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Numerical modeling of wave run-up along columns of semi-submersible platforms

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ABSTRACT: Wave run-up is one of the most important and effective parameters in designing semi-submersible platforms. Besides unforeseen effects on the movements and response of the platform, wave run up can also cause slamming forces to be exerted on the lower deck of the platform. Therefore, at the first stages of this plan, before running tests on the model of the platform, numerical methods are usually utilized for estimating the appropriate height of semi-submersible platforms' deck in order to prevent any damage on it In this paper, in order to verify the validity of simulation and also the efficiency of "Flow3D" on predicting the wave run-up and also the effect of wave impact under various steepness on a semi-submersible platform, results derived from the simulation by "Flow3D" compared to the results of both WAMIT tool and the experimental model. The results show that "Flow3D" has great capability to estimate the amount of wave run-up when investigating the waves with the steepness of up to about 4 percent. But, by increasing the steepness of striking wave in front of the aft columns, the results obtained from the software are not in good agreement with the experimental and WAMIT results.

Keywords: *Flow3D; Semi-submersible Platform; wave run-up; wave steepness*

INTRODUCTION

The oil and gas are being exploited using different methods such as applying fixed or floating platforms in shallow or deep waters for many years. Semi-submersible platform is the special type of floating platforms which is used in deep waters. It has the lowest cross sectional area with water free surface. In designing semi-submersible platforms, one of the most important issues is how to keep the lower deck safe from the impact of waves. For this, the vertical height between the water surface and the lower deck must be predicted by modeling the wave run-up along semi-submersible platform columns. Wave run-up is a nonlinear phenomenon occurring around the platform columns.

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The aim of this study is to develop a numerical method to predict the air gap in semi-submersible platforms by estimating wave run-up. However, the wave steepness should be considered as an important parameter on simulation of wave run-up.

For many years, several researches have been conducted by different methods to estimate the wave run-up and air gap along semi-submersible platform columns (Iwanowski *et al.*, 2009; Wang *et al.*, 2009; Shan *et al.*, 2011; Matsumoto *et al.*, 2013; DeVos *et al.*, 2007). Iwanowski *et al.* (2009) used a CFD tool, ComFLOW, to simulate flow around a semi-submersible platform. They investigated wave run-up in vicinity of semi-submersible columns. By comparing the results of the simulation with experimental data, it showed up that the CFD solver, ComFLOW, is able to predict wave characteristics. In the same year, Wang and You, by using a solver based on Navier-Stoke equations, named Fluent, simulated the interaction of viscous wave fields with the semi-submersible platform in a numerical wave flume. They found out that the numerical wave flume obtained, is able to numerically simulate the interaction of viscous wave fields with the semi-submersible platform. Shan *et al*., (2011) conducted some tests on a large volume drilling semi-submersible platform with a wide range of wave steepness (H/L) to investigate wave run-up characteristics around the columns. They found out that wave run-up on aft columns is more effective and complicated than on fore columns. Matsumoto *et al*. (2013) performed a test on a large semi-submersible platform and observed the effect of wave run-up on different wave steepness. Wave elevation in 7 different points was measured and compared to the results of simulations made by a BEM code (WAMIT) and a VOF code (ComFLOW).

In this research, the capability of a CFD based software, Flow3D, in simulating the wave run-up has been investigated. For this purpose, a comparison between the results obtained from Flow3D with experimental data and simulation by WAMIT tool presented in Matsumoto (2013), has been conducted which shows a good matching with experimental measurements and WAMIT tool.

MATERIALS AND METHODS

For the first time, fluid flow model was described by Navier-Stokes equations. These non-linear equations are often coupled together, which causes some intricacies to solve them. Numerical methods have resolved some of the limitations in analytical methods in governing equations. Computational fluid dynamic (CFD) method is one of the most important of the numerical models. Volume of fluid method (VOF) is a technique of CFD is used in simulation of free surface and also determining of its' location.

Flow3D:

Flow3D applies the renormalized model (RNG) to solve Navier-stokes equations and VOF to simulate changes in free surface profile. Then the stl.* file created by AutoCAD will be imported to Flow3D.

