Comparative Study on the Hydrodynamic Behavior of Half Pipe Breakwater

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Abstract— In the context of constructing mega coastal projects, this research was initiated with the objective of carrying out a comparative study to the hydrodynamic behavior of half-pipe breakwater. Primarily, literature was reviewed in the field of breakwaters. A half pipe breakwater was modeled numerically, where many parameters were varied during the simulation process. The numerical results were validated against previous experimental investigation. Both results were in good agreement. The results were presented on graphs; analyzed and discussed. The research flagged out that kt and kl decrease by increasing D/h. The research confirmed that kr followed the opposite trend. The research ascertained that as the barrier angle of inclination increases the barrier performance increases. The research designated that maximum velocities occur near the barrier at the wave crest.

Index Terms— Breakwaters; Piles; Half Pipes; Wave Transmission; Reflection; Energy dissipation; crest of wave .

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1. INTRODUCTION

HHalf-breakwater is gifted by many advantages (i.e. easily fabricated on-land, quickly installed by barges, relatively economic compared to traditional breakwaters, have low maintenance cost, applicable to weak soil, conventional in deeper zones, employed for low wave energy, occupy smaller area with trivial impact on sea bed and ensure good water circulation).

Many researchers conducted experimental and theoretical work to verify the efficiency of breakwaters (i.e. partially immersed solid walls and pipe breakwaters). In addition, many researchers investigated vertical thin structures. They investigated steel pipe breakwater in Japan, concrete-pipe breakwater in USA, steel pipe breakwater in Malaysia, wooden pile groin in Germany and wall pile breakwater in Korea.

The efficiency of partially immersed walls is investigated experimentally and theoretically by many researchers. Among them, for example are:

Ursell 1947, Weigel 1960, Reddy and Neelamani 1992, Heikal 1997, and Koraim 2005 carried experimental studies to determine their efficiency.

Liu and Abbaspour 1982 developed a theoretical solution for analyzing wave impact on breakwaters.

Losada et al 1995, Abul-Azm 1993, Heikal 1997 and Heikal 2007 developed theoretical models employing Eigen-function Expansion.

Ahmed 2014 employed FLOW-3D to investigate a vertical perforated wall.

Mohamed 2018 scrutinized double half pipes barriers hydrodynamic efficiency.

However, few researches investigated half pipe type. In the context of establishing mega coastal projects, this research was commenced with the objective of carrying out a comparative study to the hydrodynamic behavior of half-pipe breakwater, where previous experimental results were compared to the present numerical results of Flow-3D.

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2. PREVIOUS EXPERIMENTAL

Koraim (2012) investigated experimentally half pipe breakwaters. He investigated a half-pipe breakwater placed at the middle of a 12.0 m long, 0.45 m deep and 0.30 m wide wave flume. He tested 2 breakwater shapes (i.e. vertical 2 cm smooth plate and 1 horizontal raw of half pipes, at D/h = 0.5). He carried out several experiments in a wave flume in the Hydraulics and Water Engineering Laboratory of the Faculty of Engineering, Zagazig University. He measured the incident (Hi) and reflected (Hr) wave heights, at 2 points (i.e. P1 in barrier DD of the wave generator and P2 at distance from the model face). Details of Koraim wave flume, position of breakwater miniatures and wave recording locations are presented on figure (1).

3. NUMERICAL INVESTIGATION

This research numerically mimicked the physical model of (Koraim 2012). FLOW-3D was employed, which is based on RANS that stands for “Reynolds-Averaged-Navier-Stokes, figures (2) and (3).

Koraim experiments were mimicked numerically by (Flow-3D) with the same experimental scheme. Accordingly, a numerical investigation scheme was planned; table (1).

Froude scaling was implemented for numerical modeling to allow for proper representative to gravitational and fluid inertial forces, where a scale of 1:30 was selected to mimic the model dimensions and wave properties. The breakwater numerical miniature was tested in water depths that ranged between 5 and 10 m. The pipe diameter ranged between 1.7 and 3.3 cm. The wave period ranged between 0.65 and 1.33 sec. These ranges correspond to 6.0 m water depth, 0.5-1.0 m diameter pipe and wave period of 3.6 to 7.3 sec in the prototype.

