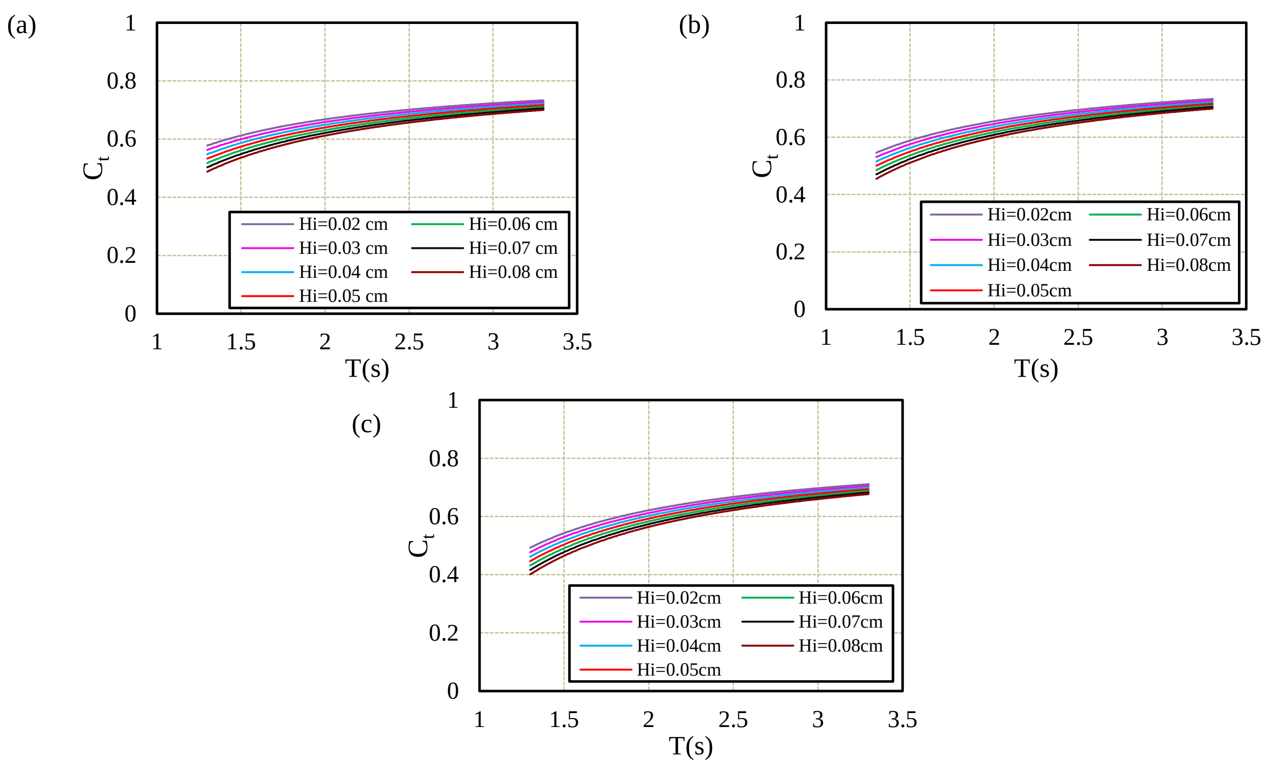


Fig. 7. The effect of incident waves' characteristics on transmission coefficient of SFBs.
a) S/B=0.071 b) S/B=0.143 c) S/B=0.214

4. Conclusion

Physical modeling method was used in this article to assess hydrodynamic performance of step floating breakwaters (SFBs) and to draw comparison between the performance of these floating breakwaters (FBs) and π-shaped FBs with similar widths and draft depths. The support vector machine (SVM) method was subsequently used on the experimental data to develop a model for predicting transmission coefficient of SFBs and was utilized for further extending the obtained experimental data. The following conclusions can be highlighted from this study.

