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Hydrodynamic Performance Efficiency of Perforated Vertical Barrier with Circular or Square Slots

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ملخص البحث

في هذه الدراسة تم اختبار نموذجين مختلفين من حواجز الأمواج الرأسية المنفذة لدراستهما باستخدام النمذجة العددية. النموذج الأول جدار رأسي مزود بفتحات دائرية والنموذج الثاني جدار رأسي مزود بفتحات مربعة. تم إجراء مقارنة بين النموذجين حيث وجد أن النموذج الاول ذو الفتحات المربعة يقلل انتقال الموجات أكثر من النموذج الثاني ذو الفتحات الدائرية بنسبة تتراوح من 5 % الي 15%. وإن استخدام صفين من الجدران مع فتحات دائرية يقلل من انتقال الأمواج أكثر من صف واحد من هذه الجدران بنسبة تصل إلى 30٪ وأيضاً زيادة تبديد طاقة الأمواج بنسبة تصل إلى 40٪. تزداد قوة الموجة الأفقية بزيادة الطول النسبي للموجة (h / L). كما أن قوة الامواج الافقية عند النفاذية (ε) = 0.25 أكبر منها عند النفاذية (ε) = 0.50 بنسبة تتراوح 10 % إلى 30%.

Abstract

In this study, two different models of vertical permeable breakwaters were tested using numerical modeling. The first model is a vertical wall with circular slots and the second model is a vertical wall with square slots. A comparison was made between the two models it was found that the square slots reduce the transmission of waves more than circular slots by 5: 15%. The use a pair of walls with circular slots reduces the transmission of the waves more than a single of wall by up to 30% and the increase of the wave energy dissipation by up to 40%. The horizontal wave force increases with increase relative length (h/L). the relative wave forces (F/Fo), at porosity (ε) =0.25, was greater than at porosity (ε) =0.50 by 10 to 30%. The velocity of the waves is great at the openings and the dissipation of the wave energy is also great the higher the wave velocity the greater the wave energy dissipation factor.

KEY WORDS: Regular wave; Vertical Slotted Barriers; numerical models; Transmission, Reflection, Energy Loss and wave force.

1. INTRODUCTION

Coastal region is a source of attraction for human activities. It encompasses significant structures (i.e. residential, buildings, infrastructure projects and harbours). Additionally, it provides food via fishing, commercial cooperation. In addition, it provides large recreation areas and tourism facilities. Unfortunately, a major problem faces the region development due to the inability of protecting the coastal region. Accordingly, problems endanger the adjacent shores.

Therefore, an economic measure should be innovated to safeguard such regions from hazards. Driven by the importance of coastal regions that play an important role in the national income to Egypt, this research was commenced to investigate the hydrodynamic performance of two kinds of a double vertical partially slotted barriers. This paper presents the literature review in the field of breakwaters, the numerical investigation, results discussion and conclusions so as recommendations, as follows:

2. LITERATURE REVIEW

Several articles in journals and periodicals were assembled and reviewed. Based on this assembled literature, it was apparent that many investigators were involved in studying breakwaters and numerical models. For example: Mani et al. (1995) investigated a suspended pipe breakwater for small harbors with moderate wave agitations. The breakwater consisted of a row of spaced pipes mounted onto a frame. This can be considered as variation of the skirt breakwater. It was concluded that suspended pipe breakwater is economic and promising substitute for pile breakwater. A gap was recommended to achieve wave transmission coefficient less than 0.5. They noticed that the suspended pipe breakwater attenuates incident waves by 50 %. Isaacson et al. (1998) outlined a numerical calculation of wave interactions with a thin vertical slotted barrier using an Eigenfunction expansion method. The authors described laboratory tests to assess the numerical method. The numerical results were compared against laboratory results of the transmission, reflection and energy dissipation coefficients for partially submerged slotted barrier. They indicated satisfactory agreement. The effect of porosity, relative wave length, wave steepness and irregular waves were discussed. The suitable parameters were selected to model the breakwater permeability. Isaacson et al. (1999) outlined a numerical calculation of wave interactions with a pair of thin vertical slotted barriers. The authors described laboratory tests undertaken to assess numerical model, which was based on Eigen function expansion method and utilizes a boundary condition at the barrier surface. Experiments were carried to pair of thin vertical slotted barriers with porosities of 0, 5 and 10 % and spacing of 0.22, 0.55 and 1.1 of λ/d. Comparisons were carried out against permeable barrier and close agreement was found in all cases. Suh et al. (2007) studied wave reflection and transmission for curtain wall-pile breakwaters using circular piles. A mathematical model was used to compute the hydrodynamic characteristics. They concluded that, the draft of the curtain is directly proportional to the porosity. As the relative water depth increases, the effect of porosity disappears due to wave motion. Huang (2007) studied wave reflection from and transmission through closely spaced rectangular cylinders. An empirical expression is proposed for the friction factor. Algebraic expressions are presented to calculate the reflection and transmission coefficients for a single or double slotted wall. His model was validated against published experimental results. He found that the proposed method could be used for slotted breakwaters design. Ji and Suh (2009) investigated mathematically the hydrodynamic characteristics of multiple-row curtainwall-pile breakwater. The results indicated that the transmission coefficient is inversely proportion to relative water depth. It was obvious that wave transmission was significantly reduced by multiple-row breakwaters compared to single-row breakwater. Rageh and Koraim (2010b) investigated the hydrodynamic efficiency of vertical walls with horizontal slots. The model consisted of one row of vertical wall suspended on supporting piles. The model was investigated experimentally and theoretically. The theoretical model was based on the linear wave theory and Eigen function expansion method. The efficiency was presented experimentally and theoretically as a function of transmission. The theoretical results were compared to the experimental results. The results indicated that the proposed theoretical model is reasonably accepted at friction factor of 5 to 6. Koraim et al. (2011) investigated experimentally and theoretically a double vertical wall with permeable lower part. The hydrodynamic characteristics were investigated. The theoretical model was based on Eigen Function Expansion Method. From the theoretical results, it was found that the hydrodynamic efficiency of the breakwater is strongly affected by the increase of upper part drafts. Elsharnouby et al. (2012) investigated the performance of double porous curtain walls fixed on two rows of vertical piles that consisted of two sets of horizontal steel strips with equal spacing. FLOW-3D software was used to examine the effect of the tested models. The research designated the effect of the model parameters on the transmission coefficient.