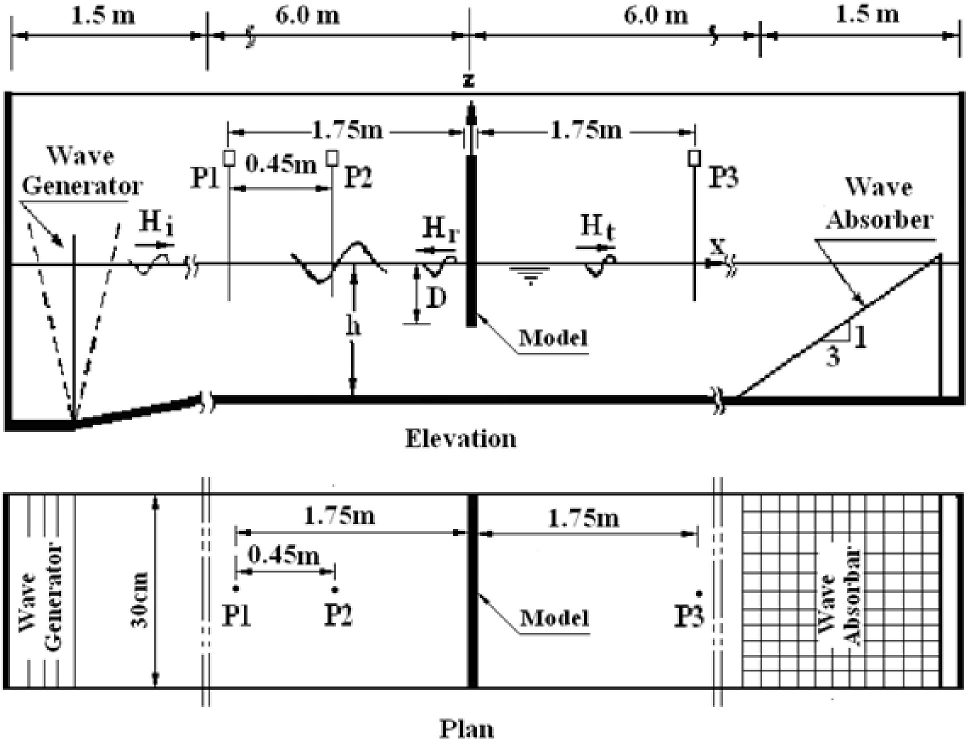


Fig. 1. Experimental flume of Koraim et al (2012)

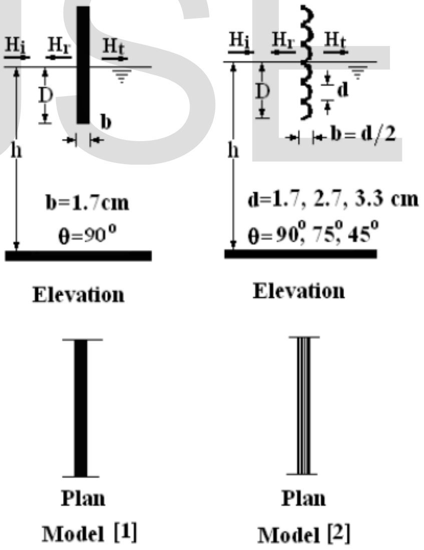


Fig.2. breakwater model of Koraim et al (2012)

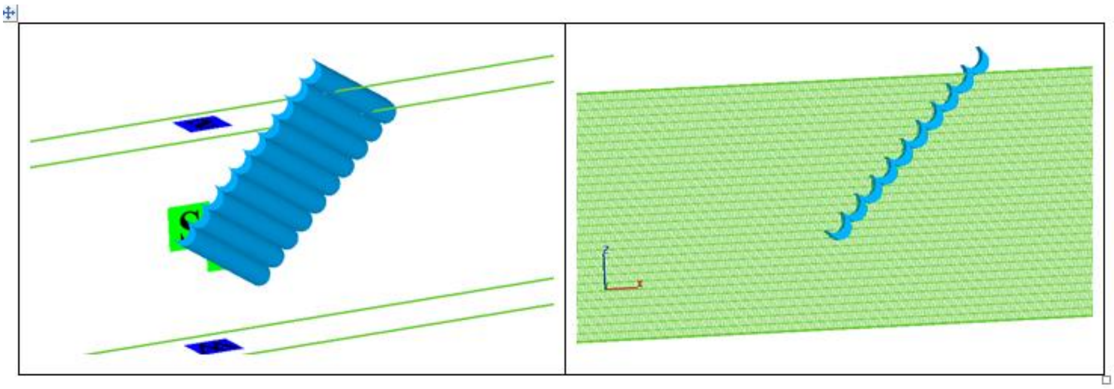


Fig.3. Flow-3D mesh and boundary for half pipe breakwater

TABLE 1

NUMERICAL INVESTIGATION SCHEME

Parameter	Units	The ranges
Water depth (h) (cm)	cm	20
Wave periods (T) (sec)	sec	0.65 to 1.33
Wave length (L) (cm)	cm	63 to 175
Relative wave length (h / L)	-	0.13 to 0.30
Dimensionless wave steepness (Hi /gT2)	-	0.003 to 0.013
Pipe diameter (d) (cm)	Cm	1.7, 2.7 and 3.3
Breakwater draft ratio (D/h)	-	0.0 to 0.85
Breakwater inclination angle (θ0)	degree	900, 750, and 450

4. NUMERICAL INVESTIGATION

This section presents the mimicking procedure of the half pipe breakwater numerically. It elaborates the tooled model, its theory, its validation process and the numerical simulations, as follows:

4.A. IMPLEMNTED MODEL

Many available models could simulate the half pipe breakwater. Among them are. However, FLOW-3D was selected. This is attributed to the fact that it is worldwide accepted and was applied to simulate similar structures and proved its capability and accuracy.

