VOL. 12, NO. 8, APRIL 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

IMPLEMENTING A VIBRATION FRAMEWORK FOR SIMULATION OF VIV ON RIGID PIER BY SPH

Mohammad Hasan Ramesht and Ali Moradi
Department of Civil Engineering, Centeral Tehran Branch, Islamic Azad University, Tehran, Iran
E-Mail: mhramesht@yahoo.com

ABSTRACT

The purpose of this study was to find, with the aid of ANSYS software, a formula for a vibration design of bridge piers that provides maximum convergence with experimental results, the effect of waves on fixed and floating platforms is an important consideration for designing of offshore structures, and thus several experimental and numerical models have recently been presented. In this paper, a numerical model was developed in an ANSYS program to simulate current wave interaction with a vertical cylinder acting as a platform leg. This involved using smooth-particle hydrodynamics method (SPH) for solving the hydrodynamics, as well as using the finite element method with regard to the structural aspect, according to an experimental sample. The required data were gathered through a library method called SPH, which is a Lagrangianun meshed method and is sufficiently accurate for free surface modeling in comparison with other Eulerian mesh-based methods. In this connection, the capacity of the method to calculate in-line and cross-flow forces on a cylinder was considered using different time solution algorithms. The results showed that the predictor-corrector algorithm led to the most accurate finding, compared to the Beeman, symplectic, and Verlet algorithms. Although vibration of cylinder have been investigated.

Keywords: wave structure interaction, in-line and cross-flow forces, numerical modeling, Lagrangian particle-based method, predictor-corrector algorithm.

INTRODUCTION

Seeing that the construction of massive offshore structures is usually costly. In these types of structures, the risk of failure and its consequences is considerable because of the complexity of random loading and uncertainty of environmental conditions. One of the complicated forces that is controlled by weight or smoothing function. In this connection, Monaghan and Kochariyan [5] modeled a multi-phase flow using this technique. Also Panizzo and Dalrymple [6] studied waves generated due to a land-sliding. Their major achievement was to propose a method to evaluate the derivatives without using structured mesh. It must be pointed out that in SPH a system condition is introduced that includes some particles that have the properties of materials, and which interact in an environment. Interestingly enough, researchers are now paying increasing attention to FSI problems in numerous field of engineering, including marine propulsion and vortex-induced vibration (VIV), which have been investigated by [1] and [2]. Similarly, the suppression of VIV on flexible submerged structures has entailed a great deal of research in the field of ocean and offshore engineering designed to ensure acceptable life spans of marine equipment, including risers, pipelines, and offshore platforms [3-5]. On a smaller scale, amplification mechanisms and other engineering systems have been developed to take advantage of VIV hydrodynamics at low Reynolds numbers and harvest power from specific devises [6-8]. Moreover, a detailed study of the flow variability along the axis of thin cantilevers was reported by [9]. Furthermore, several formulations have been proposed to consider the effect of parameters such as the presence of a solid wall, or a free surface, in the vicinity of the oscillating lamina [10], the influence of the beam width-to-thickness ratio [13], the coupling of two oscillating bodies in a viscous fluid [14], or the effect of a shear-dependent viscosity on the vibrations of a thin lamina. In each case, a different hydrodynamic response was observed and a variety of hydrodynamic functions have been cast to accurately predict fluid actions in the form of added mass and damping coefficients.

Smooth particle hydrodynamics theory

SPH is based on integral interpolation. This means that the Basic law indicates that any function can be estimated by the following statement [10]:

$$A(r) = \int_{\Omega} A(r')W(r-r',h)dr' \tag{1}$$

In which r represents the influenced positive vector, w is the weight function or Kernel function, and h is the smoothing length that adjusts the influenced zone (see Figure-1).