Koraim et al. (2014) investigated experimentally and theoretically the wave transmission, reflection and energy dissipation of double rows of vertical piles. Different wave and structural parameters were investigated. Comparison between experiments and predictions indicated that theoretical model provided a good estimate to the different hydrodynamic coefficients. Nadji Chioukh et al (2017) reflection and transmission coefficients of regular waves from/through perforated thin walls are investigated. Small scale laboratory tests have been performed in a wave flume firstly with single perforated thin Plexiglas plates of various porosities. The plate is placed perpendicular to the flume with the height from the flume bottom to the position above water surface. With this thin wall in the flume wave overtopping is prohibited and incident waves are able to transmit. The porosities of the walls are achieved by perforating the plates with circular holes. Model settings with double perforated walls parallel to each other forming so called chamber system, have been also examined. Several parameters have been used for correlating the laboratory tests' results. Experimental data are also compared with results from the numerical model by applying the multi-domain boundary element method (MDBEM) with linear wave theory. Wave energy dissipation due to the perforations of the thin wall has been represented by a simple yet effective porosity parameter in the model. at last Ibrahim (2017) studied the efficiency hydrodynamic performance of unsymmetrical double vertical partially slotted barriers was investigated, physically and numerically by Flow-3D. The experimental work identified the hydraulic performance of the barriers. In addition, the model provided reasonable results to the contributing variables (i.e. wave height, wave length and barrier characteristics.

3. WAVE INCIDENT AND PERIOD EXPERIMENTALLY

Several experiments were conducted at the hydraulics, faculty of engineering, Zagazig University, Egypt. Find wave properties (Wave incident (Hi) and wane period (T)). The experimental laboratory consists of water channel (1.2, 2.0 and 12.0 m) width, depth and length respectively and water depth was (h) = 0.40 m. the waves were generated under liner wave theory. The wave length can be obtained from the following equation.

$$L = \frac{gT^2}{2\pi}\tanh(kh) \qquad (1)$$

Experimental wave properties (Hi and T) were used in the numerical model to test proposed breakwater and study its hydrodynamic efficiency.

4. NUMERICAL MODEL

The numerical investigation was achieved via implementing numerical simulations using the commercial "Computational Fluid Dynamics" (CFD) code FLOW-3D as it's applied in all sectors of engineering. Basically, FLOW-3D applies the finite volume theory to solve the three-dimensional Reynolds- Averaged Navier -Stokes (RANS) equations.

Numerical Simulations Using Flow-3D confident with the validation process, the model was implemented, varying the different parameters. Numerical replications were achieved to simulate the proposed breakwater.

To get a good compromising between precision/accuracy and computation time, two independent meshes with different cell sizes were used. Mesh cells are sized by 1 cm in each direction for waves of small frequencies and mesh cells are sized by 0.5 cm for waves of large frequencies. The time window for analyzing the wave height is carefully selected according to the wave length and is adjusted to avoid any reflection from the flume end or the wave paddle.

The reflection coefficient was calculated by the three-probe method of Mansard and Funk (1980). The selected data are converted into frequency domain by Fast Fourier Transformation. Finally, the spectrum of the incident, transmitted and reflected wave height were calculated. Thereby, the reflection coefficient ‘kr’ is calculated from extracted wave profiles by:

$$kr = Hr / Hi \qquad (2)$$

Where: Hr is the reflected wave height, Hi is incident wave height. The transmission coefficient ‘kt’ was calculated directly from the wave transmitted profile by:

$$kt = Ht / Hi \qquad (3)$$

Where: Ht is the transmitted wave height. The energy dissipation coefficient ‘kd’ is given

$$k_d = \sqrt{1 - k_r{}^2 - k_t{}^2} \qquad (4)$$

The numerical work investigated a breakwater model presented on figure (1) in which h is the constant water depth in still water; wave flume had a rectangular cross section (0.3 x 0.6 x13 m); B is the distance between the centerlines of the two walls; b are the thicknesses of the first and the second walls; Breakwater models, were tested in 0.4 m water depth with different wave heights. Table (1) lists the domains of the investigated variables. In addition, this breakwater was modelled numerically in Flow-3D as presented on figures (2).

Numerical model (Flow-3D) divined three treads. The first input data about dimension flume which component cells mesh and components breakwater. The second tread run simulation, in this tread the program solves and the last tread output data analysis results.

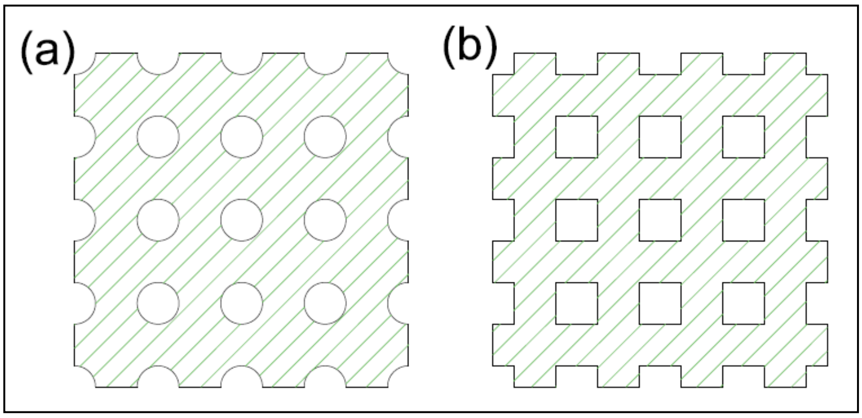

Figure (1) Breakwaters model (a) perforated wall with circular slots and (b) perforated wall with square slots.

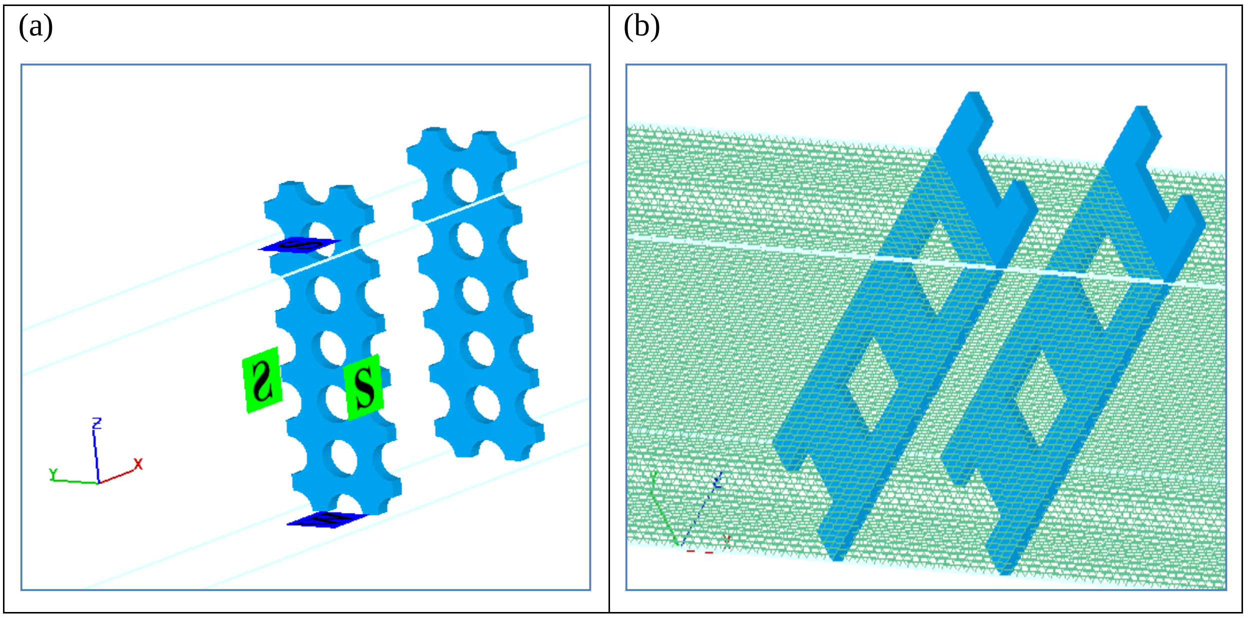

Figure (2) Breakwaters model in flow-3D with meshing geometry and boundary (a) circular slots (b) square slots.

