International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-6S, March 2019

Numerical Modeling for Wave Attenuation by Coastal Vegetation using FLOW3D

S. Hemavathi, R. Manjula

Abstract*— *Coastal vegetation, such as seagrass provides multiple ecologically beneficial functions viz., coastal protection by wave mitigation, soil erosion, and seabed stabilization. This paper investigates the efficiency of submerged vegetation as a buffer system in attenuating the incident waves by the numerical study. To simulate the wave–vegetation interactions, a fully three-dimensional numerical model was developed using Flow-3D® software. This model uses a vegetation-flow parameter that combines the characteristics of vegetation and waves; vegetal parameters that describe the length of the meadow (L), the spacing of the plant (SP), plant density (N), plant height (hs) and thickness (t) of the vegetation. Waves were simulated by specifying wave characteristics like wave height (H), water depth (h) and wave period (T). The numerical simulations results were compared with the published experimental literature (Manca et al., 2012) and wave attenuation is very well agreeing with the literature results and error is found to be 10%.

Keywords: Vegetation, Submergence ratio, Wave attenuation, Seagrass, Numerical modeling

1. INTRODUCTION

Emergent and nearly emergent aquatic plant canopies are known to be affecting the fluid flow structure due to their different size, type, and morphology. However, systematic study of wave dissipation by vegetation is a relatively new field (1) and describing the wave -vegetation interactions in the best laboratory-based studies are still in their practical use. During the past decades, most of the published studies have focused on the wave attenuation using field observation(2–4), lab experiments (5–9), analytical methods(10–13) and numerical study.

Different numerical models have been proposed over the past years. However, the most frequently used method to account for the influence of vegetation in a depth-averaged flow model is the bottom friction or bed roughness approach (8,14). Several mathematical models have also been developed and applied to simulate waves, which include the Laplace equation, mild slope equation, Boussinesq type equations, and Navier–Stokes equations. The Navier–Stokes equations have the advantage of having relatively accurate modeling of turbulence effect. Generally, phase resolving based 3-D modeling of turbulent flows is built upon the Reynolds Averaged Navier–Stokes (RANS) equations which involve numerous partial differential equations to be solved using a number of assumptions (15). In the past, several computational approaches were attempted to solve the RANS equations for the mean flow using the standard k–ε model for the turbulence field (16). For solitary wave propagation, Choi et al., (17) studied the k–ε model, a renormalization-group method based RNG model and LES method by employing commercial computer software. Utilizing the Navier–Stokes equations and the VOF method, a numerical wave tank was made by Chen et al.,(18) by combining the standard k–ε, realizable k–ε and RNG k–ε models (19)..

For the present numerical study, the RANS system is applied to investigate the wave-vegetation interactions on wave attenuation. The parameters such as wave height (H), water depth (h), wave period (T) are used for the numerical study. Posidonia Oceanica is one of the common vegetation species present along the coasts of Gulf of Mannar (20) as well as other coastlines of Tamilnadu and Southern region of Indian sub-continent. A three-dimensional numerical model is developed for generating two-way wave using FLOW-3D®, commercial software and the results of wave attenuations are compared, with the experimental data of Manca et al., 2012(21).

2. THEORETICAL BACKGROUND

The geometry of the flume, artificial vegetation characteristics and other experimental conditions for the present numerical simulation is in accordance with the published work(21). FLOW-3D® developed by developed by Flow Science Inc, Los Alamos. Zhao et al. (22) employed this CFD code for detailed computation of the regular wave propagation runup over waters with vegetation. The program solves the 3-D RANS equations with a free boundary based on the concept of a fractional volume of fluid (VOF). The details of the code are described in Flow-Science, 2016 (V11.2).