4.B. THEORY OF FLOW-3D

Theoretically, FLOW-3D is based on the finite volume theory incorporating "Reynolds-Averaged-Navier-Stokes". The model encompasses subcomponents that represent the geometrical and hydraulic boundary conditions.

4.C. MODEL CALIBRATION

The model was calibrated and validated against Koraim experimental results. The numerical and experimental results conformed together, figure (4).

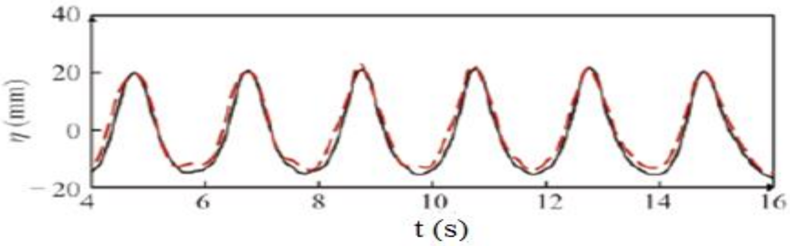


Fig.4. calibration results of the model for surface profile

at X=7.0 m and T = 1.2 s

Numerical model, -------; Experimental model, ______

4.D. MODEL APPLICATION

Confident with the calibration results, the model was employed to simulate half pipe breakwater with variable parameters.

4.E. MODEL RESULTS

Results were obtained. They encompassed the following hydrodynamic coefficients:

- Reflection coefficient
- Transmission coefficient
- Energy loss coefficient
- The height of the incident, transmitted and reflected waves

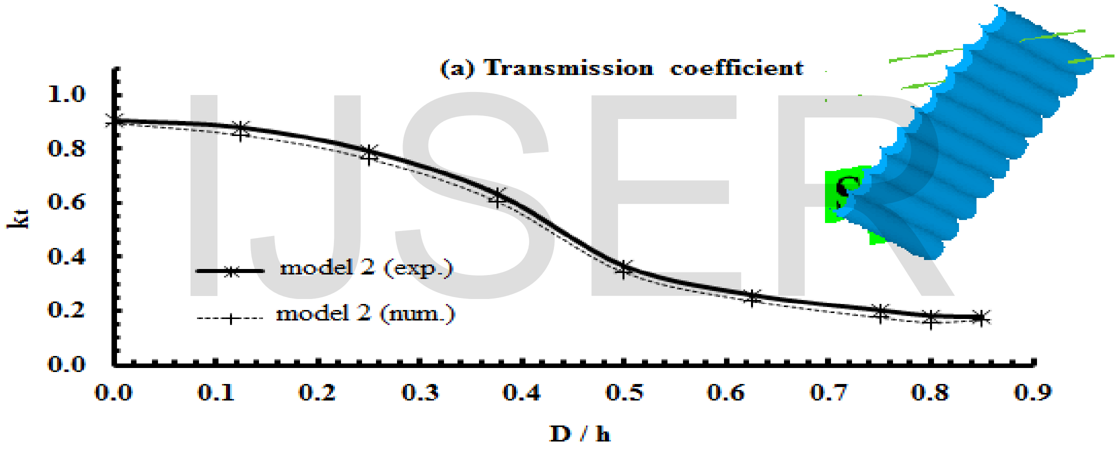
5. RESULTS ANALYSIS AND DISCUSSION

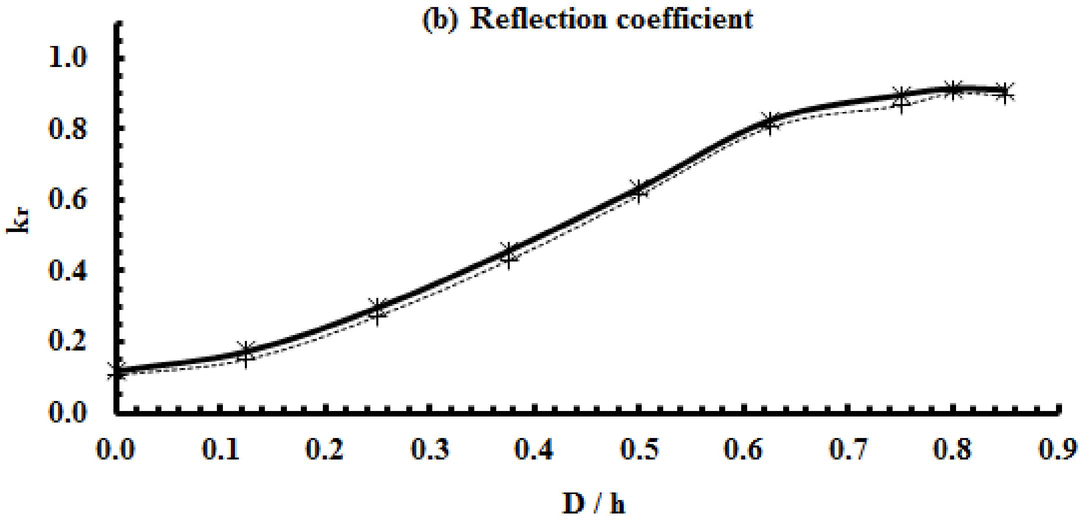
The impact of different parameters were analyzed and discussed, as follows:

5.A. IMPACT OF DRAFT (D) ON HYDRODYNAMIC EFFICIENCY

The numerical results concerning the impact of the draft D/h on the hydrodynamic efficiency were analyzed and presented. Figure (5) is provided as a sample of the obtained results. It presents the numerical and experimental results, in terms of reflection, transmission and energy loss coefficients for different D/h, at h/L= 0.16. Apparent was the conformation of both results. The figure designated the following:

- kt decreases by increasing D/h
- kr increases by increasing D/h
- half pipe arrangement impact on kt and kr is trivial
- kL increases with increasing D/h till D/h=0.5.
- kL decreases by increasing D/h at D/h>0.5.





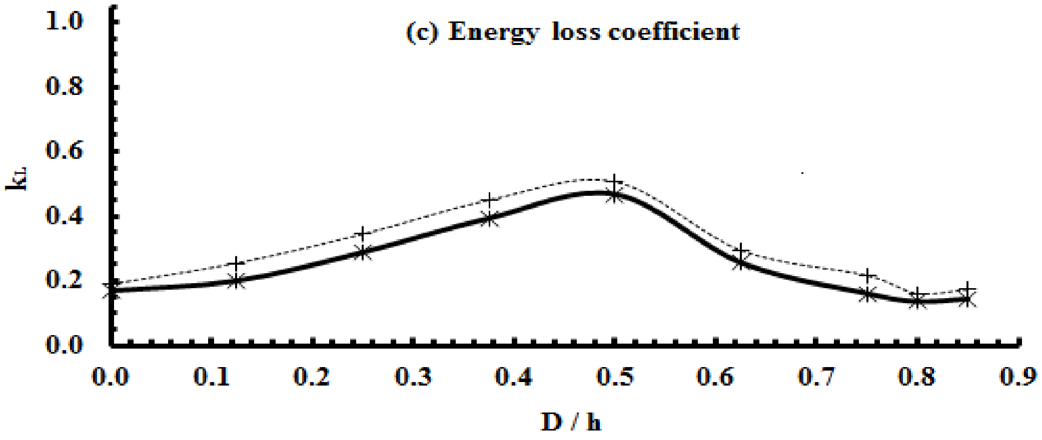


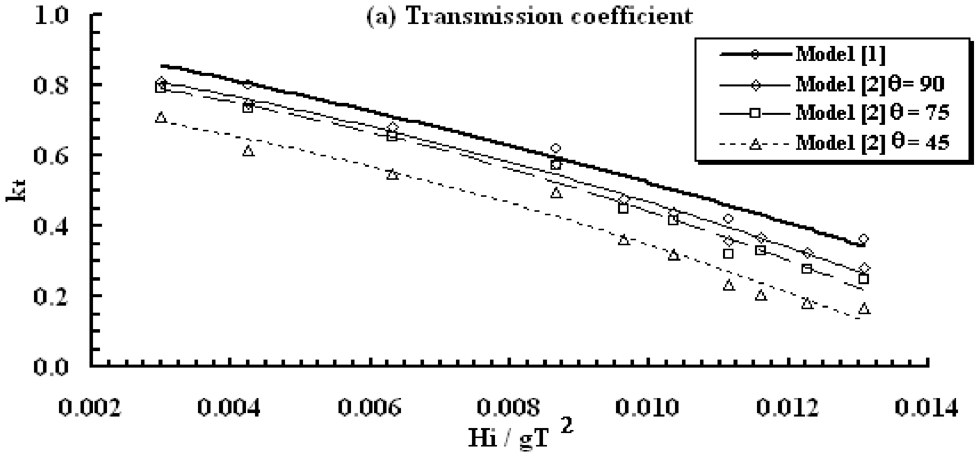
Fig.5. Numerical versus experimental results at different breakwater draft (D/h)

(At d/h=0.165 and h/L=0.3)

5.B. IMPACT OF INCLINATION ANGEL (Θ) ON HYDRODYNAMIC EFFICIENCY

The numerical results concerning the impact of the inclination angel (θ) on the hydrodynamic efficiency were analyzed and presented. Figure (6) is provided as a sample of the obtained results. It presents the numerical results, in terms of reflection and transmission coefficients for different (Hi/gT2), at d/h=0.165 and D/h=0.5. The figure designated the following:

- kt decreases by increasing Hi/gT2
- kt increases by increasing θ
- kr decreases by decreasing Hi/gT2
- kr increases by increasing θ



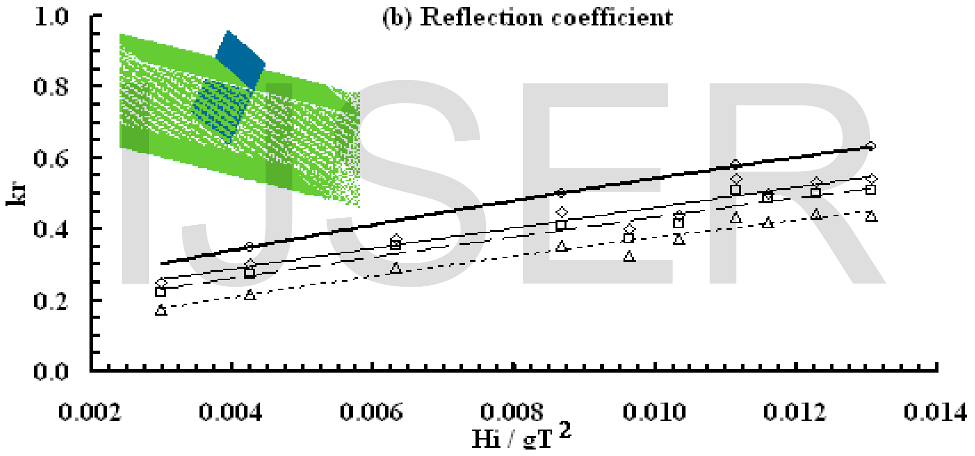


Fig.6. Impact of inclination angel (θ) on hydrodynamic efficiency

(At D/h= 0.5 and d/h =0.165)

5.C. IMPACT OF HALF PIPE BREAKWATER ON THE VELOCITY FIELD

The numerical results concerning the velocity field were analyzed and presented. Figures (7) to (12) provided a sample of the obtained results. Their description is as follows:

- Figures (7) signpost the numerical results, in terms of free surface profile, at the DD (down drift) of the horizontal; half pipe breakwater.
- Figure (8) designates the velocity field around the breakwater DD.
- Figure (9) ascertains the maximum velocities for inclined half pipe with (θ=45) and vertical thin wall breakwater, at T=12.8 sec, where the velocities were 0.72 and 0.62 m/s, respectively.
- Figure (10) presents the velocity field around inclined half pipe and vertical thin wall breakwater, at T=1.2 sec.
- Figure (11) designates the velocity DD the different barriers, at T=1.2 sec, where the velocity was greater in case of an inclined half pipe breakwater (θ=45) than the vertical thin wall breakwater.
- Figure (12) displays the velocity at the DD and UD (up drift) the different barrier down drift, at T=1.0 sec, where the velocity was recorded for the half pipe breakwater (θ=90) and the thin wall breakwater.

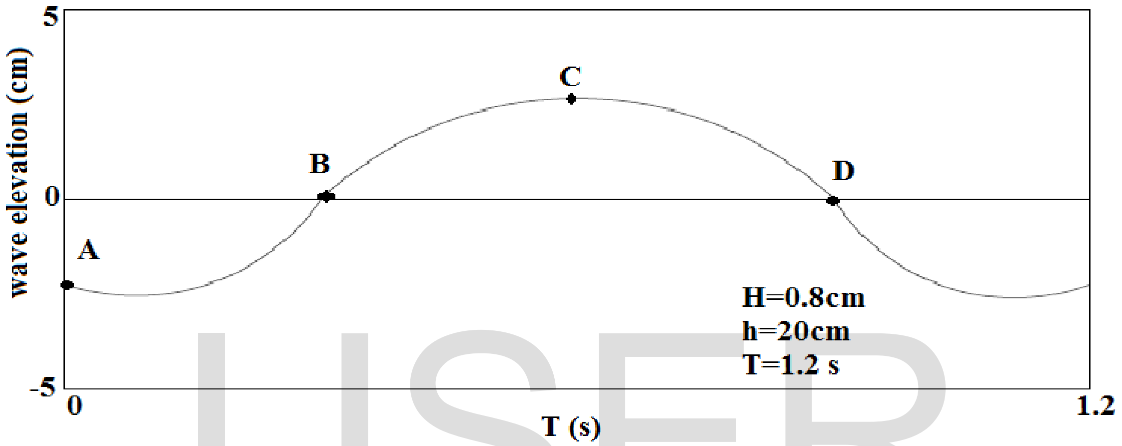


Fig.7. Free surface at 4 wave phases A, B, C and D at the DD of a horizontal half pipe breakwater

