www.cafetinnova.org

ISSN 0974-5904, Volume 10, No. 04

DOI:10.21276/ijee.2017.10.0424

International Journal of Earth Sciences and Engineering

August 2017, P.P. 892-897

Effect of Submerged Coastal Rigid Vegetation on Wave Attenuation Using Open Source CFD Tool: REEF3D

ARUNAKUMAR H S[1], PRUTHVIRAJ U[1], PRAVEEN SUVARNA[1] AND ARUN KAMATH[2]

[1]*Department of Applied Mechanics and Hydraulics, NITK Surathkal, Pin-575025, Karnataka, India*

[2]*Department of Civil and Transportation Engineering, NTNU, Trondheim 7491, Norway*

Email: *arunsaligram17@yahoo.com, pruthviu@gmail.com, civilsuvarna@gmail.com, arun.kamath@ntnu.no*

Abstract*: A numerical study to determine the wave attenuation of wave height is presented. Coastal vegetation acts as a natural coastal defense structure and protects the coast from waves by reducing the energy of the waves. A three dimensional numerical wave tank model simulation is developed using open source computational Fluid Dynamics (CFD) software REEF3D and wave attenuation due to coastal vegetation is assessed. The numerical model is developed in a numerical wave tank for artificial rigid vegetation of 2 m meadow length. The model is tested for regular waves of height 0.08 m, 0.12 m and 0.16 m and different wave periods of 1.8 sec and 2 sec in different water depths of 0.40 m and 0.45 m, wave heights at different locations along the vegetation meadow is recorded. The performance of the numerical model is validated with the experimental results. The numerically obtained results using REEF3D are concurrent with the experimental results.*

Keywords: *Coastal vegetation, Numerical model, Computational Fluid Dynamics (CFD), Wave attenuation*

1. Introduction

Coastal system is widely used and threatened natural systems (Halpern.et al. 2008; Lotze et al., 2006). The consequence is an overall decline which is affecting a number of critical benefits (Barbier et al., 2011). Coastlines are dynamic systems which are vulnerable to strong winds, storm surges, tsunamis, cyclones and erosion. Conventional structures such as breakwaters, seawalls and jetties are used to dissipate and reflect wave energy thereby alters the near-shore hydrodynamics and regional sediment transport characteristics resulting in foment of worse scenario in its surroundings. The usage of hard structures becomes costly for protecting the coast.

Reports on the assessment of damage due the 1999 Odisha cyclone along the coast of the Indian state of Odisha and the 2004 Indian Ocean tsunami on some of the coastal districts of Tamilnadu (in India) reveals that intact and healthy mangroves saved many lives by dramatically reducing the intensity of the storm surge due to the cyclone and decelerated the gush of tsunami wave shoreward (Das and Vincent, 2009; NIO, 2005).

The energy of the wave depends on the wave steepness, crest angle, depth and the impact on to the structure etc. The shape of the structure plays a major role while interacting with highly non-linear wave, including reflection, overtopping, transmission, breaking, evolution of vortices. These flow problems are resolved numerically by using different Computational Fluid Dynamics (CFD) software. REEF3D is open source software and free. REEF3D software has been used to solve the continuum mechanics problems in coastal engineering. The potential of REEF3D in coastal engineering is confirmed in the work by Arun Kamath et al. (2012). Many studies on both experimental and numerical have been conducted to observe the efficacy of coastal rigid vegetation on wave energy dissipation by attenuation of waves. Previous studies include studies on coastal kelp forests (Rosman et al., 2013, Zeller, 2014), mangroves (Struve et al., 2003;Vo-Luong and Massel, 2008; Husrin, 2012; Strusinska-Correia, 2013), Numerical studies (Coops et al., 1996; Bouma et al., 2005; Eldina et al., 2008; Arun Kamath et al., 2012). In India, the soft measures of coastal protection have gained importance after tsunami. Some of the early works include experimental investigations on the effect of vegetation in reducing the wave run up (Sundar et al., 2011), Experimental investigation of wave attenuation through artificial vegetation meadow (Beena et al., 2016).