For each submerged stem of the vegetation canopy, the velocity field is spatially heterogeneous at the stem scale (23).To account for this heterogeneity M. R. Raupach and R. H. Shaw (24) suggested the requirement of a double-averaging scheme. The continuity and momentum equations, with the application of this averaging scheme, are written as

$$\frac{\partial\rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho \mathrm{u}_\mathrm{i})=0 \quad i=1,2,3 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho \mathrm{u}_\mathrm{i})+\frac{\partial}{\partial x_\mathrm{j}}(\rho \mathrm{u}_\mathrm{i}\,\mathrm{u}_\mathrm{j})=\frac{-\partial P}{\partial x_\mathrm{i}}+\rho g_\mathrm{i}+\frac{\partial}{\partial x_\mathrm{j}}\left[\mu\left(\frac{\partial \mathrm{u}_\mathrm{i}}{\partial x_\mathrm{j}}+\frac{\partial \mathrm{u}_\mathrm{j}}{\partial x_\mathrm{i}}\right)-\quad \rho \mathrm{u}'_\mathrm{i}\mathrm{u}'_\mathrm{j}\right]-F_\mathrm{i} \qquad (2)$$

Revised Version Manuscript Received on March 08, 2019.

S. Hemavathi, Research scholar, Department of Civil Engineering, National Institute of Technology (NITT), Tiruchirappalli, Tamil Nadu, India
R. Manjula, Assistant Professor, Department of Civil Engineering, National Institute of Technology (NITT), Tiruchirappalli, Tamil Nadu, India

$$-\rho\overline{u_i'u_j'} = \mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\rho k\delta_{ij} \qquad (3)$$

where p is the static pressure, ρ is fluid density , u_s is mean velocity component, and u'_i is fluctuating velocity components, μ is molecular viscosity, and μ_t is turbulent viscosity, δ_{ij} is Kronecker delta, the g_i is the I^{th} component of the acceleration due to gravity and the term -$\overline{u_i'u_j'}$ is Reynolds stress, which represents the effects of the turbulent flow on the mean flow field. k = (1/2) $\overline{u_i'u_j'}$ is the turbulent kinetic energy F_i is the resistance force induced by vegetation. FLOW-3D®, solves the governing differential equations in a fixed Eulerian rectangular grid..

3. METHODOLOGY

Various steps generally involved in generating and validating a numerical model. Broadly, there are six steps involved in the process of generating a model.

4. NUMERICAL PROCEDURE

The following are the steps involved in solving a 3D modeling problem in FLOW-3D® software:

(1) Constructing the 3D model of flume channel: The geometry of the problem is defined either by using its own solid modeler or by importing and interpreting external solid models constructed by other programs. Use of self-solid modeler was extremely difficult as it requires objects to be defined as a combination of general quadratic functions. Therefore, in the present work, the three-dimensional model was generated by using in AutoCAD 3D®.

(2) Importing the developed 3D model file into the software and defining the problem: For modeling the channel, the general properties, physical conditions which include viscosity, gravity force, and turbulence and the geometry, built-in functions in the software are utilized. Once the geometry is defined, the computational mesh is established independently, with selective densification of particular interest.

(3) Choosing the basic governing equations that should be solved: The turbulence can be simulated through five models: Prantl mixing length, k-ε equation, RNG, Large eddy simulation model. For the present study, the RNG model is used.

(4) Defining the characteristics of fluid: The following fluids are used for the present study; (i) Fluid 1: Water at 20 ℃ (ii) Fluid 2: Air at 15℃. As these fluids and its properties are already pre-defined by the software, it can be directly loaded from the Materials Database.

(5) Defining the boundary conditions (BC): the software has a wide range of boundary conditions: At the entrance and end of the flume channel, the flow rate was considered as BC. The channel bottom (Z) is a surface boundary, and due to "no slip" condition the normal velocity there must be 0. Thus, for any static wall, the boundary conditions the velocity u used at the i=1 are for all j, k (FLOW-3D® V11.2 user's manual):

$$u_{1,j,k} = 0 \qquad (4)$$

The fluid surface (Z max interface) is set to free surface boundary. All shear (tangential) stresses at the free surface are 0. For the entire system, the acceleration of gravity is 9.81 m/s2. The initial state of moving objects is static.