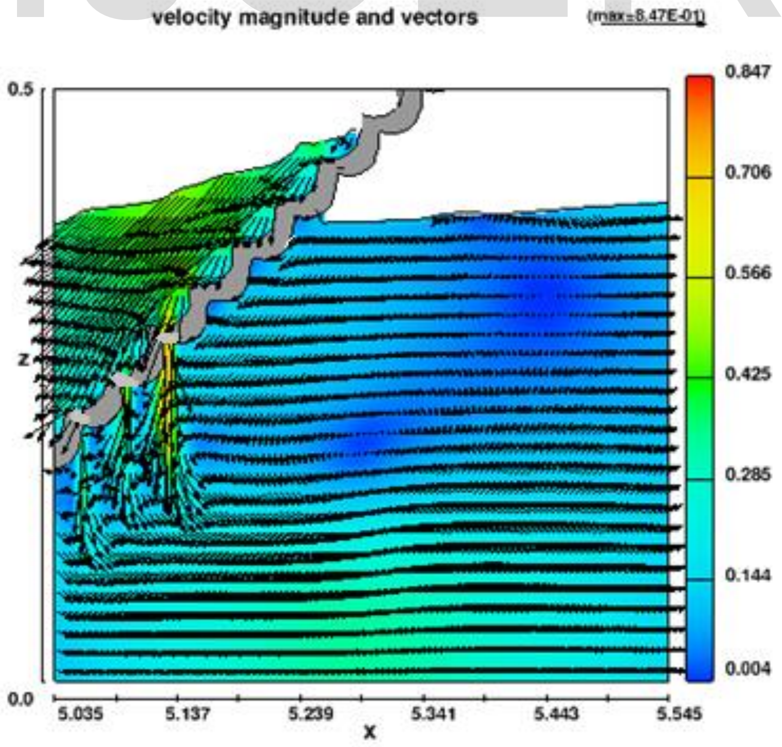


Fig. 8. Velocity field at DD of half-pipe breakwater

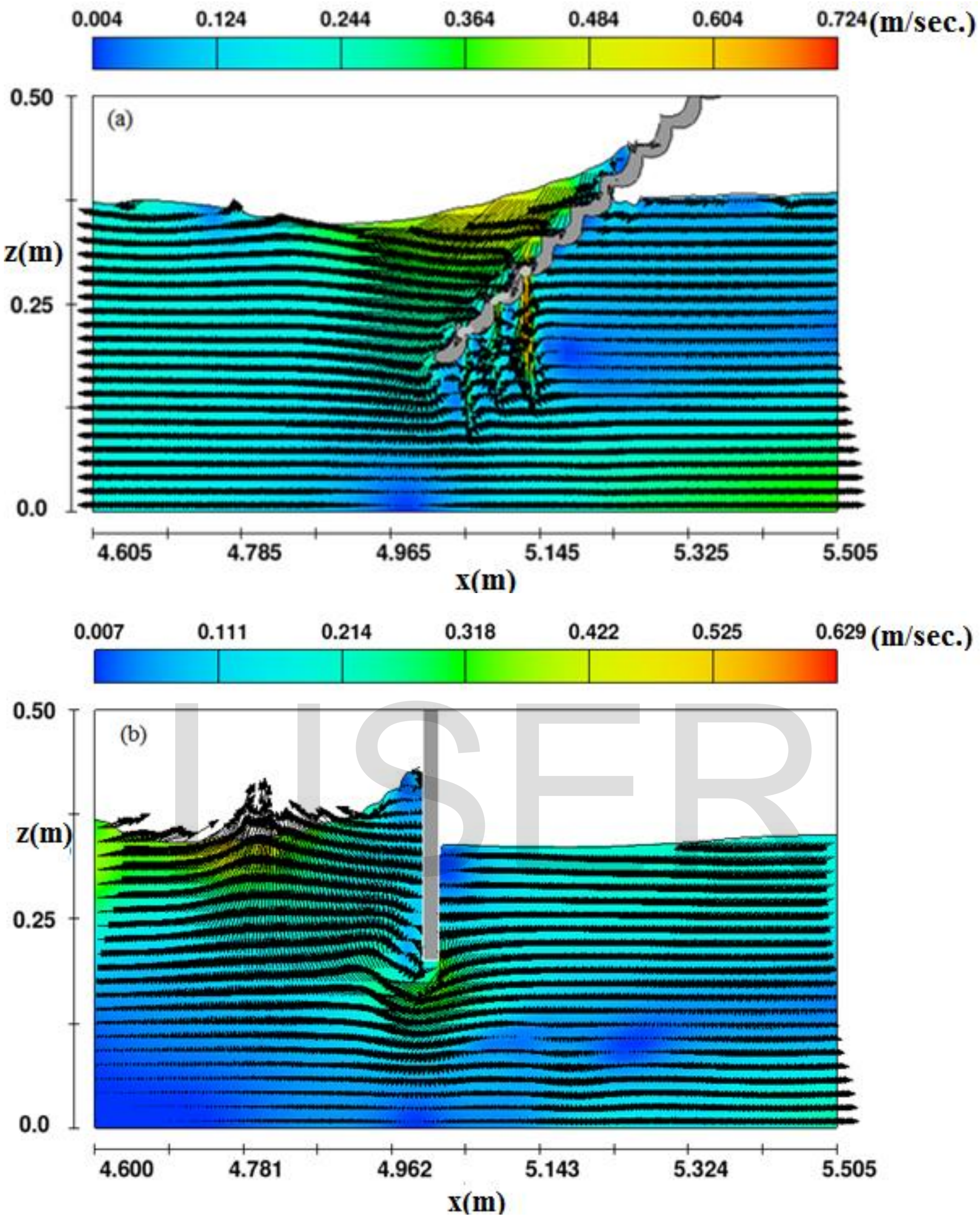


Fig.9. Maximum velocities for half pipe and vertical wall breakwater