- Changing the longitudinal section of π-shaped FBs to a stepwise shape leads to their hydrodynamic performance improvement in addition to the material usage reduction.
- The SVM method provides a satisfactory means for predicting the transmission coefficient of SFBs.
- Increasing the parameters *B/L*, *dr/d* and *S/B* as well as reducing the period and increasing the height of incident waves lead to reduction of transmission coefficient of SFBs.
- The effect of *S/B* parameter on hydrodynamic performance of SFBs is more pronounced in larger values of parameters *B/L* and *dr/d* and in subjection to waves with shorter periods and larger heights.

References

Abdolali A., Franco L., Bellotti G., Kolahdoozan M. (2012). Hydraulic and numerical modeling of the performance of p-type floating breakwaters. "The 10th International Conference on Coasts, Ports and Marine Structures, ICOMPAS," Tehran, Iran, Nov. 19-21.

Brebner A., Ofuya A.O. (1968). Floating breakwaters. "Proceedings of 11th Conference on Coastal Engineering," London, United Kingdom, pp. 1055-1085.

Dong G.H., Zheng Y.N., Lia Y.C., Teng B., Guan C.T., Lin D.F. (2008). Experiments on wave transmission coefficients of floating breakwaters. Ocean Engineering, 35(8-9), 931-938.

Drimer N., Agnon Y., Stiassnie M. (1992). A simplified analytical model for a floating breakwater in water of finite depth. Applied Ocean Research, 14(1), 33–41.

Fugazza M., Natale L. (1988). Energy losses and floating breakwater responses. Waterway, Port, Coastal and Ocean Engineering, 114(2), 191–205.

Gesraha M.R. (2006). Analysis of P shaped floating breakwater in oblique waves: I. Impervious rigid wave boards. Applied Ocean Research, 28(5), 327–338.

Koftis T., Prinos P. (2005). 2D-V Hydrodynamics of double floating breakwaters. "Fifth International Conference on Coastal Dynamics," Barcelona, Spain, April 4-8, pp.1-14.

Koutandos E.V., Prinos P., Gironella X. (2005). Floating breakwaters under regular and irregular wave forcing: reflection and transmission characteristics. Hydraulic Research, 43(2), 174-188.

Liang N.K., Huang J.S., Li C.F. (2004). A study of buoy floating breakwater. Ocean Engineering, 31(1), 43-60.

Mastunaga N., Hashida M., Uzaki K. (2002). Performance of Wave Absorption by a Steel Floating Breakwater with Truss Structure. "Proceeding of the twelfth international offshore and polar engineering conference," Kitakyushu, Japan, May 26-31, pp. 768-772.

Murali K., Mani J.S. (1997). Performance of cage floating breakwater. Waterway, Port, Coastal and Ocean Engineering, 123(4), 172-179.

Ozeren Y., Wren D.G., Altinakar M., Work P.A. (2011). Experimental investigation of cylindrical floating breakwater performance with various mooring configurations. Waterway, Port, Coastal and Ocean Engineering, 137(6), 300-309.

Patil S.G., Mandal S., Hegde A.V., Srinivasan A. (2011). Neuro-fuzzy bases approach for wave transmission prediction of horizontally interlaced multilayer moored floating pipe breakwater. Ocean Engineering, 38(1), 186–196.

Patil S.G., Mandal S., Hegde A.V. (2012). Genetic algorithm based support vector machine regression in predicting wave transmission of horizontally interlaced multilayer moored floating pipe breakwater. Advances in Engineering Software, 45(1), 203–212.

Peña E., Ferreras J., Sanchez-Tembleque F. (2011). Experimental study on wave transmission coefficient, mooring lines and module connector forces with different designs of floating breakwaters. Ocean Engineering, 38(10), 1150-1160.

Sutko A., Haden E.L. (1974). The effect of surge, heave and pitch on the performance of a floating breakwater. "Proceedings of the Floating Breakwater Conference," Newport, Rhode Island, April 23-25, pp. 41–53.

Tolba E.R. (1998). Behavior of floating breakwater under wave action. Ph.D. Thesis, Suez Canal University, Port Said, Egypt.
Vapnik V. (1995). “The Nature of Statistical Learning Theory”, Springer, NY.