Basic assumptions in this research are the continuity of flow and incompressible water. According to these assumptions, the continuity and momentum equations and the transport equation for the VOF function are as follows expressed respectively in Eq. (1 to 3) as follow:

1) $$\frac{V_f}{\rho}\frac{\partial \rho}{\partial t}+\frac{1}{\rho}\nabla.(\rho.\bar{u}.A_f)=-\frac{\partial V_f}{\partial t}$$

2) $$\frac{\partial \bar{u}}{\partial t}+\frac{1}{V_f}(\bar{u}.A_f.\nabla\bar{u})=-\frac{1}{\rho}[\nabla P+\nabla.(\tau A_f)]+\vec{G}$$

3) $$\frac{\partial F}{\partial t}+\frac{1}{V_f}\nabla.(F.\bar{u}.A_f)=-\frac{F}{V_f}\frac{\partial V_f}{\partial t}$$

With,

ρ = fluid density
U = fluid velocity
V_f = Volume fraction
A_f = Area fraction
P = Pressure
τ = viscous stress tensor
$\dot{G}$ = Gravity vector
F = fluid fraction

Then boundary conditions are defined. To simulate the incoming wave, the wave characteristics must be described as input border and, on the other side sommerfeld boundary condition is applied to let the flow out without any reflection. Assuming a horizontal sea bed the vertical component of velocity on sea bed would be considered as zero (Eq.4). Other boundaries are presented as symmetry boundaries which show the zero gradients with zero velocity.

4) $$\frac{\partial \varphi}{\partial y}=0$$

According to the paper written by Matsumoto *et al*., the sea depth is assumed 300 meters. Stokes' 5^{th} order theory is used in this simulation. As the wave run-up occurs during the time, the simulation time is considered 70 seconds.

PLATFORM CHARACTERISTICS

Dimensions of main model built in Brazil including length, width and height of pontoons are respectively 85, 17.5 and 12 meters. Length, width and height of columns are 17.5, 17.5 and 27.5 meters, and the center of gravity in x, y and z directions are 0, 25 and 5. Experimental model is built in IPT wave flume in the scale of 1:100 (Fig. 1a). After modeling the platform by Flow3D (Fig. 1b), according to Matsumoto paper, 7 wave probes (WP1 to WP7) are defined (Fig. 2) to measure the wave run-up. The effect of hitting waves with different steepness is studied by Flow3D. The mooring system includes 4 mooring lines with 25.090 N/m line stiffness (Fig. 3).

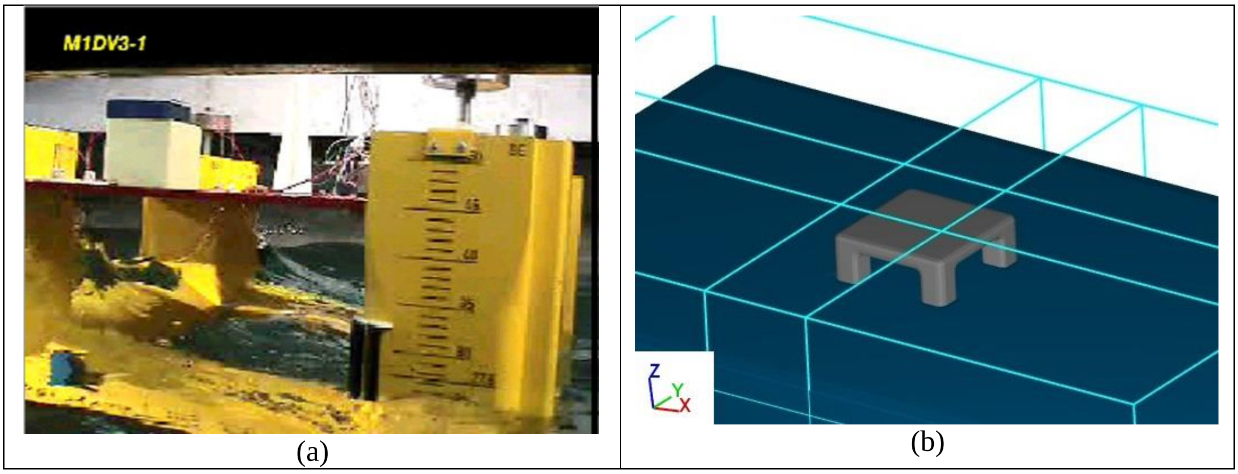

Fig. 1: (a) semi-submersible experimental model; (b) semi-submersible model by Flow3D