This work aims simulation and validation of submerged artificial rigid coastal vegetation using CFD software REEF3D. Numerical wave tank is used for the simulation and the numerical solutions are well suited to assess effect of submerged artificial rigid vegetation on attenuation of waves. Thus an initial study is presented on the attenuation of waves with rigid submerged vegetation and the numerically obtained results are validated with the experimental results which are carried out in wave flume at Department of Applied Mechanics and Hydraulics, NITK Surathkal.

2. Numerical Model

2.1 REEF3D

The software which is used for this work is 17.03 of open source software REEF3D, running on Mac OS X

Received: February 17 2017; Accepted: June 21, 2017; Published: August 30, 2017

International Journal of Earth Sciences and Engineering, 10(04), 892-897, 2017, DOI:10.21276/ijee.2017.10.0424

EI Capitan operating system. REEF3D has an extensive range of features to solve hydraulic, coastal and marine engineering flow problems. In the present numerical model the incompressible Navier-Stokes equations are solved with RANS turbulence closure.
Cartesian mesh is used to achieve wave propagation with higher stability and accuracy. Fifth-order WENO scheme is used for the convection terms of the momentum equations. Third-order TVD Runge-Kutta scheme is chosen for performing time stepping. Staggered grid with projection method is used to solve the pressure which ensures tight pressure velocity coupling. Ghost cell immersed boundary method is used to consider the irregular boundaries.The numerical model is fully parallelized based on the domain decomposition strategy and MPI (message passing interface). The free surface is modeled with the level set method. (Kamath.,A. et al., 2012).

2.2 Governing equations

Incompressible Reynolds-averaged Navier–Stokes (RANS) equations are solved in REEF3D along with continuity equation to resolve the fluid flow problem.

$$\frac{\partial U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial X_j} = -\frac{1}{\rho}\frac{\partial P}{\partial X_i} + \frac{\partial}{\partial X_j}\left[(v + v_t)\left(\frac{\partial U_i}{\partial X_j} + \frac{\partial U_j}{\partial X_i}\right)\right] + g_i$$

Where u is the time averaged velocity, ρ is the density of the fluid, p is the pressure, ν is the kinematic viscosity, ν_t is the eddy viscosity and g is the acceleration due to gravity by using the projection method the pressure is determined and by using BiCGStab solver the resulting Poisson equation is solved with a preconditioned. K–ω model is used for turbulence modeling.

2.3 Free Surface

The modeling of free surface of the waves is modelled using level set method. The shortest distance from the interface is determined by level set function. The sign of the function differentiates the two fluids at the interface and it is shown in the below equation.

$$\Phi(\vec{x}, t) \begin{cases} > 0 \; if \; \vec{x} \; is \; in \; phase \; 1 \\ = 0 \; if \; \vec{x} \; is \; in \; interphase \\ < 0 \; if \; \vec{x} \; is \; in \; phase \; 2 \end{cases}$$

Under the influence of external velocity field u_j the level set function is moved with the convection equation as mentioned below.

$$\frac{\partial \phi}{\partial t} + U_i \frac{\partial \phi}{\partial x_j} = 0$$

The level set function loses its signed distance property on convection and after every iteration it is reinitialized by using a partial differential equation based initialization procedure to regain its signed distance property.

3. Numerical Model

3.1 Assumptions

In experimental investigation, the submerged plant model is made of nylon rods and it is observed that the nylon rods show negligible sway movement for the action of waves in the direction of wave propagation. In the present numerical study, vegetation are assumed to be rigid and do not move in any direction for the action of waves.

3.2 Numerical Model Validation

The numerical validation is based on the physical experiments carried out in the wave flume by John B.M. (2015). Figure 1 shows a schematic diagram of the present experimental setup. The physical model of submerged artificial rigid vegetation meadow of 2 m width placed on the horizontal part of the flume bed and tested for wave heights 0.08 m, 0.12 m and 0.16 m and different wave periods of 1.8 sec and 2 sec in distinct water depths of 0.40 m and 0.45 m.

