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INVESTIGATING THE PERFORMANCE OF SUBMERGED HORIZONTAL PLATES AS WAVE BARRIER

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ABSTRACT

The wave transmission and energy dissipation characteristics were investigated experimentally in the Hydraulics Research Institute (HRI) wave basin. A horizontal surface wave plate barrier was used in order to study its engineering characteristics and to establish its design criteria. .The investigation was carried for a wide range of wave heights and periods using JONSWAP spectrum. The structure was placed and tested at three different water depths. The plate moved up to test different submergence depths. It was found that, the submerged horizontal plate reduced the transmitted wave and increased the wave energy dissipation.

تم دراسة وإختبار البلاطات الافقية المغمورة (كحاجز للأمواج) معمليا فى معهد بحوث الهيدروليكا بهدف دراسة الخصائص الهندسية للبلاطات المغمورة وإيجاد التصميم الهيدروليكى المناسب لها.
وتم استخدام مجال واسع من الموجات الممثلة معمليا بأطوال وإرتفاعات موجية مختلفة وبأزمنة دورية مختلفة وأيضا تمت الاختبارات عند ثلاثة اعماق للماء وعلى أعماق غمر مختلفة لمعرفة خصائص هذا النوع من المنشآت وقد أثبتت نتائج الإختبارات المعملية أن إستخدام البلاطات الافقية المغمورة كاحواجز أمواج لا تعوق نفاذية الماء فوق وأسفل البلاطات فهى ايضا تقلل من معامل إنتقال الموجات وترفع من معامل التشتت للموجات.

***Keywords*: ** Transmission coefficient, Energy dissipation coefficient, submerged plate, Relative plate width, relative submergence dept

1. INTROUDUCTION

Coastal protection attracts attention from public authorities and engineers. Different types of traditional breakwaters were used but they usually have negative impacts. They hinder the water exchange between the open sea and the protected area and obstruct the view over the open sea.

The submerged horizontal plate is considered to be a porous wave barrier that can reduce these impacts. Actually, there is insufficient knowledge about their design. Therefore, the present research was put on track to find out sufficient data for the design of such structure.

2. PREVIOUS INVESTIGATIONS

Many researchers investigated submerged plates. Among them are:

Kee. [1] Investigated the coupled mechanism of wave energy dissipation by a submerged porous plate and by a submerged solid plate. He found that, wave resonance caused destructive interferences and stimulating wave energy dissipation.

Park, et al. [2] studied numerically and experimentally the wave absorbing performance of fully submerged system which was composed of multi-layered horizontal porous plates. They attributed that it had an excellent efficiency in energy dissipation. Subba Rao, et al. [3] had examined the results of physical model studies conducted in a monochromatic wave flume to evaluate the wave transmission characteristics of a submerged horizontal plate breakwater consisting of a fixed plate of 0.50 m length and 0.003 m thickness and found that, the horizontal plate was effective for short waves with steepness parameter higher than 5×10-3 in relative depth grater than 0.21. Xiping et al. [4] employed the linear analysis to determine the semi-emperically breaking inceptive condition between the local waves over the plate and the incident wave. Also they carried out a laboratory experiment to verify the semi-empirical established breaking condition, and found satisfactory agreement between the experimental observation and the semi-empirical prediction. Graw. [5] Through some experiments that undertaken in his institute, he concluded that the submerged plate as a wave filter was good enough to carry out a detailed research program to describe all parameters influencing the efficiency of that structure. Moreover, Neelamani et al [6] have carried out experimental investigations on ‘T’ type wave barriers, the effect of adding a vertical barrier along with the horizontal plate barrier in reducing the wave transmission was brought out in this investigation. Neelamani et al [7] studied the wave transmission and reflection characteristics and wave induced pressures on single surface plate and twin plate barrier through experimental investigation for a wide range of wave heights and periods in regular and irregular waves, and found that the hydrodynamically the effect of twin plates gave better results in reducing the wave transmission and increasing the wave reflection. Yu [8] has thoroughly reviewed and consolidated important research findings on horizontal plate breakwater and explained the influence of various parameters like plate length, submergence, inclination, porosity, vibration, currents, wave irregularity and non-linearity on wave transmission. He found that minimum value of K_t occurred with the values of B/L = 0.3–0.44 and d_s/d = 0.2. K_t values were reported to vary somewhat periodically with the increase of B/L, where:

- K_t is the wave transmission coefficient (ratio between incident and transmitted wave height [H_t/H_i]).
- B is the plate width
- L is the wave length of the incident wave.