5. THEORETICAL INVESTIGATIONS

Focusing on the hydrodynamic force, it was expressed by linearizing Bernoulli's equation and the hydrodynamic forces were evaluated by integrating the pressure around the body's wetted surface as figure (3). Total hydrodynamic pressure (p= pressure differences between surfaces) is expressed by linearizing Bernoulli's equation:

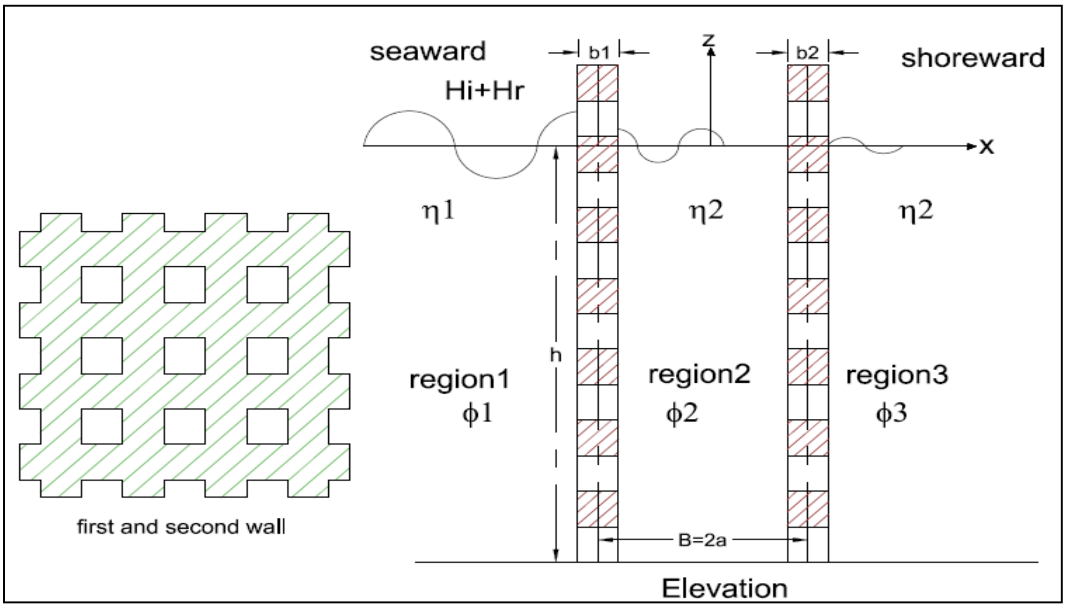

Figure (3) Details and dimensions of proposed breakwater

$$p = -\rho\left(\frac{\partial\phi}{\partial t}\right)_{x=0} = i\omega\rho(\phi_1 - \phi_2) \qquad , x = 0 \tag{5}$$

$$p = \frac{-\rho g H_i}{2}\frac{\cosh k(z+h)}{\cosh kh}(1 + k_r - k_t) \tag{6}$$

Hydrodynamic force (F*) is evaluated by integrating pressure around the wetted surface as follows:

$$F^* = \int_{-h}^{0} p(0,z)dz \tag{7}$$

$$F^* = -\frac{\rho g H_i}{2k}(1 + k_r - k_t)\tanh kh \tag{8}$$

$$F = \mathrm{Re}[F^* e^{-i\omega t}] \tag{9}$$

Dimensionless wave forces [F/F0, F0 are due to fully standing waves, F0=ρgHi tanh (kh) / k]

6. RESULTS AND DISCUSSIONS

After audition proposed models numerically by flow-3d obtain on many of results. Figures (4) and (5) show that wave profile for proposed breakwaters at behind models trend harbor side. Vertical axis is the free surface elevation (cm) and horizontal axis is the time (sec). Wave profile consists under wave period (T) = 1.2 sec and wave elevation showed after passes three second. Notes the different between two proposed breakwaters at range 10 %

Figure (6) presents a Comparison of the efficiency of the hydrodynamic performance of the proposed breakwaters numerical results for the different dimensionless parameters (h/L) at porosity =50% and B/h=1.0. The figure indicated that for perforated walls with square slots, kt decreased by increasing h/L from 0.80 to 0.40, where h/L increased from 0.11 to 0.33 at (ε) =50% and B/h=1.0 For perforated walls with circular slots, the transmission coefficients (kt) decreased from 0.65 to 0.30 when h/L increased from 0.11 to 0.33, at the same parameters. While the reflection coefficients (kr) increased by decreasing h/L. For perforated walls with square slots, (kr) increased from 0.30 to 0.40, when h/L increased from 0.11 to 0.33. For perforated walls with circular slots, (kr) increased from 0.25 to 0.30, when h/L increased from 0.11 to 0.33. The coefficient (kd) for perforated walls with square slots increased from 0.70 to 0.88 and that of perforated walls with circular slots, it increased from 0.50 to 0.83. Based on the obtained results, it was clear that perforated walls with square slots are better than perforated walls with circular slots by 5% to 20%. A present a sample of the numerical results of the different hydrodynamic coefficients show that transmission coefficient (kt) decreases with the increase of relative length (h/L) while reflection and dissipation coefficients increase with the increase of relative length (h/L).