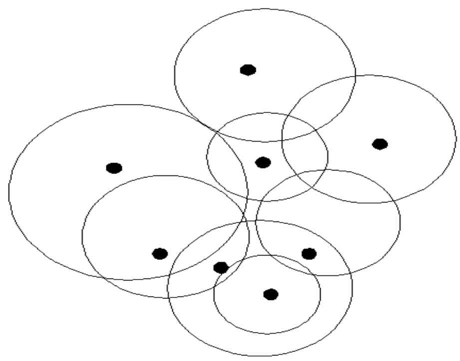

Figure-1. Influence domain of hydrodynamic particles.

It is obvious that the value of h should be greater than the primary distance between particles. If equation (1) is defined discretely, then in order to produce experimental estimation of particle a, it can be written as follows:

$$A(r) = \sum m_b \frac{A_b}{\rho_b} W_{ab} \tag{2}$$

In which is the mass, is the density, and is the weight or Kernel function. One of the superiorities of weight function in SPH is that the derivative of the former is analytically achieved. In contrast, derivatives are calculated by neighboring points, using their distances, in the finite difference method. When points are far from each other with an irregular pattern, this calculation is cumbersome. The derivative of equation 2 is evaluated as follows:

$$\nabla A(r) = \sum m_b \frac{A_b}{\rho_b} \nabla W_{ab} \tag{3}$$

The performance of the SPH model depends on the selection of Kernel function, which should satisfy various conditions, such as positivity, normalization, and uniform reduction with distance. It depends on the smoothing length and dimensionless distance between particles ($q = \frac{r}{h}$) , in which is the distance between *a* and *b*. Parameter h controls the area around particle *a* to affect its neighboring particles. Of course, different smoothing functions could be applied. In the present study, cubic spline smoothing functions were used as follows:

$$w(r,h) = \alpha_D \begin{cases} 1 - \frac{3}{2}q^2 + \frac{3}{4}q^3 & 0 \le q \le 1 \\ \frac{1}{4}(2-q)^3 & 1 \le q \le 2 \\ 0 & q \ge 2 \end{cases} \tag{4}$$

In this equation, have different values in 2D and 3D problems.

Governing equations

Basic equations governing fluid dynamics are based on three fundamental physical rules: conservation of mass, conservation of momentum, and conservation of energy. Equations of SPH motion are achieved on the basis of the Lagrangian form of these three laws. Accordingly Mass conservation can be expressed as:

$$\frac{d\rho}{dt} = -\rho \nabla . V \tag{5}$$

The equation for conservation of momentum in a continuous media is as follows:-

$$\frac{Dv}{Dt} = -\frac{1}{\rho}\nabla P + g + \theta \tag{6}$$

$$\frac{dv_a}{dt} = -\sum_b m_b \left(\frac{P_a}{P_a^2} + \frac{P_b}{P_b^2} + \Pi_{ab}\right) \nabla a W_{ab} + g \tag{7}$$

In which the pressure gradient term is as follows:

$$-\frac{1}{\rho}\nabla P = -\sum_b m_b \left(\frac{P_a}{P_a^2} + \frac{P_b}{P_b^2}\right) \nabla a W_{ab} \tag{8}$$

The viscosity statement is defined as:

$$\Pi_{ab} = \begin{cases} \frac{-\alpha \overline{C_{ab}} \mu_{ab}}{\overline{\rho_{ab}}} V_{ab}.r_{ab} < 0, \\ 0 \qquad forothervalues \end{cases} \tag{9}$$

In which the statements of μ_{ab} and $\overline{\rho}_{ab}$ are:

$$\mu_{ab} = \frac{h v_{ab}.r_{ab}}{r_{ab}^2 + \eta^2} \tag{10}$$

$$\bar{\rho}_{ab} = \frac{1}{2}(\rho_a + \rho_b), \bar{C}_{ab} = \frac{1}{2}(C_a + C_b); \eta^2 = 0.01\, h^2 \tag{11}$$

$$\vec{v}_a^{n+1/2} = \vec{v}_a^n + \frac{\Delta t}{2} F_a^n;\ \rho_a^{n+1/2} = \rho_a^n + \frac{\Delta t}{2} D_a^n;\ \vec{r}_a^{n+1/2} = \vec{r}_a^n + \frac{\Delta t}{2} \vec{V}_a^n \tag{12}$$

$$\vec{v}_a^{n+1/2} = \vec{v}_a^n + \frac{\Delta t}{2} F_a^{n+1/2};\ \rho_a^{n+1/2} = \rho_a^n + \frac{\Delta t}{2} D_a^{n+1/2};\ \vec{r}_a^{n+1/2} = \vec{r}_a^n + \frac{\Delta t}{2} \vec{V}_a^{n+1/2} \tag{13}$$