A review of the available literature underlines the potential of plate breakwater for partial wave attenuation. The review also indicated that, the most of recent studies focused on the uses of wave plate as energy converter a little bit researches shows the potential of this structure as wave barrier, so until now there are some areas where the analytical formula were inadequate or missing and the physical hydraulic models is the only method.

3. EXPERIMENTAL WORK

Laboratory experiments, procedures and measurement of wave transmission through the Submerged Horizontal Plate System (SHPS) were carried out in a wave basin at the Hydraulics Research Institute (HRI), National Water Research Center (NWRC), Delta Barrages, Egypt. This study was done within the technical cooperation established between HRI and Civil Engineering Department, Faculty of Engineering, Minufiya University.. This research studied the mechanism of wave transmission, and velocity profiles under a wide range of design conditions. The wave height, wave period, water depth, plate width (in terms of row numbers), structure arrangement configurations, depth of submergence and velocities beneath the submerged plate were considered in this investigation.

4. LABORATORY FACILITIES AND INSTRUMENTATION

Regarding the implemented facilities, The proposed structure was constructed to be a flat steel surface due to economical reasons. Two supports were used in the form of steel pipes. The submerged plate attenuates waves by propagating the orbital motion of the water particles from a certain water depth to relatively a smaller water depth. The wave energy transmission mechanism was by the plate crest width. Therefore the width of the submerged plate was the main concern of this study in addition to its crest level measured from the top water level. A definition sketch and details, general view of a unit of the SHP model were shown in Figs. 1 and 2.

***The wave basin of the HRI* was used to** perform the experiments. The basin is 34m long, 31m wide and 1m height. Both sides of the basin wall boundary are made of concrete bricks as shown in Fig. 3. At the downstream/end of the basin, a flexible wave absorber was constructed of hollow plastic panel ramp with a slope of approximately 1:10. A wave absorber was installed to help in absorbing wave energy and reduce turbulence reflection velocities. The upstream end of the basin was equipped with a wave generator. Six wave probes "wave height meter" were installed. Two wave probes were at a distance of 2m from the wave generator, two wave probes in front of the structure, one wave probe was installed on the lee of the structure and one wave probe was installed on the lee of the structure parallel to the previous one but in the unprotected area. Two current meters were placed (i.e. one in front of the structure and other one in the lee of the structure) to measure the velocity around the SHP model. The maximum water depth in front of the wave generator can reach 0.50m. Large size rock was placed in the back of the wave generator and in the other side of the wave generator to absorb the wave and to reduce the reflection effects which may result from the model boundary.

As for the wave generating system, it was manufactured by Delft Hydraulics, The Netherlands. It is 25m long and installed in the wave basin. The wave generator consists of 96 paddles; each of 26.5 cm width and 40 cm height. These paddles were connected with joints to the hydraulic-type piston, Fig. 4. The wave generator comprises of an electric control and switch unit control panel. The signal for the wave generator was controlled by a PC and the CED 1401 converter control interface. The limitations of the wave generator for wave heights in the model were 2.0 cm as minimum and 15.0 cm as maximum. The wave generator produces unidirectional regular or JONSWAP spectrum wave condition.

Regarding the measurements devices, the available measuring devices of the HRI were used in the present research. These facilities were wave height meters and electro-magnetic current meters.

The wave height meters were arranged in the basin, Fig. 5

The ***wave height meter*** was designed for dynamic fluid level measurements. It was composed of two parts; a gauge with integral pre-amplifier, and a separate main-amplifier, Fig. 6. The gauge consisted of two parallel stainless steel rods, above which a small box exists. It contains the pre-amplifier and the DC-DC converter. The rods act as the electrodes of an electric resistance meter. The dimensions of the wave meter including electronics were 70cm x 8cm x 9cm. The output of the probe was 0.05 VDC/cm of the level variations.

5. MODEL CONSTRUCTION

The model was conducted in a wave basin with scale 1:40. The basin is constructed of free surface plain concrete floor equipped by a wave generator (25 meter long) to produce the required wave train.

Segments were manufactured from wood and were used to form the bed configuration. A leveling instrument was used to place these segments with the designed levels. A design slope of 1:25 was chosen to simulate the bed slope, Fig. 7. The bed material composed of highly compacted sand that was dumped at the model using a small dumper, and then forming the bed slope to reach to the final model bed configuration. Fig. 8 shows the final bed configuration according to the desired bed slope.