(6) The model is run using run simulation.

5. NUMERICAL MODEL

The numerical procedure for modeling of Posidonia Oceanica (21) and its components are attributed to its input values, like elastic modulus, bending angle, etc. The initial fluid elevation in the flume is set to be 1.7m. The flume dimensions 100m×3m×5m (21) is created in the software domain. The plant characteristics for the seagrass Posidonia Oceanica is given in Table 1.

Table 1 Physical Parameters of Posidonia Oceanica(21) (25)

No.	Physical Parameters	Attributes
1	Name	*Posidonia Oceanica*
2	Width (b) cm	1.0
3	Thickness(t) mm	0.2
4	Density of material (ρ)	800-1020kg/m^3
5	Modulus of elasticity(E) GPa	0.41-0.53
6	Leaves structure	Ribbon-like leaves

The wave characteristics such as T and H are used as input to the numerical model while there are control parameters such as water depth(h)and plant density(N) is used for studying the effect of wave attenuation. There are eight probe points (See Figure 1)(21) in the meadow on the flume which is used for retrieving the wave profile.

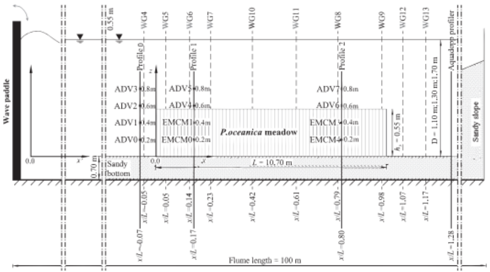

Fig. 1. The Experimental flume with artificial P. oceanica meadow (E.Manca et al.)(21)

The submergence ratio (hs/h) is 0.32 for different plant density (N)=180stems/m2 and 360stems/m2, the wave attenuation (H/HO) is observed. A typical sketch of numerical wave tank with observed probe points for wave height is shown in Figure 2.

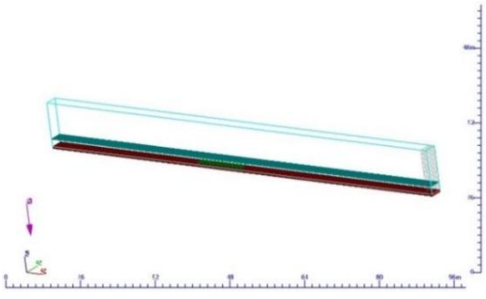

Fig. 2. Geometrical model of wave flume

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

6. RESULTS AND DISCUSSIONS

Vegetation based wave attenuation depends upon the interaction effects between the flow induced by waves and the plant's meadow zone. The simulated wave profile in the numerical wave tank at one of the probes is shown in Figure 3.

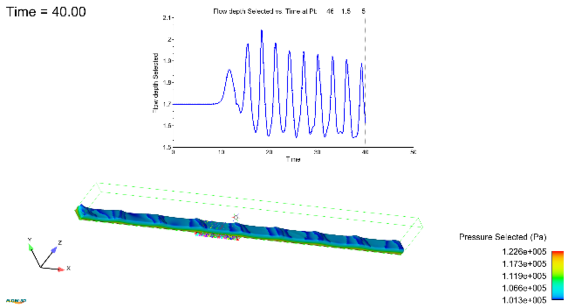

Fig.3. Wave profile for probe distance at 46m

Figure 4 shows the variation of wave attenuation from numerical modeling and experimental literature for submergence ratio of 0.32 and N=180stems/m2. It is observed that numerical results are matching with experimental literature with an error of less than 10%. Similarly, the variation of wave attenuation from numerical modeling and experimental literature for submergence ratio of 0.32 and N=360stems/m2 is shown in Figure 5 with an error of around 12%.