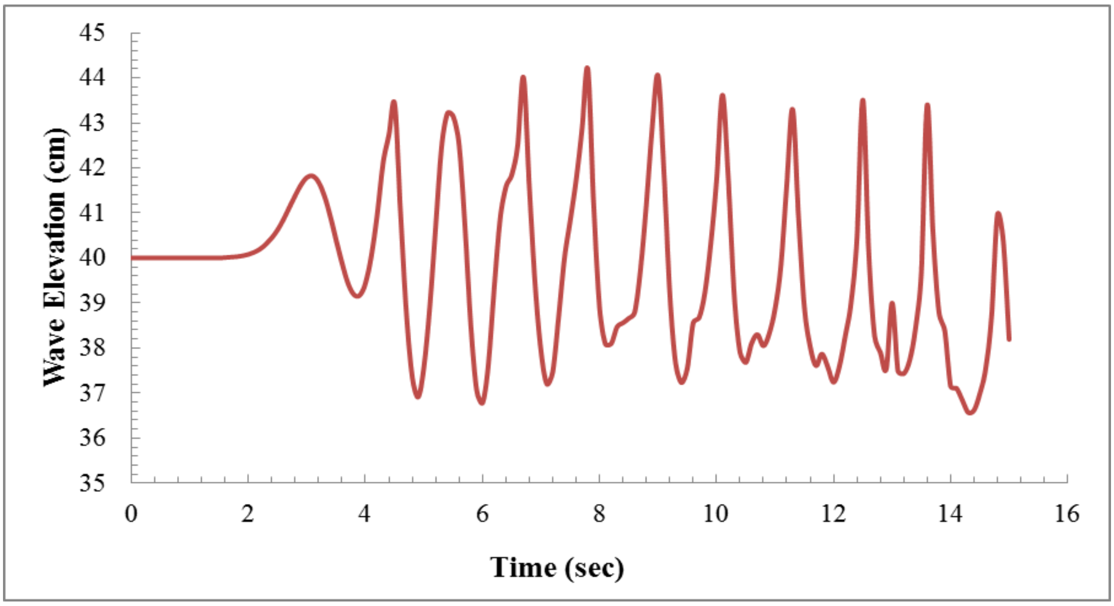

Figure (4) Wave profiles using (Flow-3D) at wave period (T) =1.2 sec for perforated walls with circular slots at behind model (Ht).

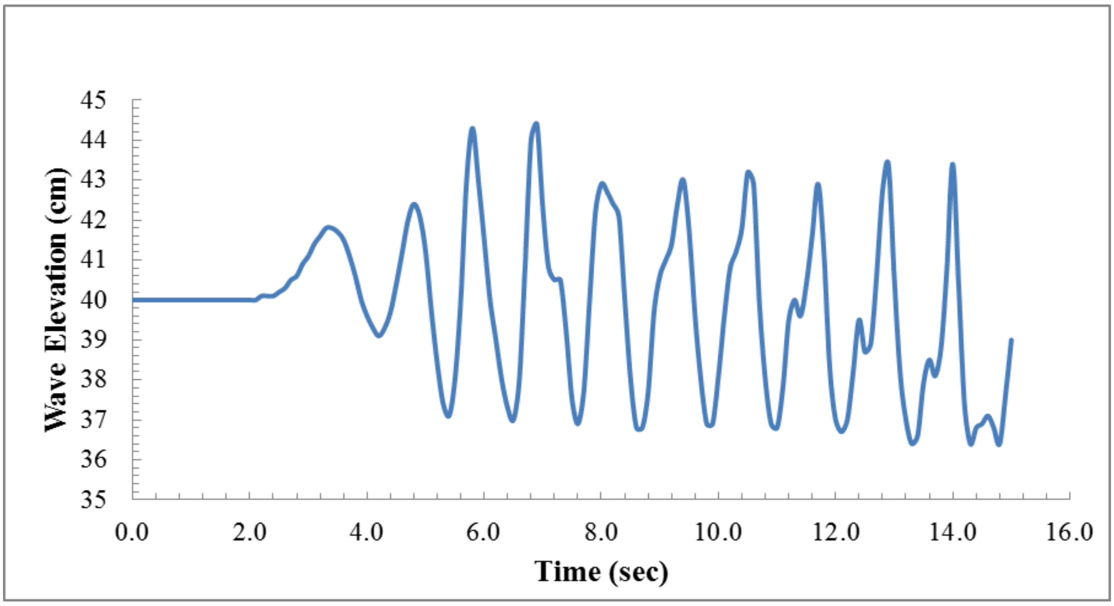

Figure (5) Wave profiles using (Flow-3D) at wave period (T) =1.2 sec for perforated walls with square slots at behind model (Ht).

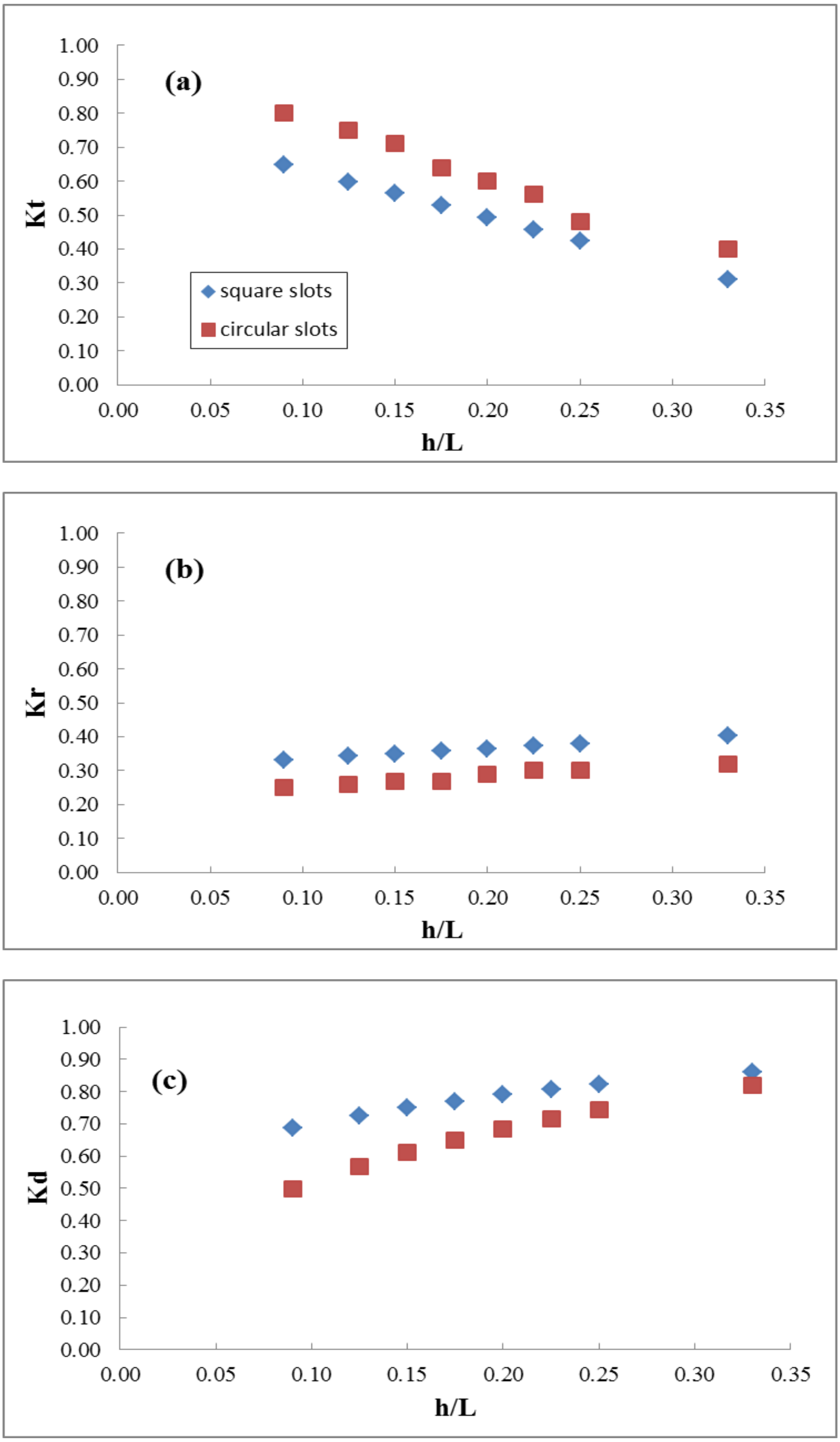

Figure (6) Comparison between vertical walls with circular slots and vertical walls with square slots numerical results for (h/L) at (ε) =50% and B/h=1 (a) kt, (b) kr and (c)kd