6. MODEL CALIBRATION

The generated irregular waves were calibrated to ensure that the produced waves with defined wave amplitude are equivalent to the required wave. The calibration was executed once at the early beginning of the experimental work. The wave height meters placed in the deep water facing the wave generator were used. Table (1) shows the calibration results. This was done in order to determine the required amplitude value for each wave height. It was found that almost the average generated wave height and wave periods were equal to the required designed values.

7. TEST PROGRAM AND MEASUREMENTS

192 runs were designed for the experimental runs. The hydrodynamic measurements were executed in three series for the different structure location. In each series the submerged horizontal plate system was examined under 4 “wave condition, plate width, and submergence depth”.

With different arrangements and plate width (number of rows) of SHP, the flow characteristics around the model structure were observed. Table (2) provides a summary of the program test.

8. RESULTS AND DISCUSSIONS

The attenuation efficiency of submerged horizontal plate (SHP) was quantified (i.e. by its transmission and dissipation coefficients) the transmission coefficient describes the amplitude of the transmitted wave relative to the incident wave.

The reflection coefficient was neglected due to the fact that the submerged horizontal plate has very small influence as it doesn't block the flow over and beneath the plate (i.e. the wave reflection depends on returning momentum.) As the average wave energy reflection and wave energy transmission characteristics of the structure are known, the wave energy dissipation coefficients can be calculated. The dissipation coefficient K_L is obtained by using the equation $K_L = (1- K_r - K_t)^{0.5}$. Wave dampening characteristics of SHP for different types of row system are presented in the section below. Finally, comparison of wave transmission (K_t), and wave energy dissipation (K_L) for 1-row to 4-row SHP system in three different water depths and 4 wave condition for each case was obtained and plotted

8.1 The effect of plate characteristics on (K_t) and (K_L)

The submerged horizontal plate system (SHP) has been tested under different conditions related to its geometry as shown in Figs. 9 and 10, and the characteristics of the induced waves.

Where:

Hs: The significant wave height (generated)
Hi: The incident wave height (generated)
Ht: The transmitted wave height (generated)
B : Plate Width
d : Total water depth
ds: submergence depth
L_P: Plate Length parallel to shoreline
L : Wave Length

The results of K_t and K_L for the SHPS were plotted with different wave conditions and different water depths, where the ratio of B/L varying between 0.074 and 0.55.

8.2 The Results of K_t and K_L with [d/L_P =0.025]

The plate system was tested under four different wave height where Hs/d = 0.375, 0.625, 0.875, and 1.25. The relative plate width B/L was ranging between 0.078 and 0.56. The results showed that, the K_t decreases as B/L increases and the minimum values were observed with ds/d=0.2. As shown in Fig. 11, the K_t value decreased to be 0.42, 0.40, 0.46, and 0.50 with Hs/d = 0.375, 0.625, 0.875, and 1.25 respectively at ds/d=0.2. and Hs/d = 0.625. the relative submergence depth was (ds/d=0.2).

The wave energy dissipation K_L was further calculated and was found that it increases with B/L.

The greatest values of K_L were found when ds/d=0.2. On the other hand, the smallest values of K_L were found when ds/d=0.5. It was found that when ds/d =0.2, the values of K_L reach 0.76, 0.78, 0.74 and 0.70 respectively with the above mentioned Hs/d.

8.3 The Results of K_t and K_L with [d/L_P =0.0375]

Since the plate length L_P is constant so the change in d/L_P means changing in total water depth at the structure. By changing of water depth ratio (d/L_p = 0.0375) with B/L ranging from 0.075 to 0.53. In Fig. 12 the results show that, the K_t decreased as B/L increases. The minimum values of K_t were occurred at minimum values of ds/d. at ds/d = 0.2 the values of K_t were found to be 0.43, 0.43, 0.49 and 0.52 respectively with Hs/d = 0.25, 0.417, 0.583, and 0.833.

In the same group tests the wave energy dissipation K_L is calculated and it is clearly increases with the increasing of B/L. The greatest values of K_L were found when ds/d=0.2, on the other hand the smallest values of K_L were found when ds/d=0.5. It was observed that when ds/d =0.2 the values of K_L reached to 0.76, 0.76, 0.72, and 0.69 respectively with Hs/d = 0.25, 0.417, 0.583, and 0.833.

8.4 The Results of K_t and K_L with [d/L_P =0.05]

In Fig. 13, the plate system was shifted to the sea side to increase the total water depth until reach to the ratio of d/L_P = 0.05. Under different wave heights where Hs/d = 0.187, 0.313, 0.438, and 0.625 the transmission and dissipation coefficient were observed with different values of B/L and ds/d. the results shows that, K_t decreases as B/L increases and the minimum values were observed with ds/d=0.2. The K_t value decreased to be 0.54, 0.52, 0.46, and 0.49 with the maximum values of B/L and the minimum values of ds/d.