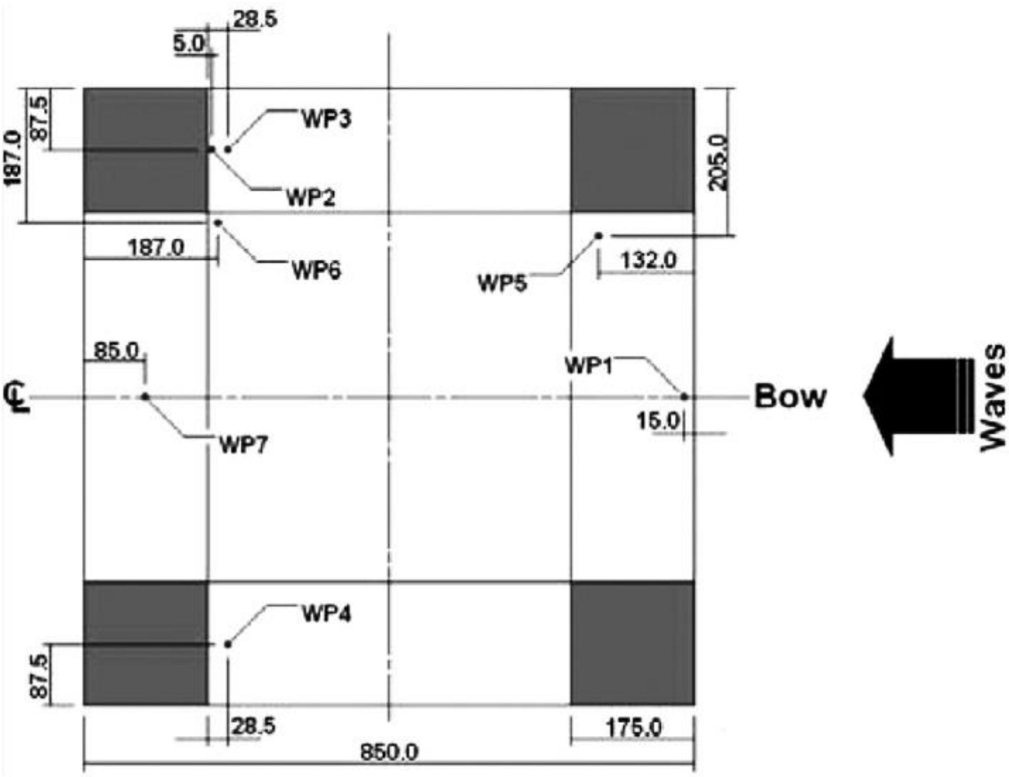

Fig. 2: Location of wave probes (values in mm) [4]

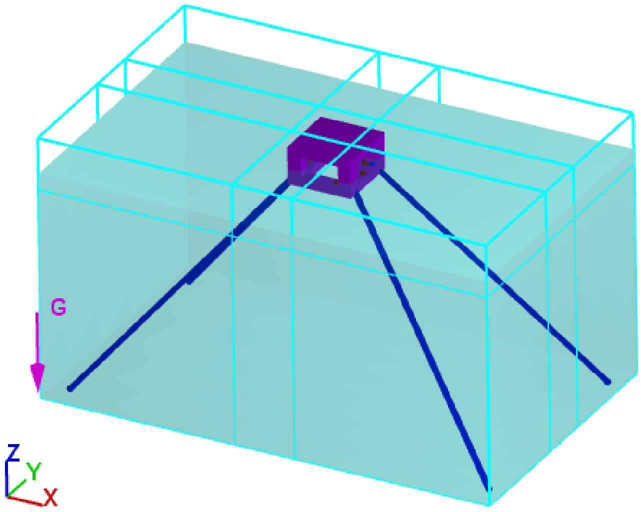

Fig. 3: Mooring lines of semi-submersible platform modeled in Flow3D

RESULTS AND DISCUSSION

To evaluate the potential of Flow3D in simulating the wave run-up with different wave steepness, different wave characteristics adopted in the test as incoming waves (Table 1).

Table 1. Wave tested parameters [4]

Wave steepness (H/λ)	Wave amplitude (m)	Wave period (s)
2.07 %	6.17	19.53
2.78 %	6.70	17.58
4.02 %	7.28	15.23
3.98 %	5.98	13.87
4.90 %	5.61	12.11

Then the maximum height of wave run-up measured in all probes under different wave steepness. In order to compare the results of Flow3D to the results of WAMIT and also experimental model, the maximum wave height at each point should be divided to the maximum height of the incoming wave to produce non-dimensional numbers to be able to use graphs in the mentioned article.

The result of simulating wave run-up at the steepness of 2.07 % is shown as an example. In Fig. 4, 3D model of semi-submersible platform under the mentioned wave is presented in the second of 49. There are similar Fig.s for every other wave.

To see the exact number of wave run-up, 2D results of the modeling are used. Fig. 5 presents the wave run-up at every probe. By using Fig. 5 the maximum wave run-up at each point and then the non-dimensional number is derived. The results are compared to the results obtained from WAMIT and experimental test in Fig.s 6 to 12.

As we can see, by increasing the wave steepness to 4.02 % there is good agreement to all the results. But when the wave steepness increases to 4.90 % there is a noticeable disagreement between the results of Flow3D and the experimental model. To explain this disagreement we may mention the increase of the non-linear effects of waves with steepness higher than 4% which the proposed method does not allow to model all these non-linear effects especially in diffracted waves.

There is good agreement between all three methods at WP1 and WP5 (Fig.6 and Fig.7). It is almost because of interaction of waves and the platform columns which keeps the wave characteristics unchanged.