Finally, values at the end of the time step will be calculated, as follows:

$$\vec{v}_a^{n+1} = 2\vec{v}_a^{n+1/2} - \vec{v}_a^n;\ \rho_a^{n+1} = 2\rho_a^{n+\frac{1}{2}} - \rho_a^n;\ \vec{r}_a^{n+1} = 2\vec{r}_a^{n+1/2} - \vec{r}_a^n \tag{14}$$

In which is the velocity, is the pressure, is the density, is the gravity, and represents the dispersion. The three forms of this statement are artificial viscosity, laminar viscosity, and turbulence model. Moreover, artificial viscosity, proposed by Monaghan [10], was applied in the present study. According to this method, equation (9) is converted to a discrete form, as follows.

α is a parameter that may vary according to the physical conditions of the problem. Particles move on the basis of the hydrodynamics variance of smooth particles.

$$\bar{\rho}_{ab} = \frac{1}{2}(\rho_a + \rho_b) \tag{15}$$

$$\frac{dr_a}{dt} = V_a + \epsilon \sum_b \frac{m_b}{\bar{\rho}_{ab}} V_{ab} W_{ab} \tag{16}$$

In fact, this method is the correction speed of particle *a*, which can be obtained by considering the previous speed of particle a, as well as the average speed of its neighboring particles. The correction allows the particles better establishment and, with regard to the high speed of fluid particles, prevents them from penetrating one another [11].Beeman, symplectic, Verlet, and predictor-corrector time algorithms can be used for time discretization. In the present study, these algorithms were used to find what was the most efficient for this physical phenomenon. The predictor-corrector algorithm demonstrates the variation in time interval.

Value of $P_a^{n+1/2} = f\left(\rho_a^{n+\frac{1}{2}}\right)$ is then calculated using the equation of state. These values will be modified according to the forces in the middle time step.

Wave generation

Generated waves were derived from the first order theory, using a piston wave maker. The displacement of paddle can be obtained as [13].

$$X_p(t) = \frac{H}{k}\left[tanh(X(t)) + tanh\left(\frac{k}{d}\lambda\right)\right]; \quad X(t) = \frac{k}{d}\left(ct - X_p(t) - \lambda\right) \tag{17}$$

In which, H is the wave height, $k = \sqrt{\left(\frac{3H}{4d}\right)}$ is the wave number, and $c = \sqrt{g(d+H)}$ is the speed.The speed of wave-generated motion is obtained from the following relationship [13]:

$$u_p(t) = \frac{cH}{d} \cdot \frac{1}{cosh^2 X(t) + \frac{H}{d}} \tag{18}$$

RESULTS

The schematic modeling and diminutions are presented in Table-1 and Figure-3. The piston type wave maker is in the left side of the tank, while the vertical cylinder is in the middle of the calculation range. In the Figure-2, R is the radius of the cylinder. The width of the above channel is considered 50 times the radius of the cylinder, and its length is considered 55 times the radius of the cylinder; the height of computational domain is considered 3 meters and water depth is considered 1.5 meters. Furthermore, radius of vertical cylinder is considered 0.05 meter, and the varying flow rate and Reynolds number is considered 12 meters per second in accordance with their corresponding table.

Table-1. Computational domain.