In the same group tests the wave energy dissipation K_L is calculated and it is clearly increases with the increasing of B/L. The greatest values of K_L were found when ds/d=0.2, on the other hand the smallest values of K_L were found when ds/d=0.5. It was observed that when ds/d =0.2 the values of K_L reached to 0.63, 0.69, 0.73, and 0.72 when the water depth ratios Hs/d were 0.187, 0.313, 0.438, and 0.625 respectively.

9. CONCLUSIONS

The submerged horizontal plate, supported on piles, gives good results in terms of wave energy dissipation and reduced the transmitted wave height through the wave transformation and breaking on the plate's surface. The wave transmission is effected by some parameters related to the geometry and the location of the structure, and also the wave characteristics. The results show that, the K_t significantly decreases as B/L increases especially with the high wave height, but with small wave height the K_t values slowly decreases. The minimum values of K_t were observed with the ratio of submergence depth (ds/d = 0.5), while the maximum values were observed with ds/d = 0.2, which means that the depth ratio plays a significant role in the attenuation mechanism of the horizontal plate. It was also observed from the results, the threshold level of K_t = 0.5 was attained for B/L ranged from 0.25 to 0.35 especially with the high wave height.

10. ACKNOWLEDGMENTS

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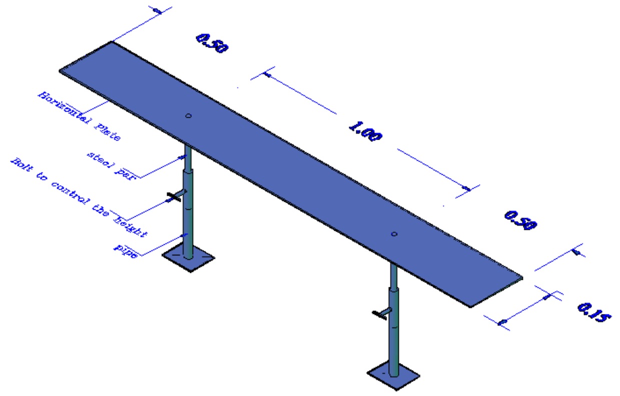