Figure (7) it is also of interest to compare the performance of double vertical square slotted walls with that of a single wall. A comparison of the transmission, reflection and energy dissipation coefficients of single and double vertical perforated-wall as functions of (h/L), for ε = 50 % and(B/h=1.0) is shown in figure (6). As expected, the addition of the second barrier has no distinct influence on the reflection coefficient while it has concrete influence on the transmission and energy dissipation coefficient. It is noted that there is a noticeable decrease in the transmission coefficient up to 40 % and a noticeable increase in the energy dissipation coefficient up to 30 %, because the second wall dissipate an additional part from the energy of the wave.

Figure (8) presents the comparison between the hydrodynamic performance of the present breakwater numerical model (square slots) and different similar physical models investigated by other author's e.g. double rows of piles suspending horizontal c shaped bars (Koraim at al 2014). The transmission coefficient decreases with increasing h/L, while the energy dissipation coefficient follows the opposite trend. Present breakwater (square slots) decreases the transmission coefficient more than pervious similar physical model by about 35 %. The present breakwater numerical model gives values of kt, kr and kd better than (Koraim at al 2014) similar physical model.

Figure (9) indicated that h/L increased from (0.11) to (0.33) and the dimensionless wave forces F/Fo increased from (0.2) to (1.08), at porosity (ε) =0.25. Nevertheless, the dimensionless wave forces F/Fo increased from (0.16) to (0.75), at porosity (ε) =0.50. The observed dimensionless wave forces F/Fo, at porosity (ε) =0.25, was greater than at porosity (ε) =0.50 by 10 to 30%. This occurred at B/h=1.0 and ε=50 %, in the permeable part. Note that horizontal wave force increases with increase relative length (h/L).

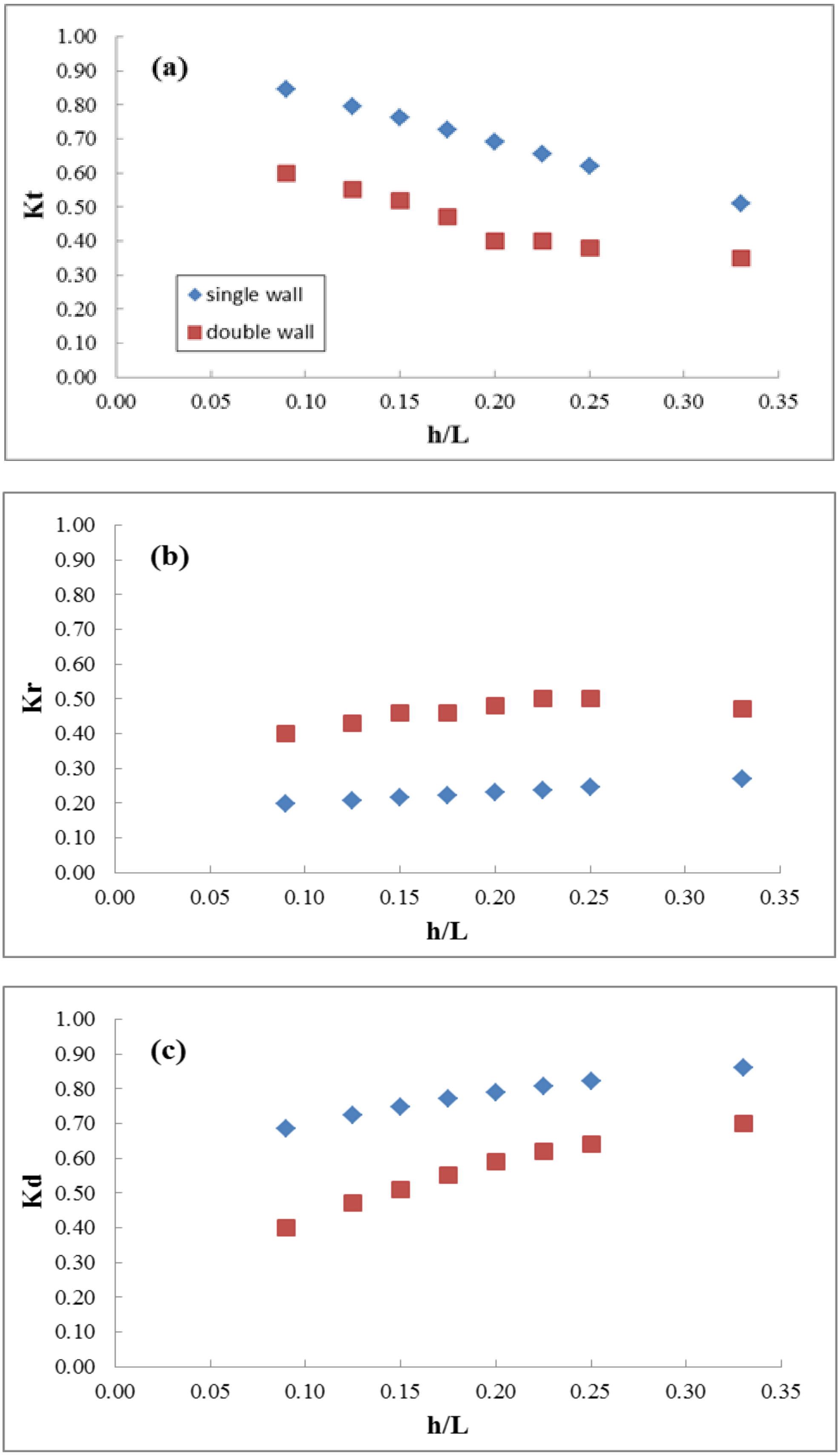

Figure (7) Comparison between single and double of perforated vertical thin walls with circular slots (a) kt, (b) kr and (c)kd