Parameters	Values
Cylinder diameter	0.1m
Reynolds number	Different
Channel width	5 m
Channel length	10 m
Height of channel	5 m
Strouhal number	0.13

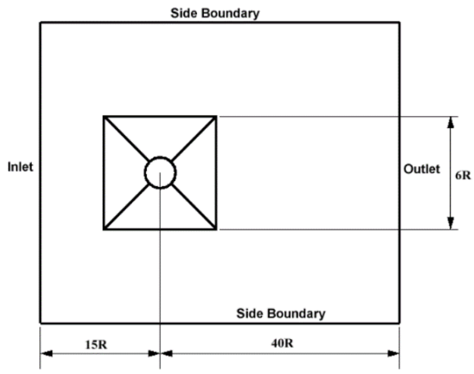

Figure-2. Boundary condition.

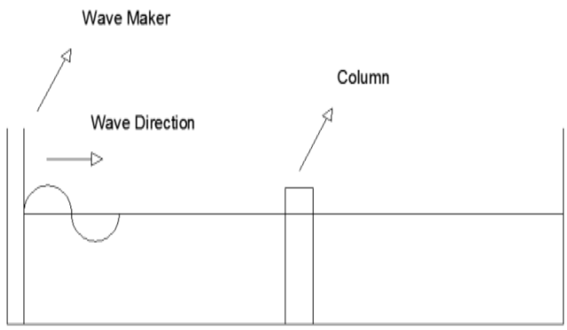

Figure-3. Study domain.

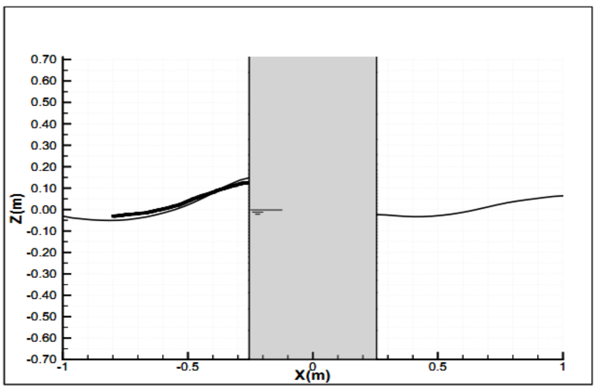

Figure-4. Wave graph.

ARPN Journal of Engineering and Applied Sciences

The geometry of the problem cross-flow forces on the cylinder, the Keulegan-Carpenter number was assumed to be 3.14.Using this geometry, the number of particles in this problem was 585,000. In addition the total analysis time was selected as 50 seconds. All the problems were solved using a personal computer with 16 gigabytes of memory, and a four-cell processor of 3.4 Hz power. It should be noted that the developed code was serial in nature, so the time consumed to solve the problem was between 300 and 320 hour with respect to the time algorithm that was used. With regard to this problem, the necessity of using parallel codes is obvious. Even using the super-computers to save time appears to be logical.Figures-4-14 show the total wave-induced fluctuating forces (lift) on the cylinder in the time domain, using different time algorithms: the Beeman, symplectic, Verlet, and predictor-corrector.

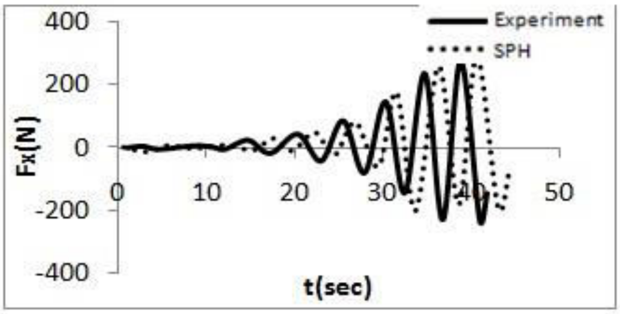

Figure-5. Wave induced lift force using the Beeman time algorithm.