Fig. 1 Sketch for the plate and supports

Fig. 2 Different views of the one row structure

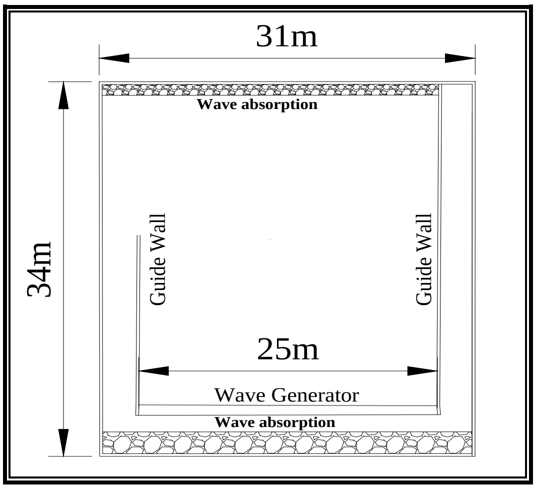


Fig. 3 Wave basin layout

Fig. 4 Wave generator

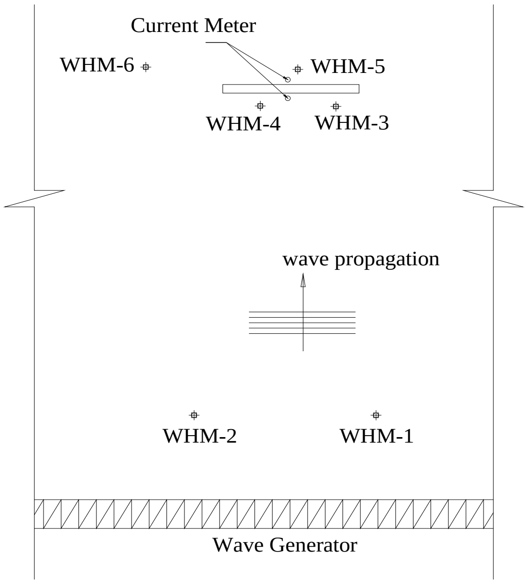


Fig. 5 Layout of model

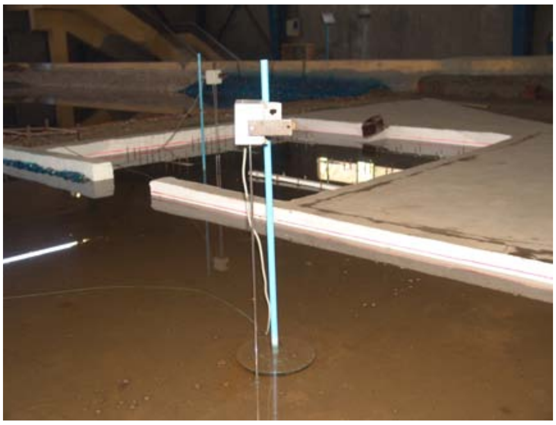


Fig. 6 Wave Height meter (WHM)

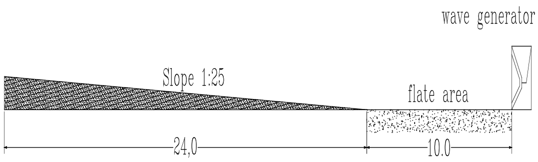


Fig. 7 Longitudinal bed profile

Fig. 8 Model construction

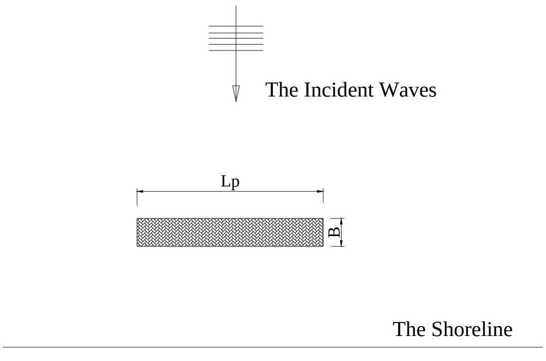


Fig. 9 Plate Dimension (Plan)

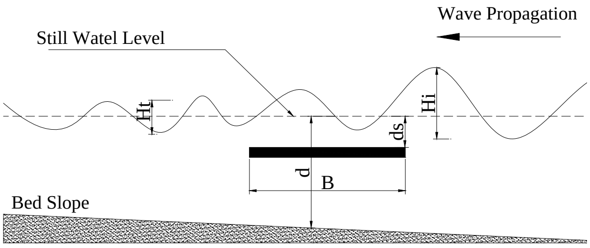
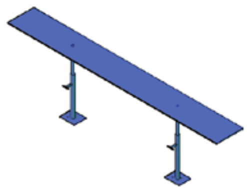
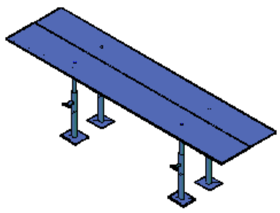
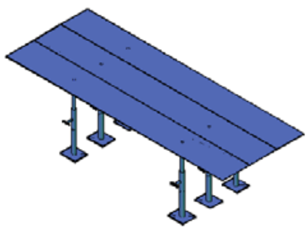
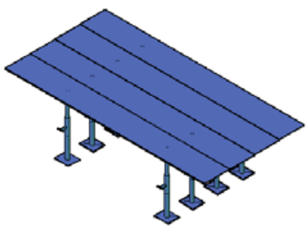


Fig. 10 Plate Dimension (Side view)

Table 1, Model Calibration

Designed Values		Measured Values Hs (m)		Measured Values T (s)		Average Measured values	
Hs (m)	T (s)	WHM-1	WHM-2	WHM-1	WHM-2	Hs (m)	T (s)
0.0375	0.95	0.03652	0.038562	0.954589	0.955499	0.037541	0.955044
0.0625	1.23	0.061586	0.063132	1.22085	1.22604	0.062359	1.223445
0.0875	1.42	0.08905	0.087172	1.43134	1.42109	0.088111	1.426215
0.125	1.71	0.128835	0.121523	1.69551	1.71676	0.125179	1.706135