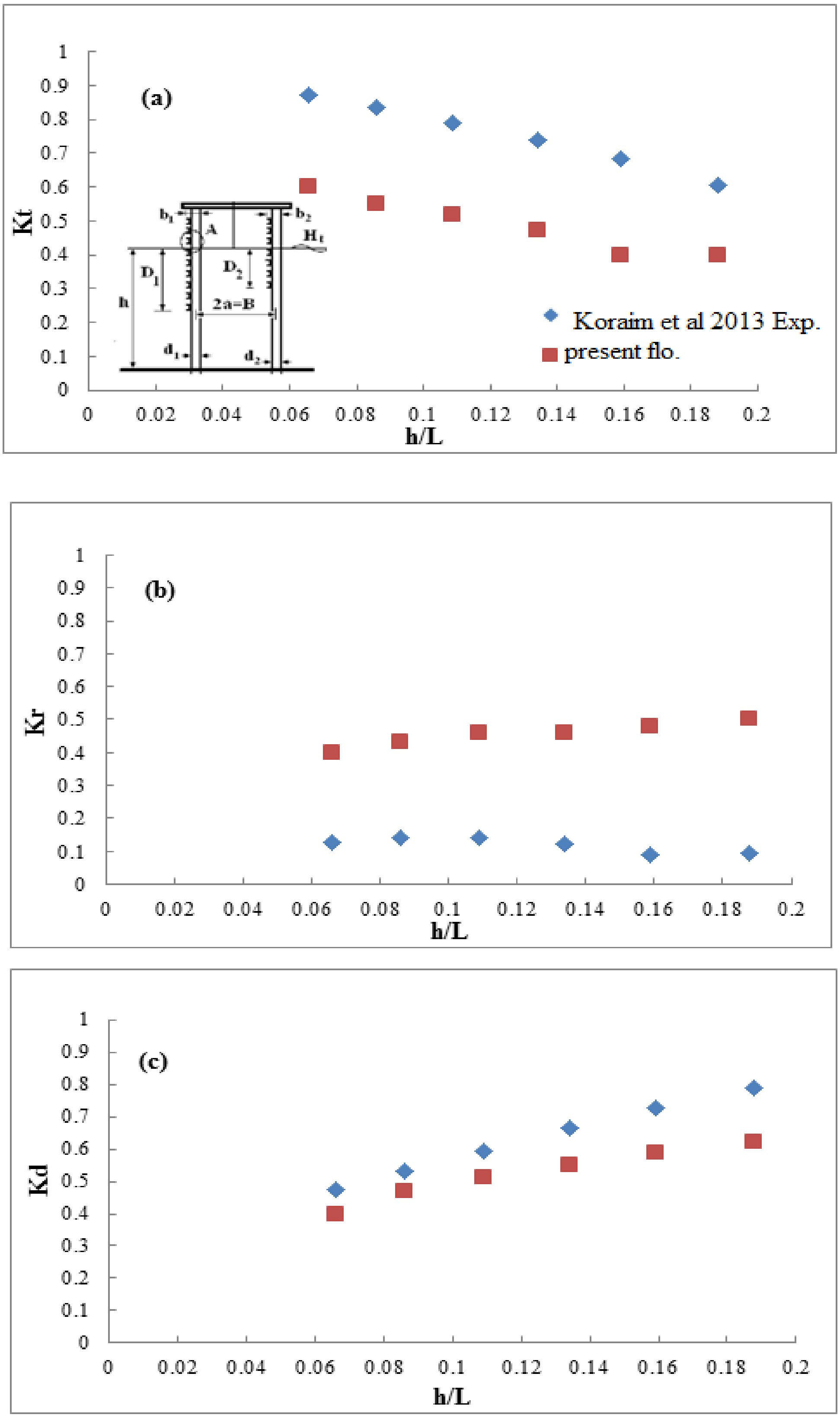

Figure (8) Comparison of predicted hydrodynamic coefficients (kt, kr and kd) with results from Koraim at al 2014 as a function of h/L, when D/h=0.5, B/h=1, εs=0.5, εp=0.83. (a) kt, (b) kr and (c)kd

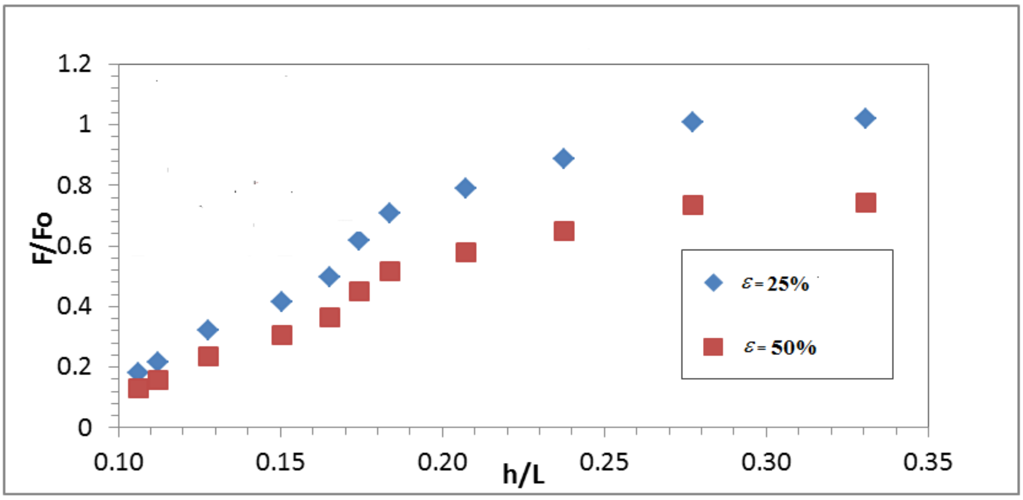

Figure (9) Effect of horizontal wave force on a single wall with square slots at deferent porosity when (f) =3 and (Cm) =0.0.

Figure (10) the numerical model was implemented to detect the velocity field and the velocity vectors near the barriers. This was achieved to indicate how energy was dissipated. Figure (10) presents the velocity vector and velocity field, provided by FLOW-3D, for three times. The higher velocities were observed at the wave crests around the slots. The higher velocities are formed through the slots due to the presence of the obstacle, which causes contraction of moving wave. The velocity magnitude is very high in front of the barrier and very low behind it, where a part of wave energy is banned, another part is transmitted, and the rest part is dissipated, as a vortex as presented by the velocity vectors. The transmitted part is redistributed along the total depth beyond a distance equals the water depth. The surrounding area of the barrier is considered by Flow-3D, while other areas are 2-dimensional flow. The flow within the area between the barriers is turbulent and the motion seems to be vertical, except for the region located near the slots. At the vertical double perforated walls for B/h=0.5 the mean velocity field in the breakwater area is presented on figure (10), where (a) t=10.25T, (b) t=10.50T and (c) t=10.75T over the 10th wave cycle. Maximum velocities were observed to be 51.0cm/s in the region of the impermeable barriers; figure (10). In the seaward side of the structures, where the main structure-interaction takes place, intense vortices were observed. A recirculating region is observed in the region beneath the body of each barrier. The first one is stronger and wider than the mean velocity field for permeable barriers with porosity 0.50. This was observed in the impermeable barriers case, under the same hydrodynamic conditions. In this case, the recirculating region was obvious beneath the first barrier. The interaction of the water mass with the gaps on the body of the barriers is presented. Also, figure (11) presents the vertical perforated wall in FLOW-3D. From the figure, it is obvious that FLOW-3D could compute the velocity that differs by changing the measurement location. In the same context, figure presents the distribution of X- velocity at different probe for double vertical walls at T=1.20 sec and hi=9 cm. The velocity at the top was seen to be greater than the velocity at the bottom. In figure (12) it is noted that the wave moves in a circular shape and the large circles are in the upper and then gradually lower down Figures (13) the pressure distribution has two modes static or dynamic distribution. FLOW-3D could present both and could recognize their places of application. FLOW-3D could determine the force resulting from these pressures. Figures (13) present the static and dynamic pressure distributions. The figur indicated that the hydro static pressure increases as water depth increases and the hydro dynamic pressure increases as the energy losses cofficent increases.