Figure 1. *Experimental setup of submerged vegetation in wave flume (Source: John B.M., 2015)*

Table 1. *Vegetation characteristics and experimental conditions*

Plant	Characteristics of modeled vegetation		Wave height h (m)	Wave period, T (s)	Water depth, d (m)	Relative vegetation height (hs/d)
submerged rigid vegetation	Length of rod	0.21 m	0.08	1.8	0.40	0.525
	Diameter of rod	0.01 m	0.12	2	0.45	0.467
	Density (plants/m^2)	394	0.16			

The wave heights at different locations along the vegetation are recorded using numerical wave probes along the meadow. The vegetation rods are 0.010 m in diameter and 0.21 m long and the density of the vegetation is 394 plants/m^2. Figure 5 shows the simulation of numerical wave tank with submerged rigid vegetation.

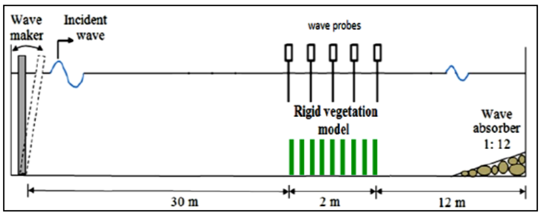


Figure 2. *Schematic diagram of experimental set up (Source: John B.M., 2015)*

The dimension of submerged vegetation and wave parameters are similar to the physical experiment. The simulated time is 30s. The generated waves are 5^{th} – order Stokes waves and weighted Essentially Non-Oscillatory (WENO) scheme is used for the velocity discretization.

A 3D numerical wave tank of 20.0m long, 0.71m wide and 1.0m high is used for the wave generation and the wave heights are 0.08, 0.12m and 0.16m generated at different water depths of 0.40m and 0.45m. The waves simulate for time periods of 1.8 sec and 2 sec. 0.008m size grids are used for the domain. The wave simulated for 30 seconds

Numerical beach and wave generation zones are shown in Figure 1. Water surface elevation measured by numerical probes and those probe readings are in the form of surface elevations in m. These surface elevations convert into wave heights by Mat lab programming. The probe locations are described in the Figure 1.

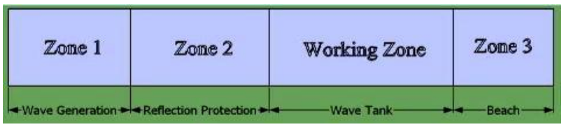


Figure 3. *Sections of a Numerical Wave Tank (Source: Kamath A., 2015)*

The grid size, dx = 0.008m is used. The numerical results are in the form of surface elevation which is converted to wave height using mat lab and validate the numerical results with the experimental results.