Table 2, Model Test Program

water depth ratio (d/L_P = 0.025, 0.0375, and 0.05)			
Plate width (No. Of rows)	**Submergance depth (ds/d)**	**Wave height ratio (Hs/d)**	**Wave period (s)**
	0.2	0.375, 0.625, 0.875, 1.25, 0.25, 0.417, 0.583, 0.833 0, 0.187, 0.313, 0.438, 0.625	0.95, 1.23, 1.42, 1.71
	0.3		0.95, 1.23, 1.42, 1.71
	0.4		0.95, 1.23, 1.42, 1.71
	0.5		0.95, 1.23, 1.42, 1.71
	0.2	0.375, 0.625, 0.875, 1.25, 0.25, 0.417, 0.583, 0.833 0, 0.187, 0.313, 0.438, 0.625	0.95, 1.23, 1.42, 1.71
	0.3		0.95, 1.23, 1.42, 1.71
	0.4		0.95, 1.23, 1.42, 1.71
	0.5		0.95, 1.23, 1.42, 1.71
	0.2	0.375, 0.625, 0.875, 1.25, 0.25, 0.417, 0.583, 0.833 0, 0.187, 0.313, 0.438, 0.625	0.95, 1.23, 1.42, 1.71
	0.3		0.95, 1.23, 1.42, 1.71
	0.4		0.95, 1.23, 1.42, 1.71
	0.5		0.95, 1.23, 1.42, 1.71
	0.2	0.375, 0.625, 0.875, 1.25, 0.25, 0.417, 0.583, 0.833 0, 0.187, 0.313, 0.438, 0.625	0.95, 1.23, 1.42, 1.71
	0.3		0.95, 1.23, 1.42, 1.71
	0.4		0.95, 1.23, 1.42, 1.71
	0.5		0.95, 1.23, 1.42, 1.71