As it can be seen on Fig.s 8 to 12, concerning these probes positioned next to the aft columns, there is a good agreement between the results of wave run-up in the steepness lower than 4%. However, there is no good estimation of wave height in higher steepness. So it seems that Flow3D is acceptably capable of modeling wave run-up in low wave steepness.

With respect to Fig. 12 and the fact that WP7 is located between the aft columns, there is no good agreement in higher than 4% steepness. The most probable reason is the nonlinear effect of diffraction and also effects of sloshing the water particles which is caused by the interaction of incoming waves and waves trapped among the columns.

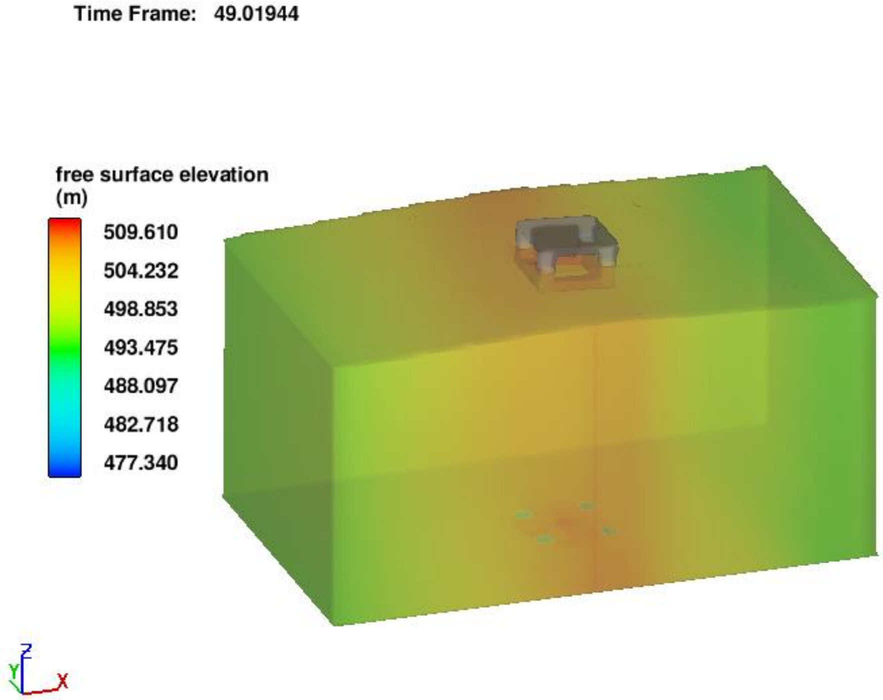

Fig 4: 3D model of semi-submersible platform under the wave with the steepness of 2.07 % by Flow3D

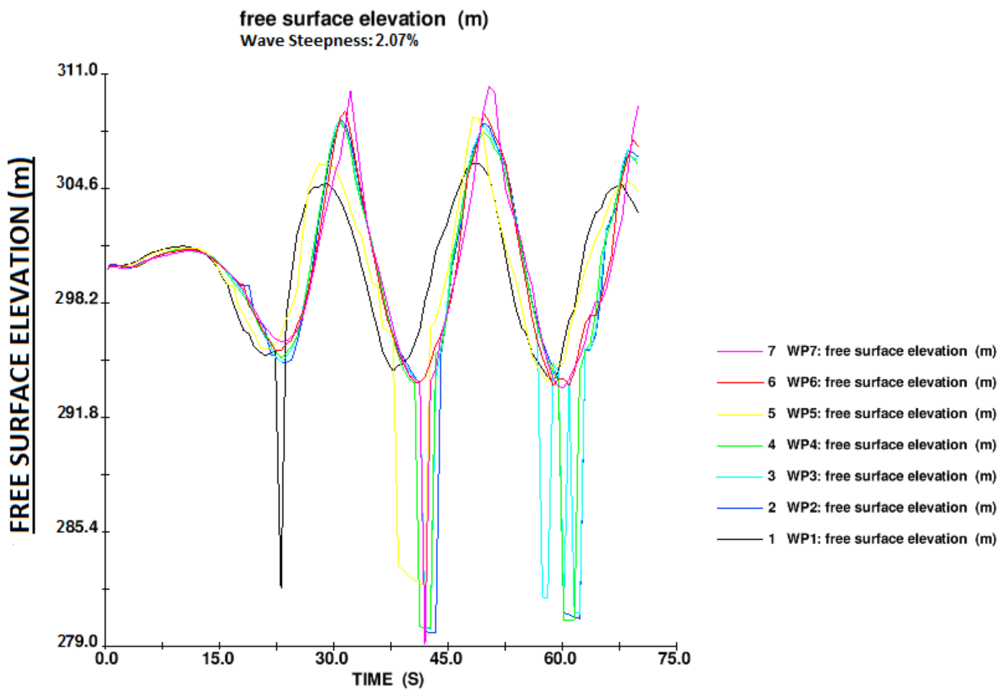

Fig. 5: Wave run-up at each point under the wave with the steepness of 2.07 % by Flow3D