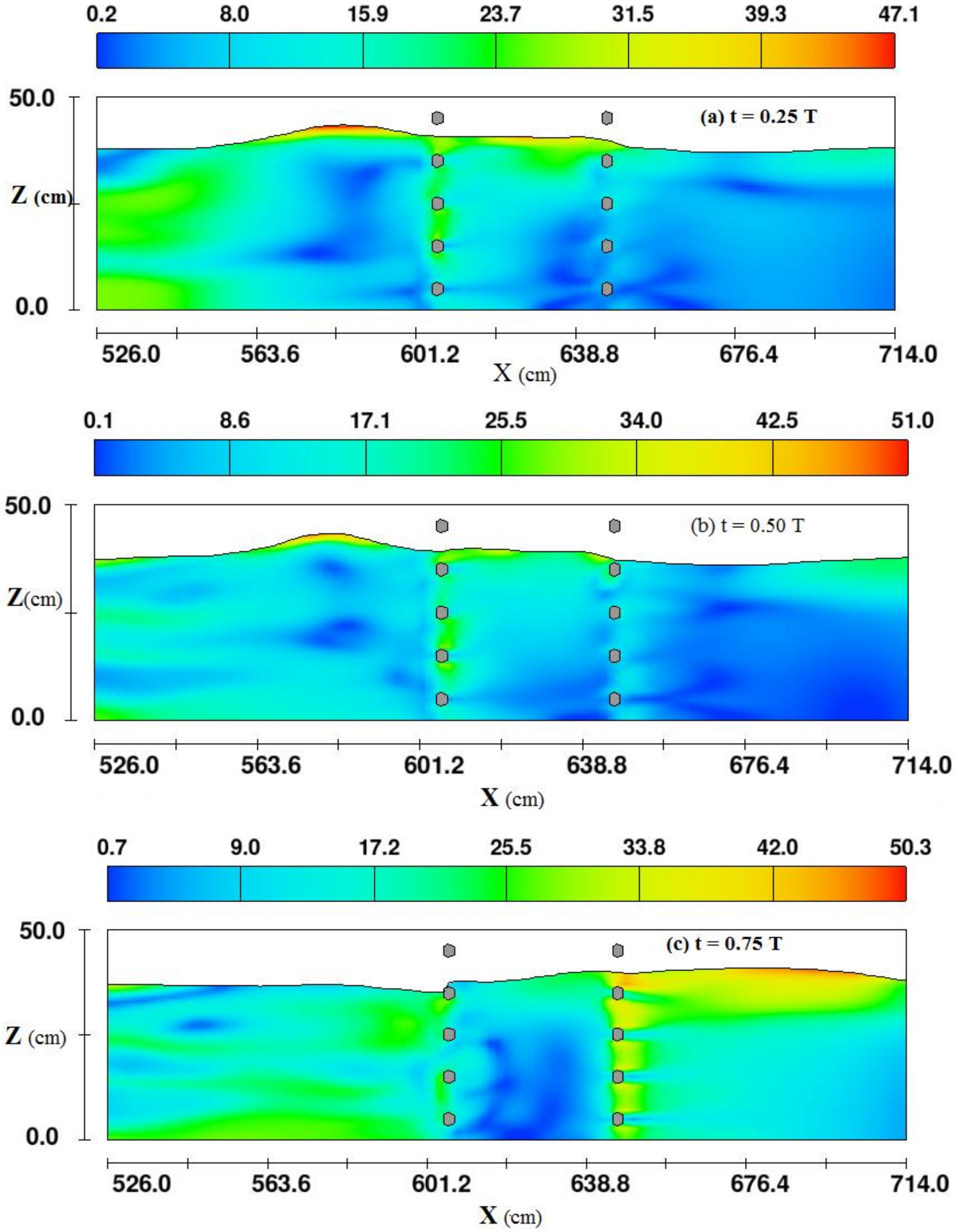

Figure (10) velocity distribution through slots at (a) quarter wave period, (b) half wave period and (c) three quarters wave period.