(at wave period (T) =1.2 sec)

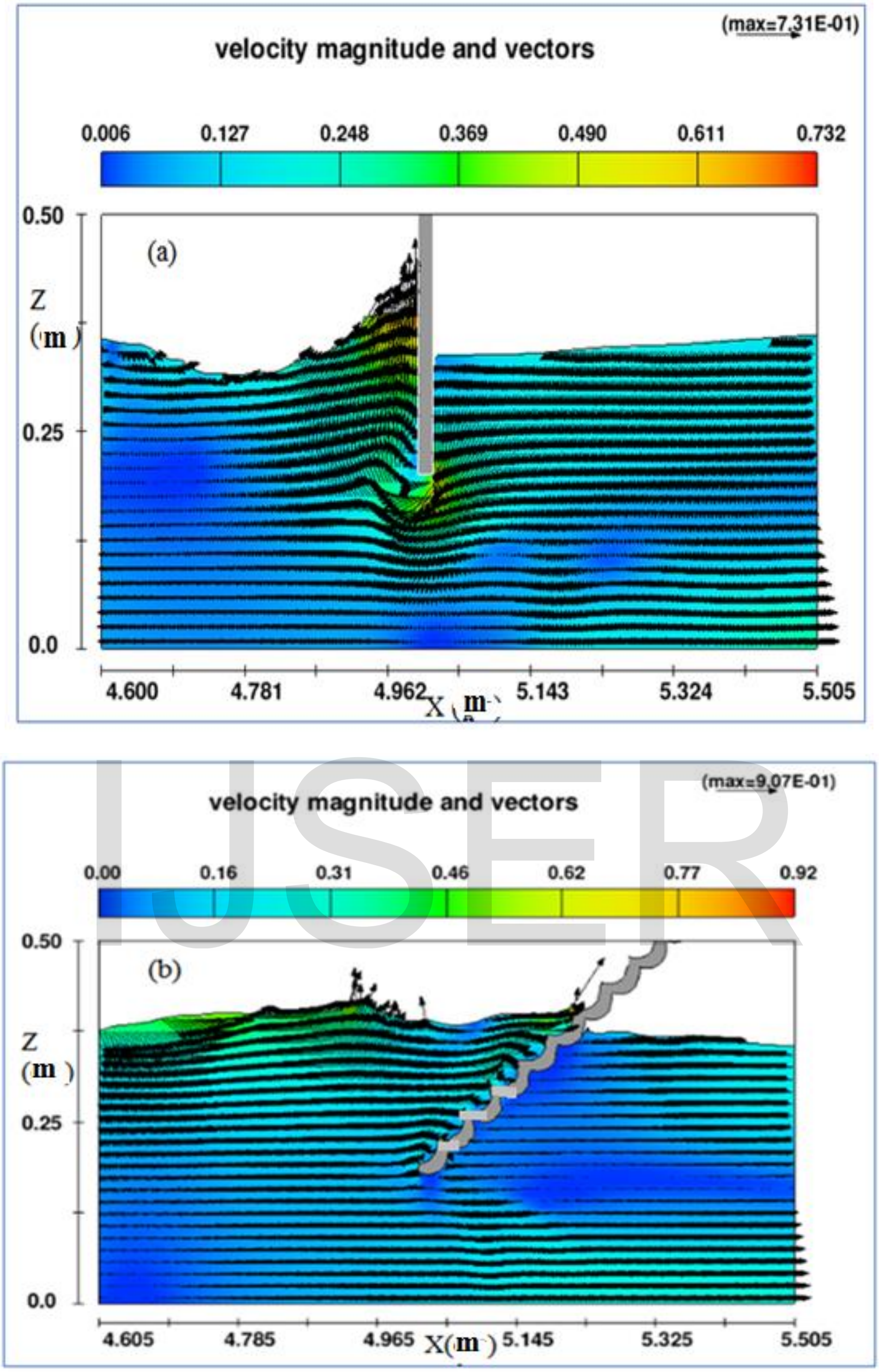


Fig. 10. Velocity field around vertical wall and suspended half pipe at T= 1.2 sec.