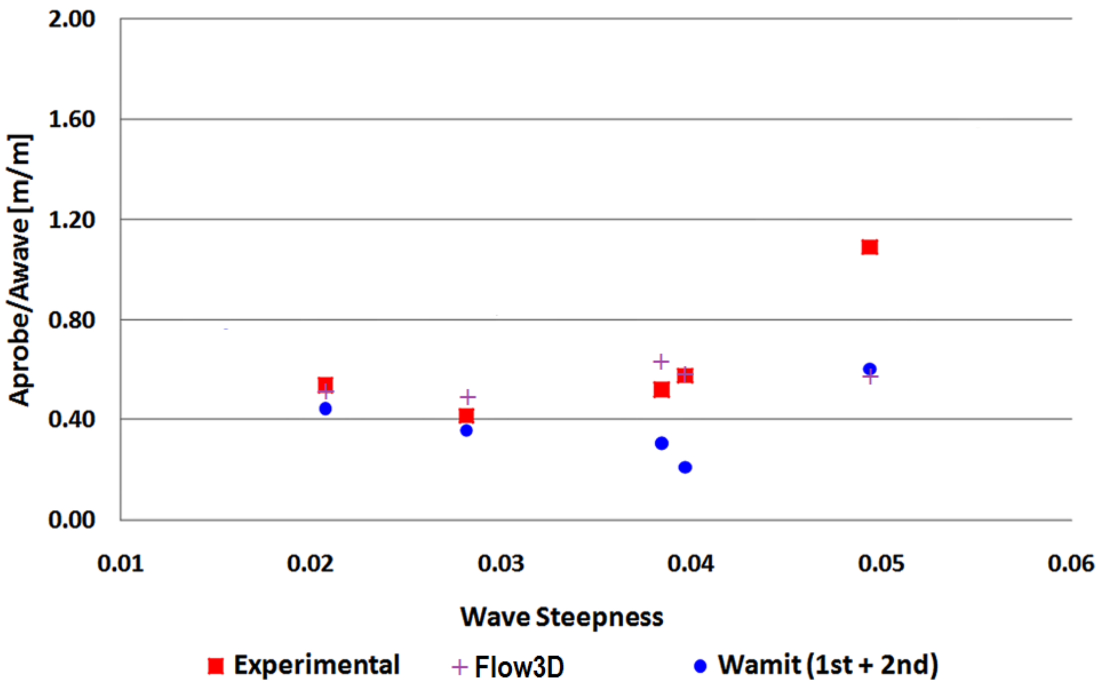

Fig. 6: Non-dimensional wave height at WP1

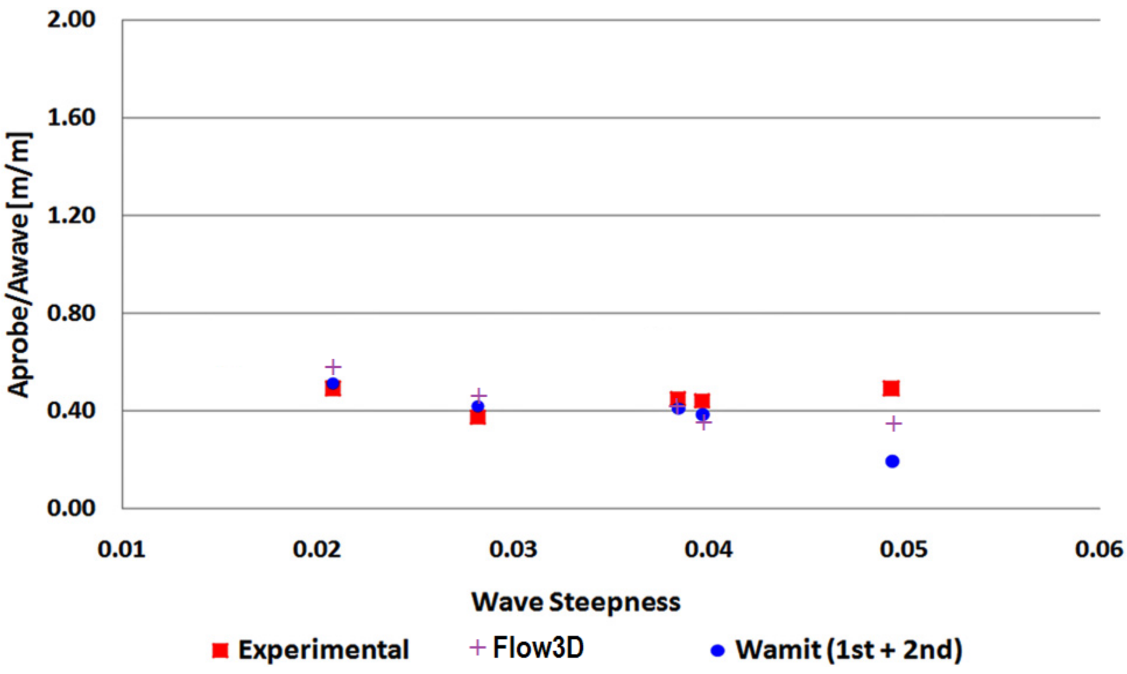

Fig. 7: Non-dimensional wave height at WP5

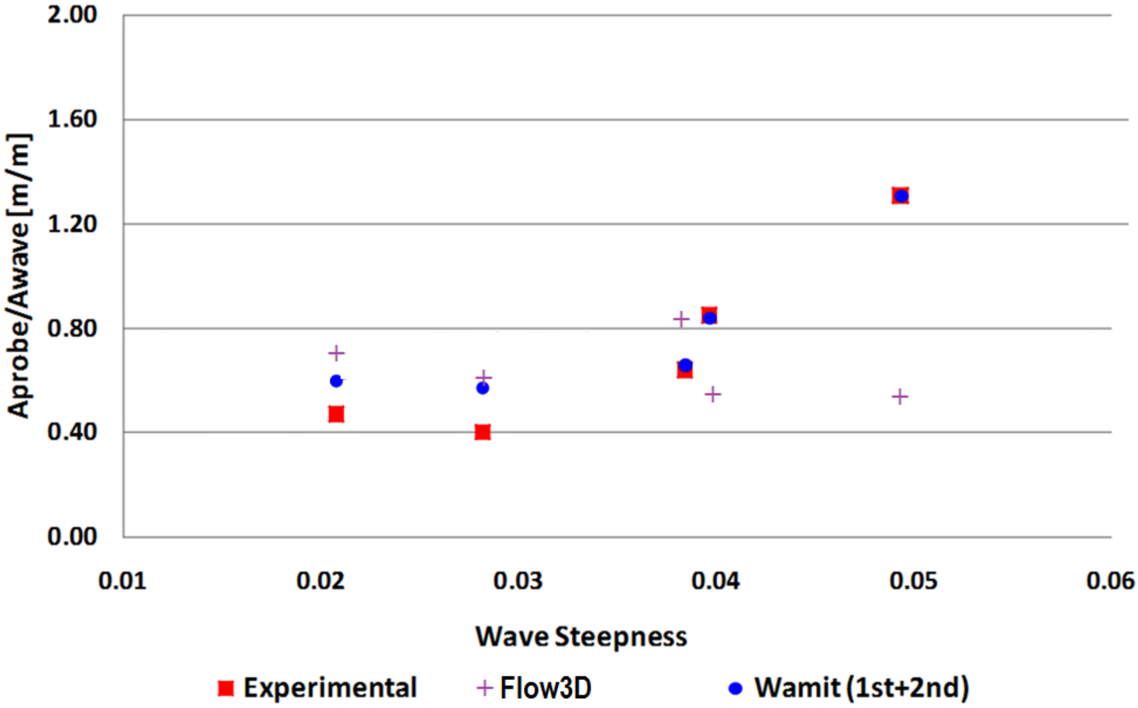

Fig. 8: Non-dimensional wave height at WP2

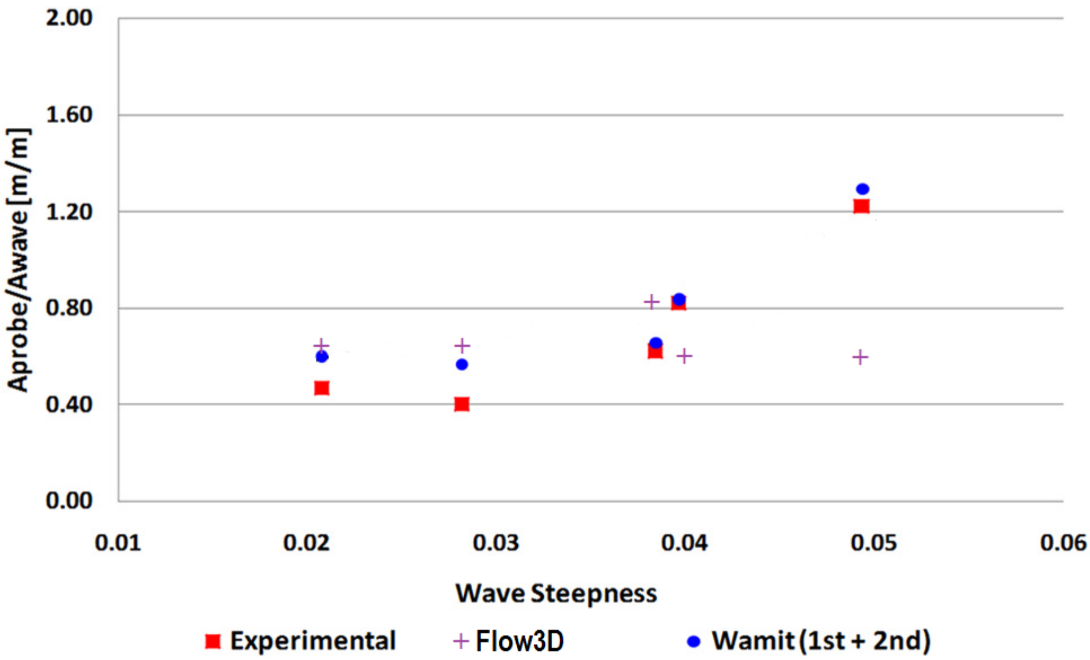

Fig. 9: Non-dimensional wave height at WP3

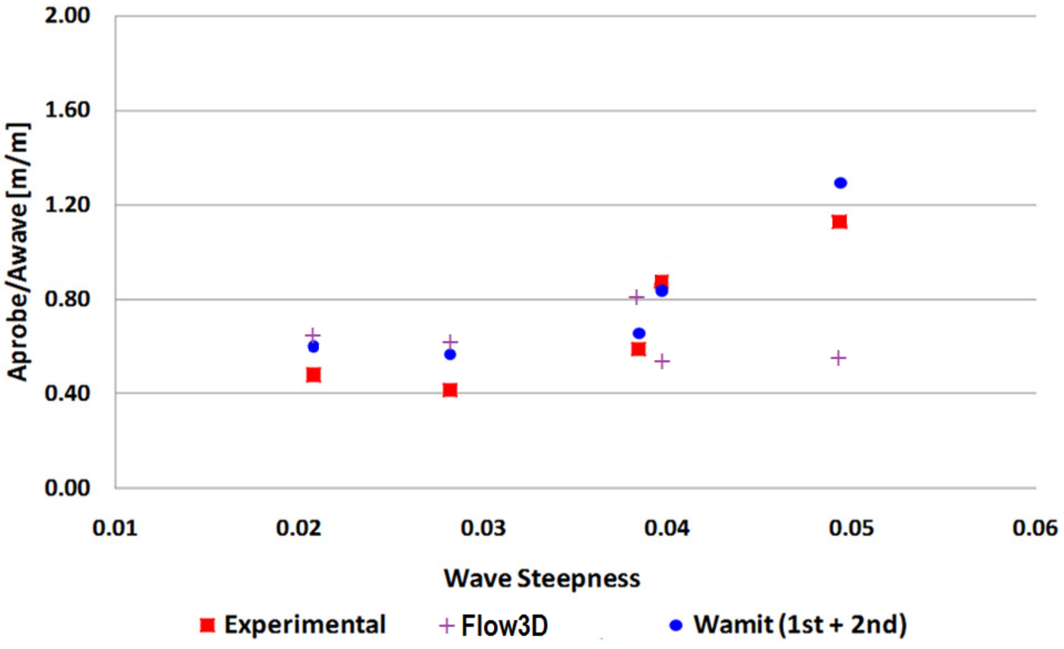

Fig. 10: Non-dimensional wave height at WP4

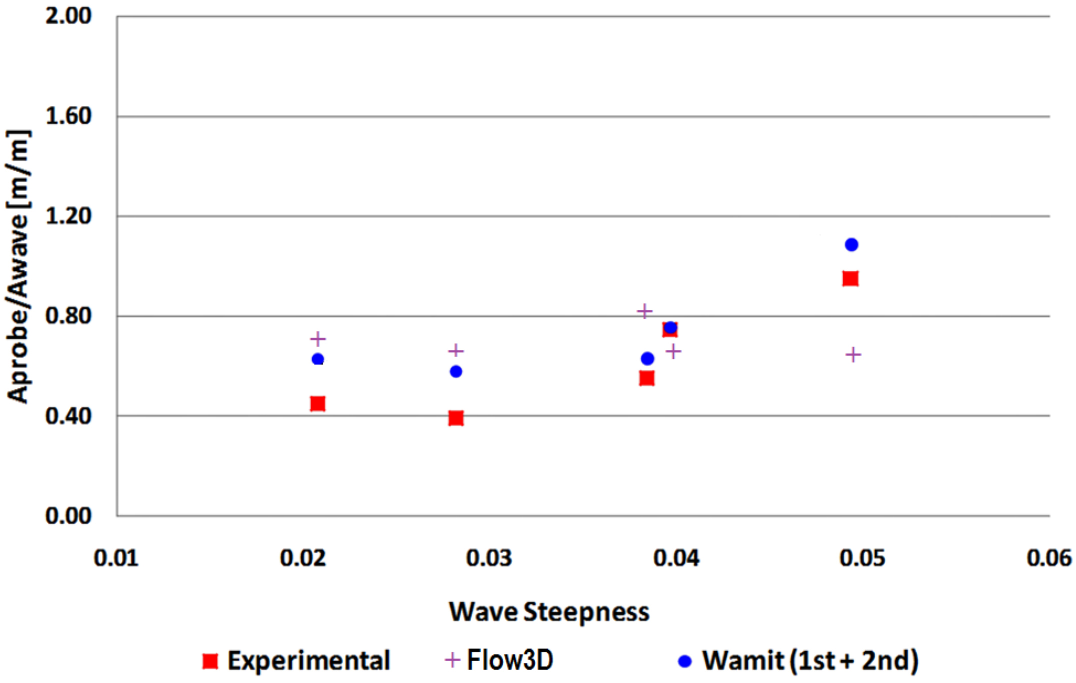

Fig. 11: Non-dimensional wave height at WP6