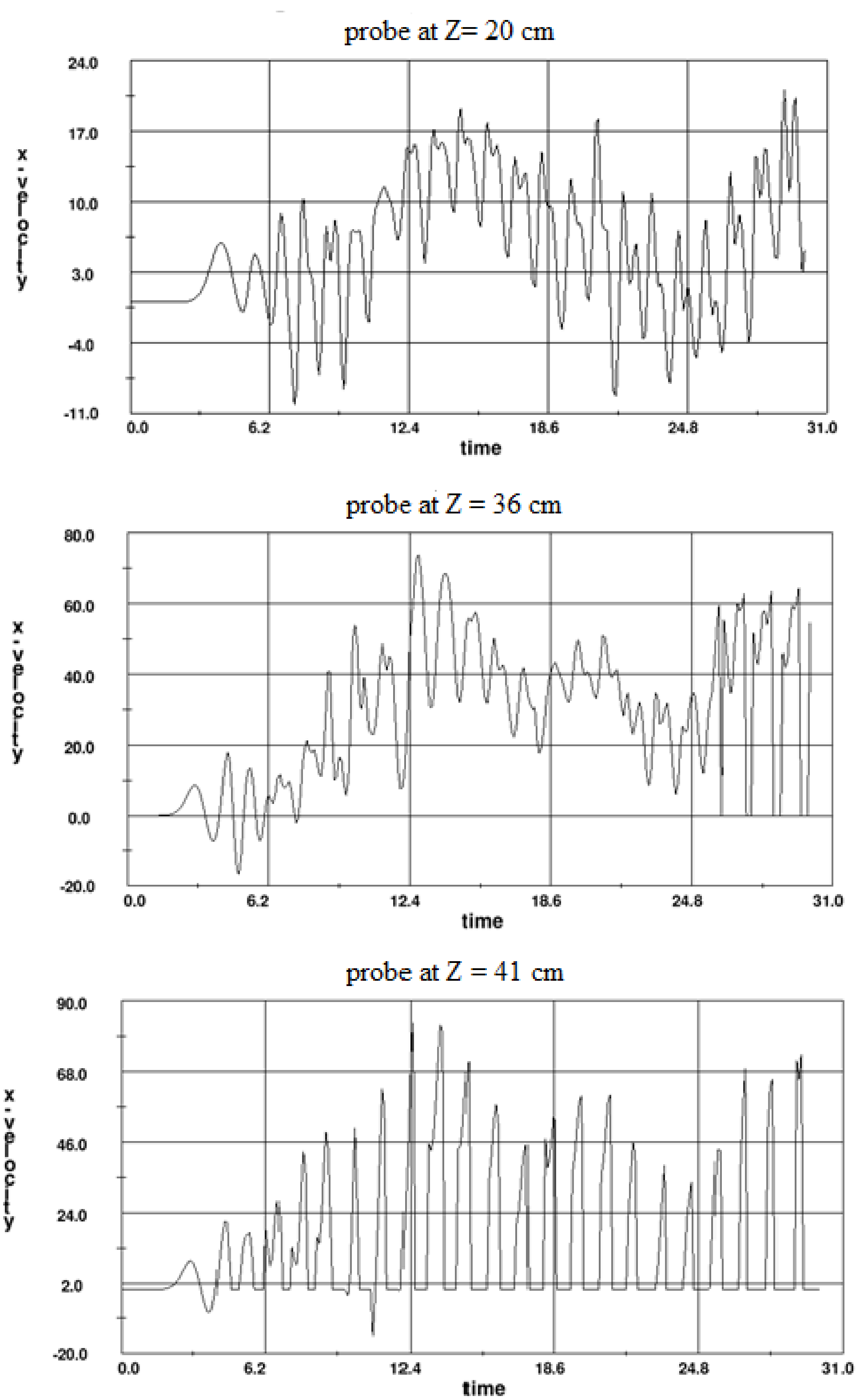

Figure (11) distribution of X-velocity at different probe for vertical perforated thin wall with circular slots at T=1.20 sec and hi=9 cm

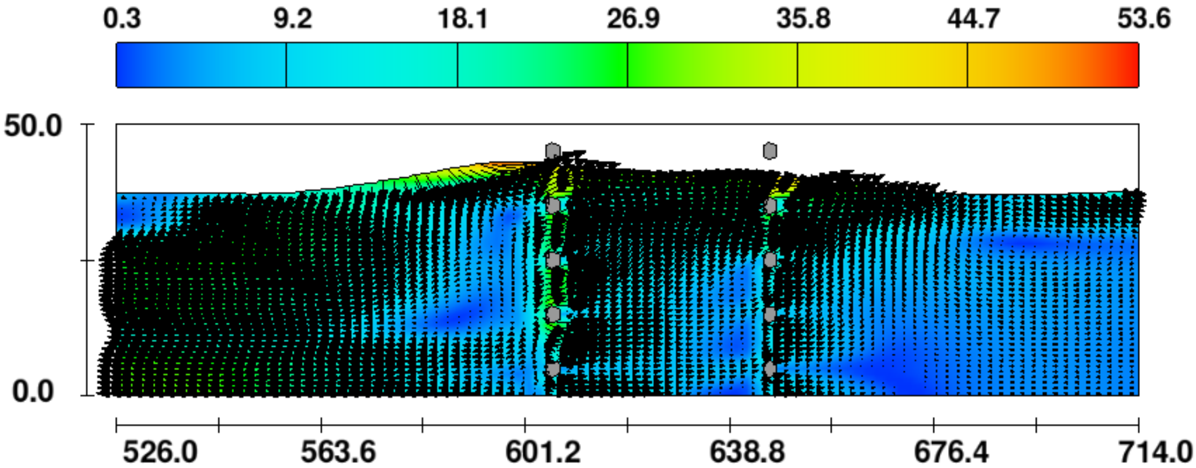

Figure (12) velocity vectors at front, between and behind barriers

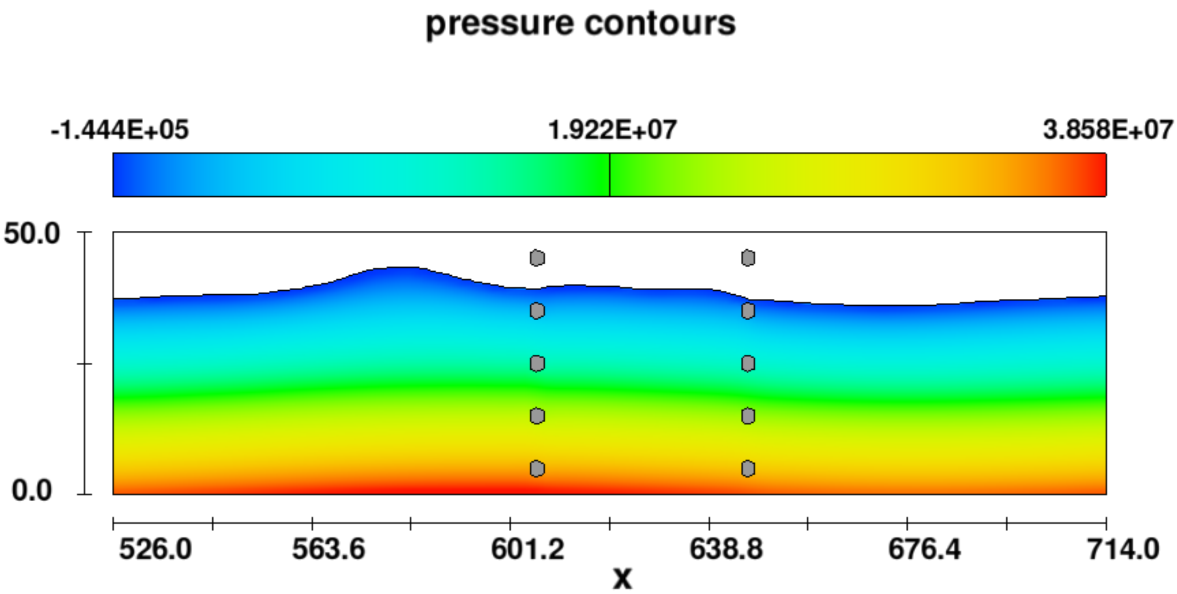

Figure (13) Pressure field in the region of vertical perforated wall (Porosity=0.50, B/h=1.0 and Hi =9 cm-T=1.20 sec)

Table (1) Domains of variables.

Parameter	Units	Domain
Water depth (h)	m	0.40
Wave periods (T)	s	0.90, 1.1, 1.2, 1.3, 1.4, 1.6, 1.9
Wave length (L)	m	1.21 to 3.77
Incident wave height (Hi)	m	0.042 to 0.13
Breakwater thickness(b)	cm	2.50
porosity (ε)	-	0.50
Distance between walls(B)	m	0.40

7. CONCLUSION

This research is summarized in the following points:

The square slots reduce the transmission of waves more than circular slots by 5: 15%.

The use a pair of walls with circular slots reduces the transmission of the waves more than a single of wall by up to 30% and the increase of the wave energy dissipation by up to 40%.

The horizontal wave force increases with increase relative length (h/L). the relative wave forces (F/Fo), at porosity (ε) =0.25, was greater than at porosity (ε) =0.50 by 10 to 30%.

the wave moves in a circular shape and the large circles are in the upper and then gradually lower down

The velocity of the waves is great at the openings and the dissipation of the wave energy is also great the higher the wave velocity the greater the wave energy dissipation factor.

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