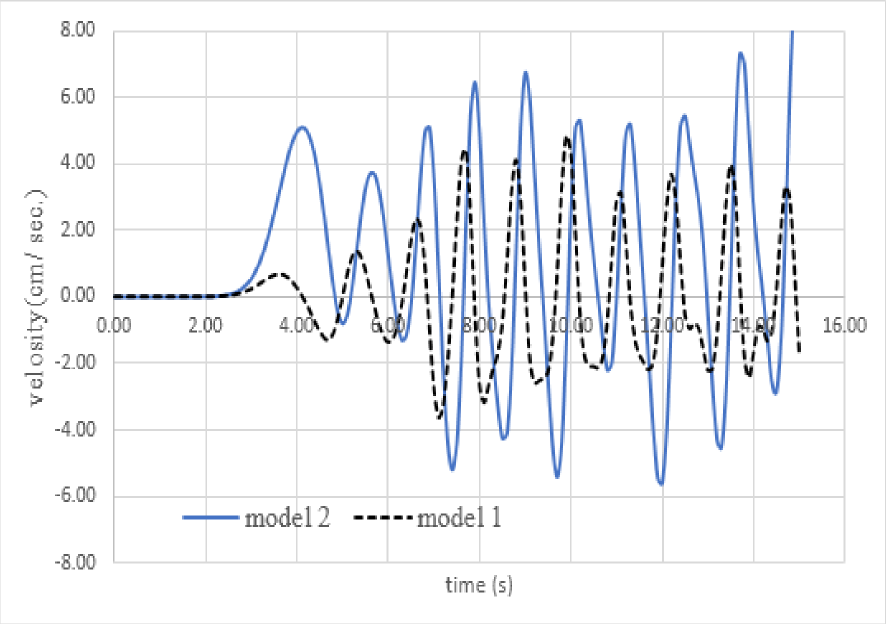


Fig.11. Computed velocity DD of different barriers at wave period T = 1.2 sec

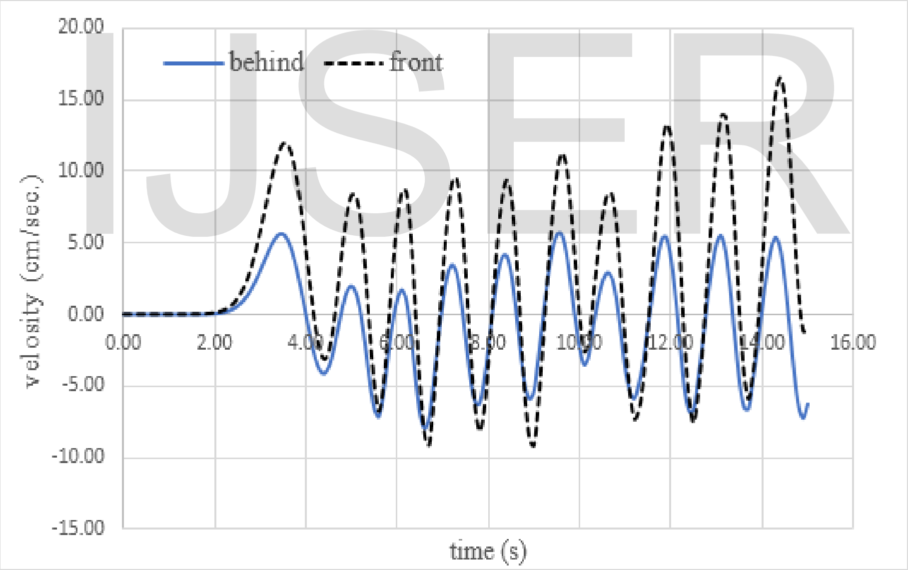


Fig .12. Barrier UD velocity versus barrier DD velocity at the surface of the water for half pipe breakwater at (θ=90) for wave period (T) =1.0 sec

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the reached results, the following conclusions were educed. These are, as follows:

- The half pipes barriers perform more efficiently than vertical wall barriers, in terms of wave energy dissipation.
- The numerical model results conformed well to the experimental results.
- Increased draft (D) of the barriers, improves the efficiency of hydrodynamic performance.
- Maximum velocities were traced in the barrier vicinity, where the velocity is higher at crest of the wave.

Based on the reached results, the following recommendations were suggested. These are, as follows:

- Execute further experiments with larger variables domain to elaborate the efficiency of half pipe breakwater precisely.
- Carry out numerical simulation to the inspected larger domain.

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