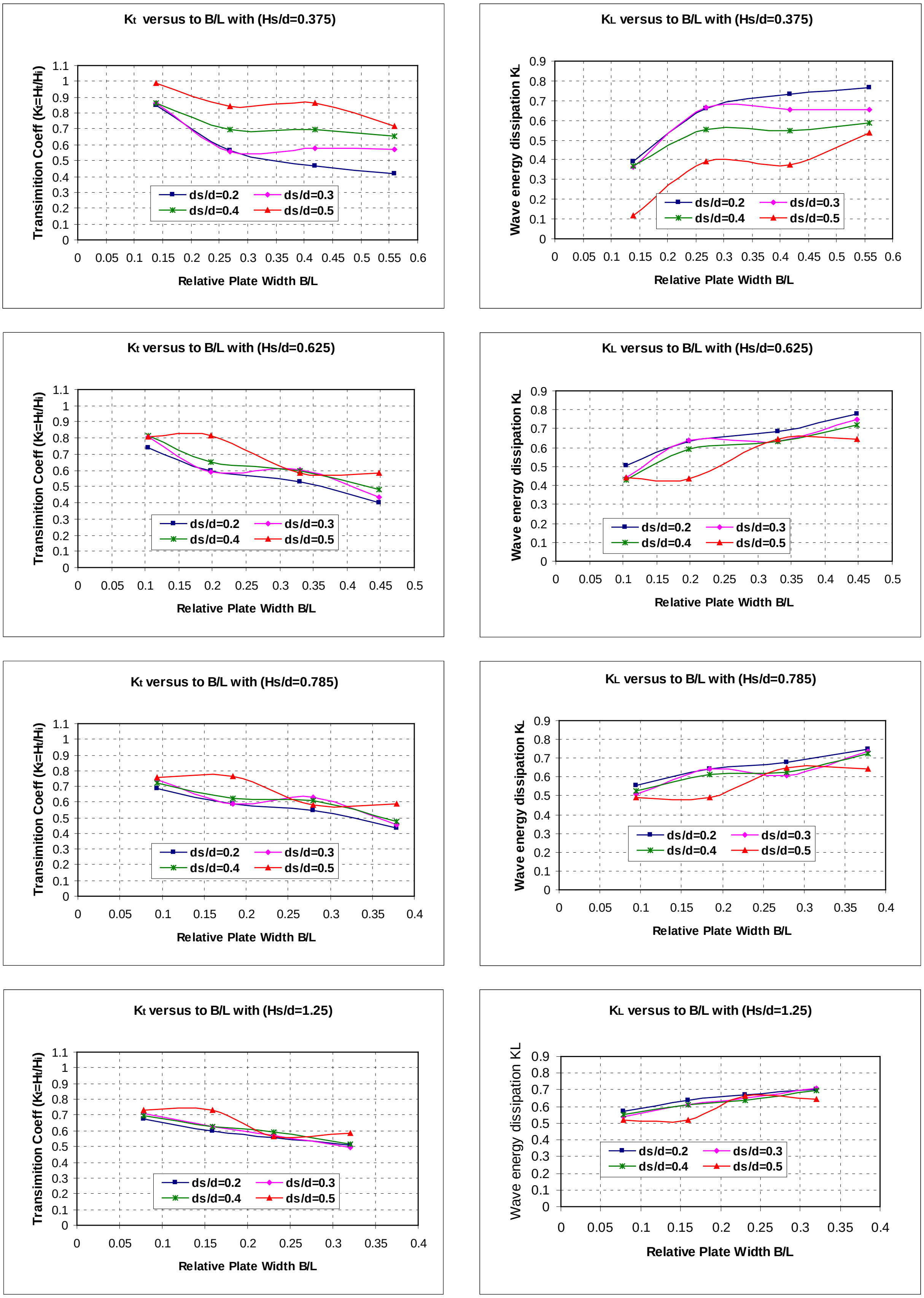


Fig. 11 The wave transmission coefficient (K_t) and wave energy dissipation (K_L) with relative plate width at (d/L_p=0.025)

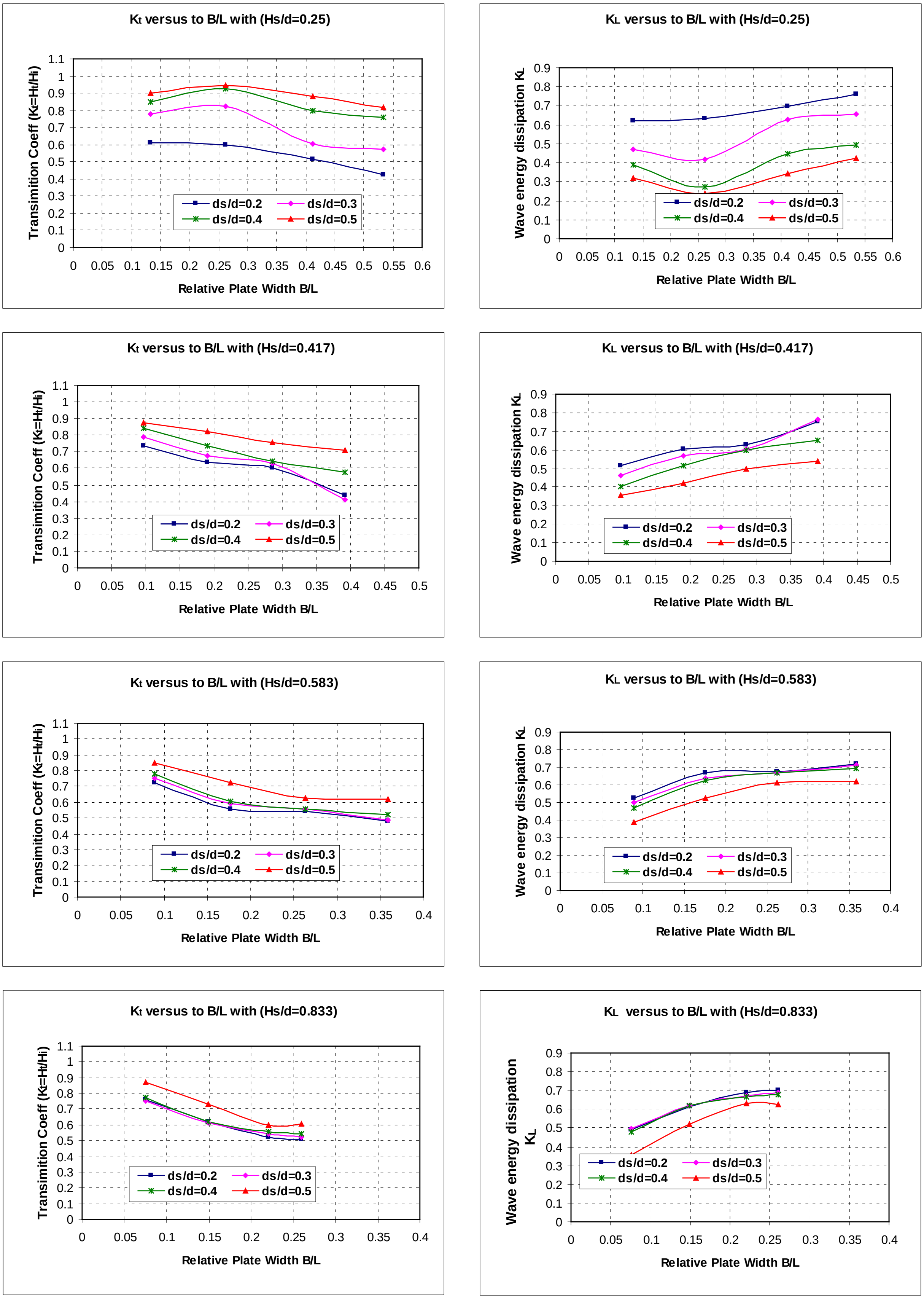


Fig. 12 The wave transmission coefficient (K_t) and wave energy dissipation (K_L) with relative plate width at (d/L_p=0.0375)