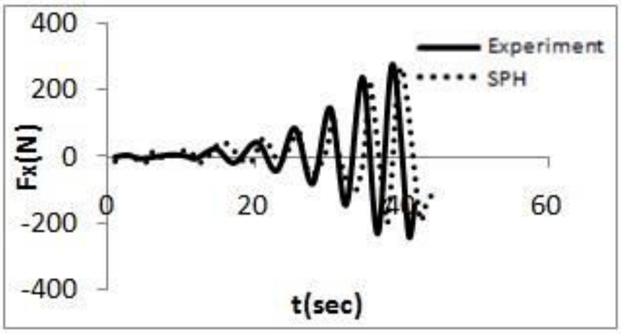

Figure-6. Wave induced lift force using the sympletic time algorithm.

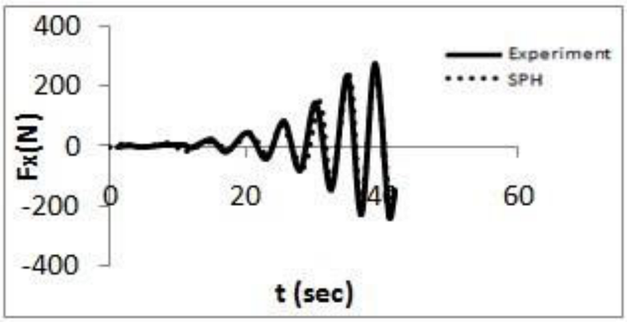

Figure-7. Wave induced lift force using the Verlet time algorithm.

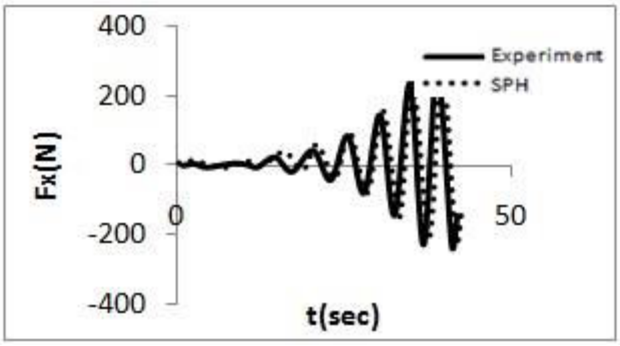

Figure-8a. Wave induced lift force using the predictor-corrector time algorithm.

It can be seen that some of these time algorithms demonstrate discrepancies both in amplitude and phase. The average calculated error for each of these is shown in Table-2.

Table-2. Average calculated error for time algorithm.

Algorithm of time solution	Value of average error (%)
Beeman	9.93
Symplectic	5.68
Verlet	3.25
Predictor-corrector	1.08

As can be observed, the predictor-corrector time algorithm is associated with the lowest value of average computational error in this problem. Its computational time was 318 hrs and 20 min for the above problem with 585,000 particles. After extracting the pressure distribution on the cylinder, with the help of ANSYS, the deformation of the cylinder was investigated, and the results are shown in Figures-8-14.

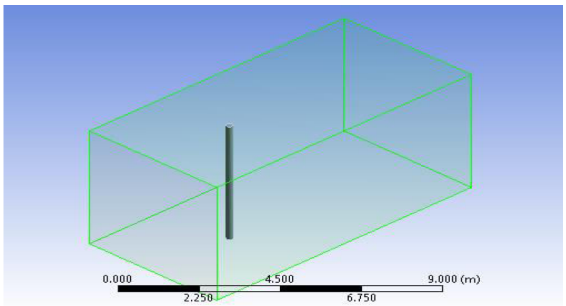

Figure-8b. Computational domain.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

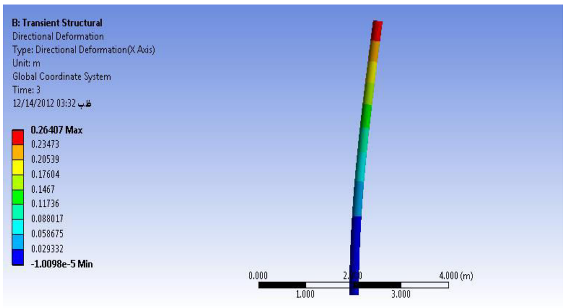

Figure-9. Deformation of cylinder due to vortex shedding by ANSYS.