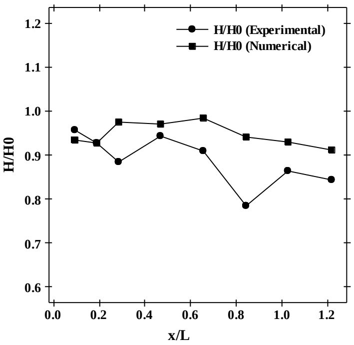

Fig. 4. H/Ho graph representing wave attenuation for submergence ratio- 0.32, Tp=3s and N=180 stems/m2

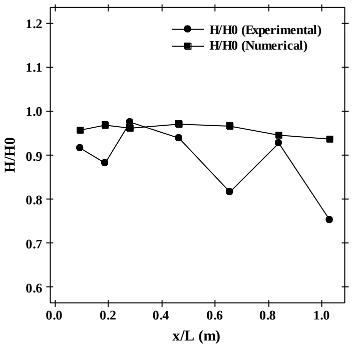

Fig. 5. H/Ho graph representing wave attenuation for submergence ratio- 0.32, Tp =3s and N=360 stems/m2

There has been a significant reduction in the incident wave height due to the presence of vegetation observed by the numerical results coinciding quiet accurately with an error percentage (lesser than 10%) corresponding to the experimental results. The wave height reduction is consistent in two different stem density.The loss of energy as a result of interference of the vegetation with the wave propagation causes the reduction in wave heights. When the stem density is increasing (180 to 360 stems/m2), wave attenuation is decreasing up to 10%. The reason is that energy dissipation will be more in case of moderately dense vegetation since water can easily flow through it while dense vegetation will not allow free flow of water and hence energy dissipation is less.

7. SUMMARY AND CONCLUSION

A fully three-dimensional numerical model was developed by Flow 3D® to simulate the wave–vegetation interactions, and the model has been validated using large-scale experiments carried out by Manca et al. (2012). The model has shown a high degree of agreement between the literature data and the numerical predictions in free wave surface evolution. As the results obtained from the experimental procedure and the numerical model, do not have a variation of more than 10-12%, this model is said to be validated and accepted. Successful simulation results of the modeling show that the CFD technique is a suitable tool for simulating the wave–vegetation interactions so as to evaluate sustainable wave attenuation. The simulated model allows reproducing the wave attenuation along the vegetation meadow for different flow and vegetation characteristics.

REFERENCES

1. Suzuki T, Zijlema M, Burger B, Meijer MC, Narayan S. Wave dissipation by vegetation with layer schematization in SWAN. Coast Eng [Internet]. 2012;59(1):64–71. Available from: http://dx.doi.org/10.1016/j.coastaleng.2011.07.006
2. Knutson PL, Brochu RA, See WN. 1982.Wave damping inSpartina alterniflora marshes. 1982;(1978):87–104.
3. Möller I, Spencer T, French JR, Leggett DJ, Dixon M. Wave transformation over saltmarshes: a field and numerical modelling study from North Norfolk, England. Estuar Coast Shelf Sci. 1999;49:411–26.
4. Bradley K, Houser C. Relative velocity of seagrass blades: Implications for wave attenuation in low-energy environments. J Geophys Res Earth Surf. 2009;114(1):1–13.
5. Fonseca MS, Cahalan JA. A preliminary evaluation of wave attenuation by four species of seagrass. Estuar Coast Shelf Sci. 1992;35(6):565–76.
6. Augustin LN, Irish JL, Lynett P. Laboratory and numerical studies of wave damping by emergent and near-emergent wetland vegetation. Coast Eng [Internet]. 2009;56(3):332–40. Available from: http://dx.doi.org/10.1016/j.coastaleng.2008.09.004
7. Stratigaki V, Manca E, Prinos P, Losada IJ, Lara JL, Sclavo M, et al. Large-scale experiments on wave propagation over Posidonia oceanica. J Hydraul Res. 2011;49(SUPPL.1):31–43.
8. Anderson ME, Smith JM. Wave attenuation by flexible, idealized salt marsh vegetation. Coast Eng [Internet]. 2014;83:82–92. Available from: http://dx.doi.org/10.1016/j.coastaleng.2013.10.004
9. YIPING L, ANIM DO, WANG Y, TANG C, DU W, LIXIAO N, et al. Laboratory Simulations of Wave Attenuation By an Emergent Vegetation of Artificial Phragmites Australis: an Experimental Study of an Open-Channel Wave Flume. J Environ Eng Landsc Manag [Internet]. 2015;23(4):251–66. Available from: https://journals.vgtu.lt/index.php/JEELM/article/view/1398
10. Dalrymple RA, Kirby JT, Hwang PA. Wave Diffraction Due to Areas of Energy Dissipation. J Waterw Port, Coastal, Ocean Eng. 1984;110(1):67–79.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