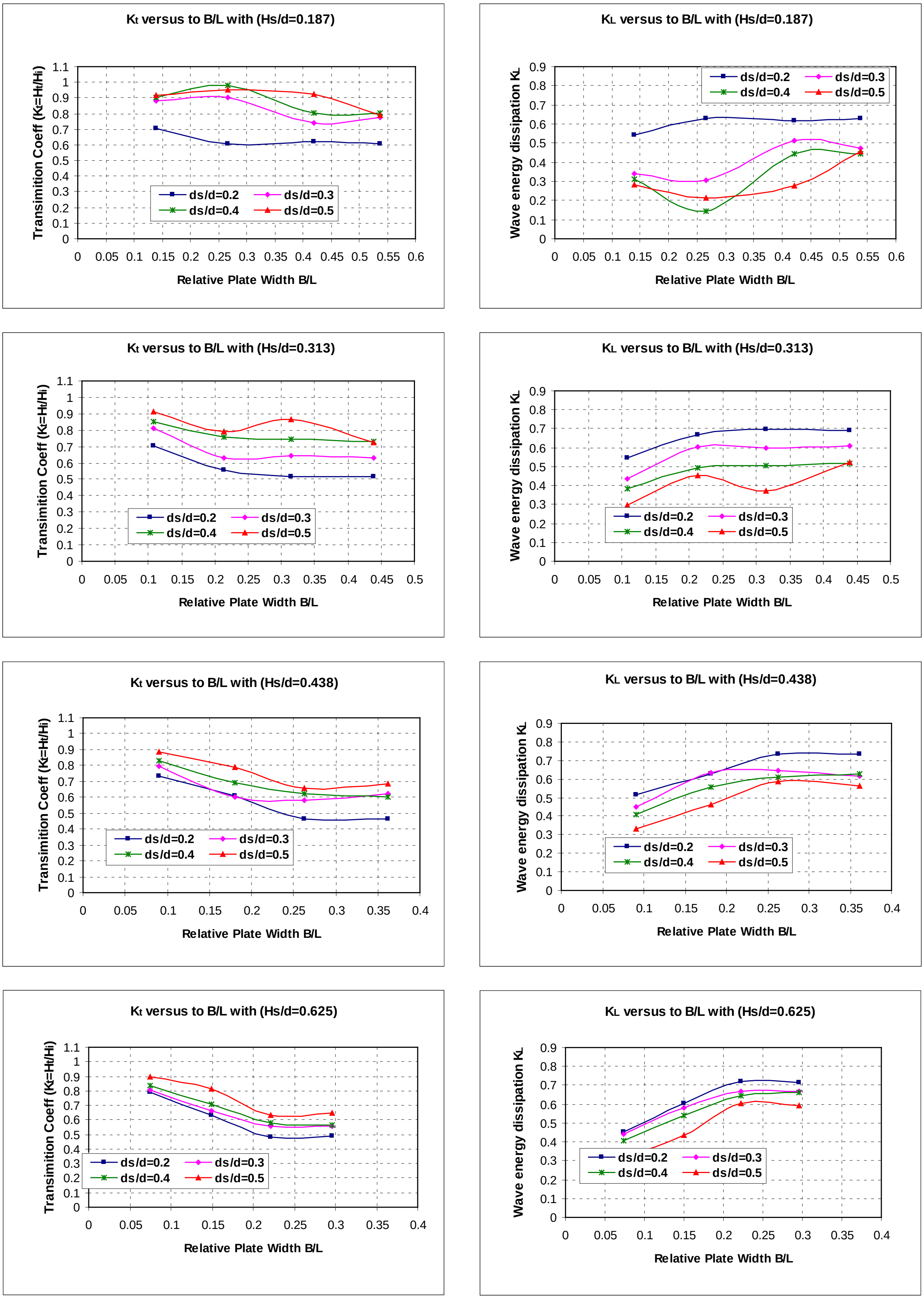


Fig. 13 The wave transmission coefficient (K_t) and wave energy dissipation (K_L) with relative plate width at (d/L_p=0.05)