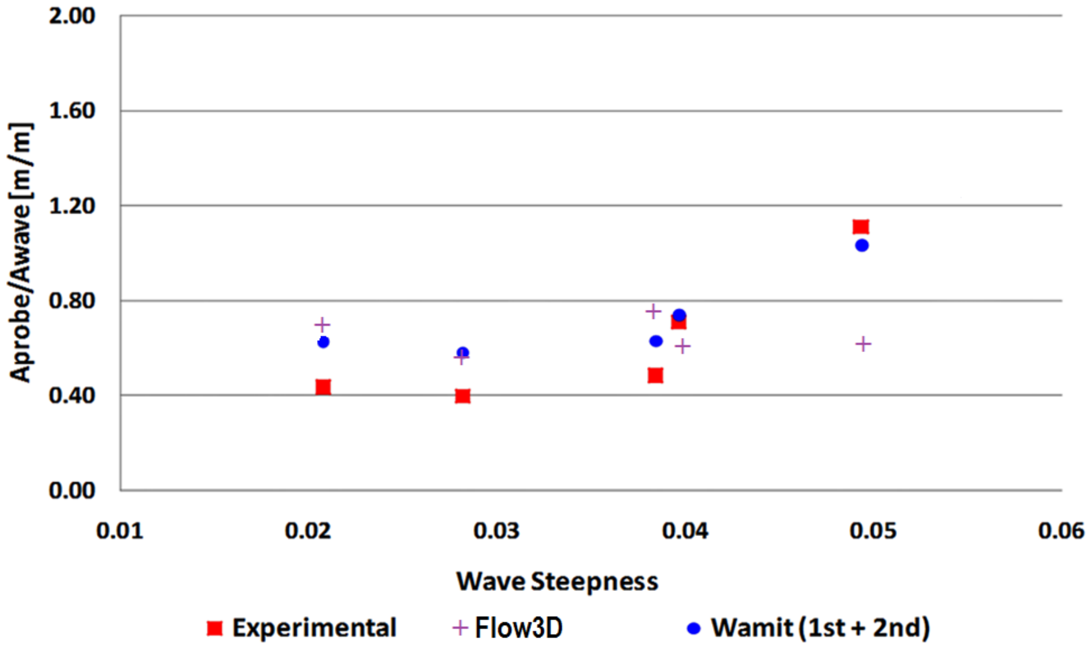

Fig. 12: Non-dimensional wave height at WP7

CONCLUSION

One of the most important and effective issues in designing semi-submersible platforms is wave run-up along columns of these platforms. This can cause wave slamming on lower deck in addition to unpredicted effect on motions and response of platform. In this research we evaluate the capability of Flow3D in simulation of wave run-up along columns of semi-submersible platform by assessing the impact of wave with different steepness. By comparing the maximum wave height at probes next to the columns, it can be seen that at probes next to aft columns there is good agreement between the results derives from flow3D, WAMIT and experimental modeling. As we approach the aft columns, there is still good agreement while the wave steepness is not more 4percent, but with increasing wave steepness, there is obviously a conflict between results of these methods. This conflict can be explained by considering the interaction of waves among the columns and sloshing in experimental model and WAMIT, and the fact that Flow3D simulates free surface without considering interaction of waves among columns. However, it should be noted that simplicity of simulation of wave run-up along columns by Flow3D, in addition to the advantages of using VOF method, reveals the advantages of applying it especially in the early stages of designing semi-submersible platforms.

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