11. FORMULATION z Wave Gages. 1993;119(1):30–48.
12. Maza M, Lara JL, Losada IJ. A coupled model of submerged vegetation under oscillatory flow using Navier-Stokes equations. Coast Eng [Internet]. 2013;80:16–34. Available from: http://dx.doi.org/10.1016/j.coastaleng.2013.04.009
13. Mendez FJ, Losada IJ. An empirical model to estimate the propagation of random breaking and nonbreaking waves over vegetation fields. Coast Eng. 2004;51(2):103–18.
14. Zink JM, Jennings GD. Channel roughness in north carolina mountain streams. J Am Water Resour Assoc. 2014;50(5):1354–8.
15. Lara JL, Maza M, Ondiviela B, Trinogga J, Losada IJ, Bouma TJ, et al. Large-scale 3-D experiments of wave and current interaction with real vegetation. Part 1: Guidelines for physical modeling. Coast Eng [Internet]. 2016;107:70–83. Available from: http://dx.doi.org/10.1016/j.coastaleng.2015.09.010
16. Christensen ED, Deigaard R. Large eddy simulation of breaking waves. Coast Eng. 2001;42(1):53–86.
17. Choi BH, Pelinovsky E, Kim DC, Didenkulova I, Woo S. Nonlinear Processes in Geophysics Two- and three-dimensional computation of solitary wave runup on non-plane beach. Nonlin Process Geophys. 2008;15(2006):489–502.
18. CHEN X bin, ZHAN J min, CHEN Q. Numerical simulations of 2-D floating body driven by regular waves. J Hydrodyn [Internet]. 2016;28(5):821–931. Available from: http://dx.doi.org/10.1016/S1001-6058(16)60682-0
19. King AT, Tinoco RO, Cowen EA. A k-ε turbulence model based on the scales of vertical shear and stem wakes valid for emergent and submerged vegetated flows. J Fluid Mech. 2012;701:1–39.
20. Seagrasses of India. Jagtap, T.G.; Komarpant, D.S.; Rodrigues, R. Citation: World atlas of seagrasses, eds. Green, E.P.; Short, F.T. 101-108pp. 2003.
21. Manca E, Cáceres I, Alsina JM, Stratigaki V, Townend I, Amos CL. Wave energy and wave-induced flow reduction by full-scale model Posidonia oceanica seagrass. Cont Shelf Res. 2012;50–51:100–16.
22. Zhao Q, Armfield S, Tanimoto K. Numerical simulation of breaking waves by a multi-scale turbulence model. Coast Eng. 2004;51(1):53–80.
23. Nepf H, Ghisalberti M. Flow and transport in channels with submerged vegetation. Acta Geophys. 2008;56(3):753–77.
24. Raupach MR, Shaw RH. Averaging procedures for flow within vegetation canopies. Boundary-Layer Meteorol. 1982;22(1):79–90.
25. Folkard AM. Hydrodynamics of model Posidonia oceanica patches in shallow water. Limnol Oceanogr. 2005;50(5):1592–600..