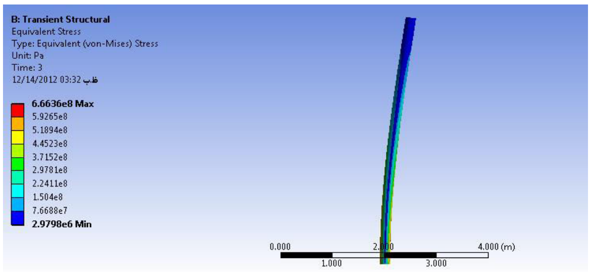

Figure-10. Shear stress of cylinder due to the vortex shedding by ANSYS.

Table-3. Inlet current conditions.

Reynolds	Inlet velocity(m/s)	State
214	0.00214	1
10000	0.1	2
50000	0.5	3
100000	1	4

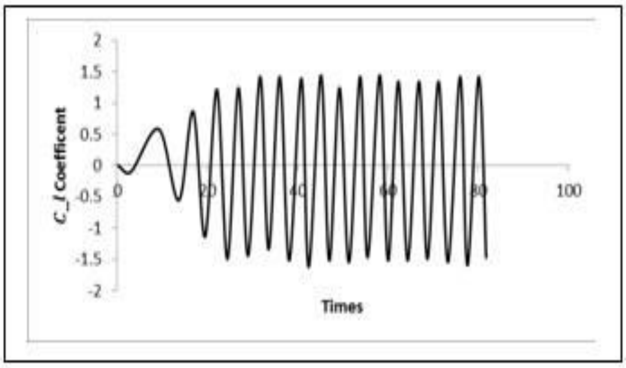

Figure-11. Lift coefficient for Re = 50000.

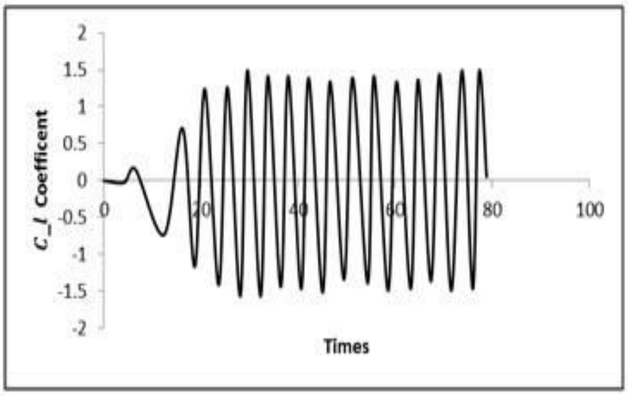

Figure-12. Lift coefficient for Re = 100000.

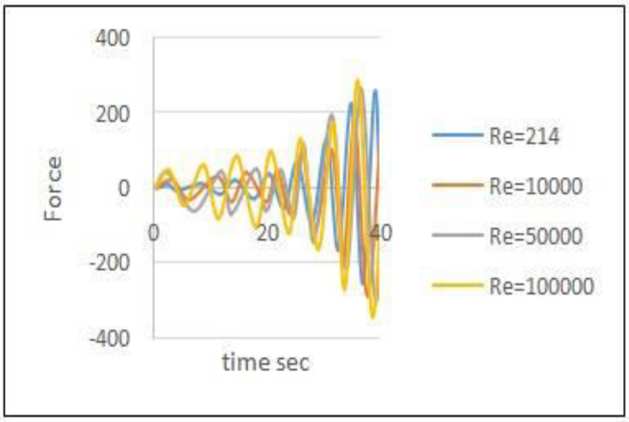

Figure-13. Computed lift forces on colum in different Re.

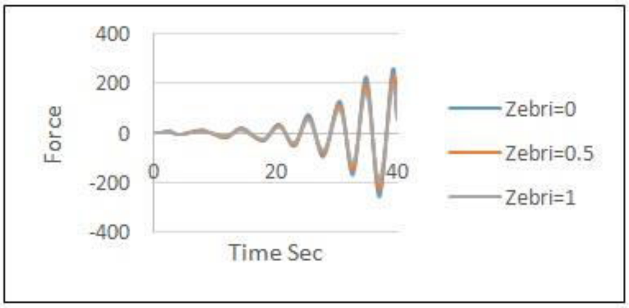

Figure-14. Force in different porous coefficients

CONCLUSIONS

In the present study, a wave collision with platform bases was modeled using SPH. In section two, the equations governing this method were considered, and the manner of solving the problem was defined. For different situations, different boundary conditions were used. Following a definition of the problem and the procedure of solving the Navier-Stokes equations by SPH, modeling of wave interaction with platform bases was then conducted. In the numerical modeling, four time-algorithms were used, and each of these was compared with the experimental results. It was found that the predictor-corrector algorithm had greater accuracy, as well as higher computational cost, in comparison with the other time algorithms. In addition, the high cost of computation means that use of the parallel codes appears necessary to accelerate the time process in the solving procedure. Use of the “predictor corrector” numerical model in ANSYS software was more advantageous than the experimental model in terms of cost and time efficiency, and also provided results that were more convergent with the experimental results, which enables experts to gain easy access to its benefits. This solution can be utilized for all aspects of vibration design of piers in marine structures. In the following, utilized algorithms are presented in order of their convergence and analyzed accuracy is compared with the experimental results. Beeman<Symplectic<Verlet< predictor-corrector.

REFERENCES

[1] Benz W. and Buchler J.R. 1990. The Numerical Modelling of Nonlinear Stellar Pulsatations. Kluwer Academic Publishers. pp. 269-288

[2] Monaghan J. J. 1982. Why particle methods workon Scientific and Statistical Computing. 3(4): 422-433.

[3] Lucy, L. B. and Astron J. 1977. A numerical approach to the testing of the fission hypothesis. 82(12): 1013–1024.

[4] Gingold R. A., and Monaghan J. J. 1977. Smoothed particle hydrodynamics—theory and application to non-spherical stars. 181:375–389.

[5] Monaghan J. J. and Kocharyan. 1995. A SPH simulation of multi-phase flow, Computer Physics Communication. 87: 225-235.

[6] Panizzo A. and Dalrymple R. A. 2004. SPH modelling of underwater landslide generated waves. In Proc. 29th International Conference on Coastal Engineering.pp: 1147-1159.

[7] Gomez-Gesteira M. and Dalrymple R. A. 2004. Using a 3D SPH Method for Wave Impact on a Tall Structure. J. Waterway, Port, Coastal and Ocean Engineering. 130(2): 63-69.

[8] Shao S. and Gotoh H. 2004. Simulating coupled motion of progressive wave and floating curtain wall by SPH-LES model. Coastal Engineering Journal. 46(2): 171-202.

[9] Lee E. S., Violeau D., Benoit M., Issa R., Laurence D. and Stansby P. 2006. Prediction of wave overtopping on coastal structures by using extended Boussinesq and SPH model. In Proc. 30th International Conference on Coastal Engineering. pp: 4727-4740.

[10] Liu G. R. and Liu M B. 2002. Smooth Particle Hydrodynamic a mesh free particle method. World scientific publishing Co. Pte .Ltd. ISBN 981-238-456-1.

[11] Crespo, A. 2008. Application of the smoothed particle hydrodynamics model SPHysics to free surface hydrodynamics. Ph.D. thesis, University of De Vigo.

[12] Liu, G. R. and Liu M. B. 2003. Smoothed particle hydrodynamics: a mesh free particle method. World Scientific, Singapore.

[13] Sangita M. 1999. Computation of Solitary Waves during Propagation and Runup on a Slope. J. Ocean Engineering. 26(11): 1063–1083.

[14] Deng G. B., Guilmineau E., Queutey P. and Visonneau M. 2001. Capture etsuivi d interfaces d ecoulements de fluid visqueuxin compressible. Nantes, France. pp. 17-30.