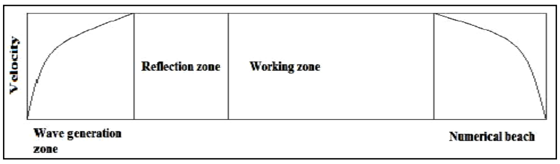


Figure 4. *Velocity change in wave tank (Source: Kamath A., 2015)*

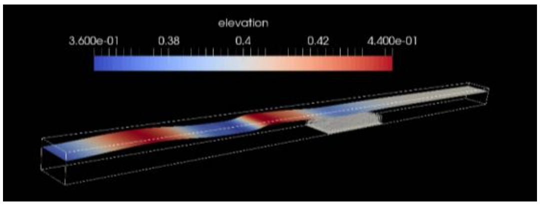


Figure 5. *Numerical wave tank with submerged rigid vegetation*

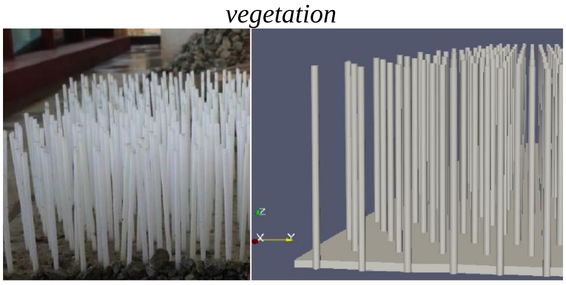
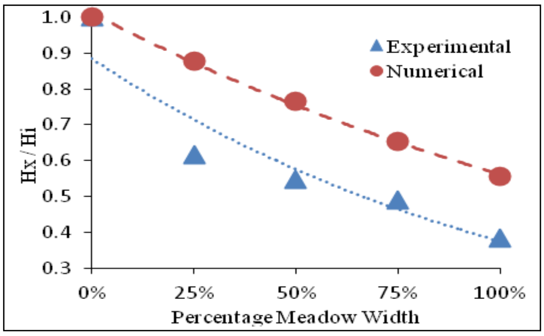


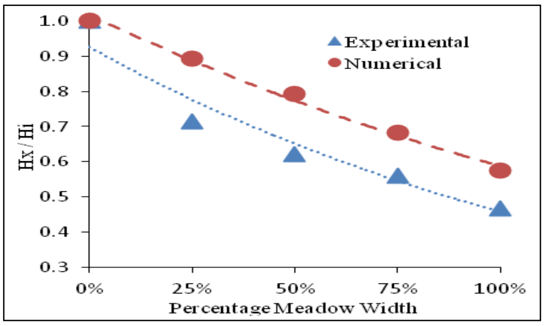
Figure 6. Artificial rigid vegetation (left side) and numerically simulated vegetation (right side)

4. Results and Analysis

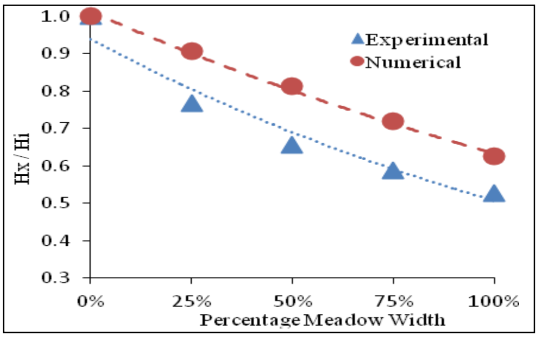
The wave heights measured at different locations in the numerically simulated model along the 2m meadow of submerged vegetation model is compared with the experimental results. It is observed that attenuation of wave height along the meadow is following exponential decay.



(a)



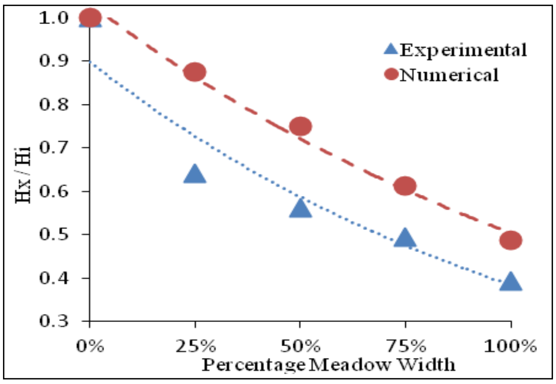
(b)



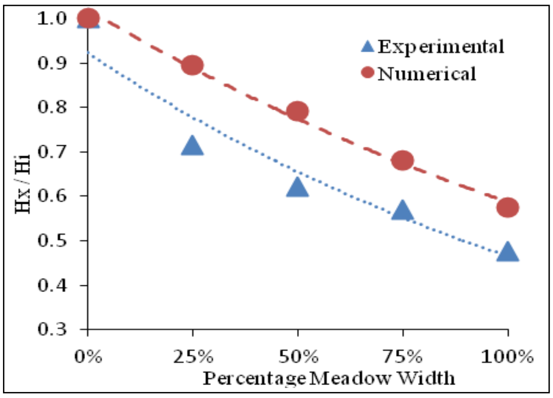
(c)

Figure 7. *Relative wave height (H_s/H_i) measured along the submerged vegetation meadow for a) h = 0.08m, T = 1.8 s, hs/d = 0.525, b) h = 0.12m, T = 1.8 s, hs/d = 0.525, c) h = 0.16 m, T = 21.8 s, h_s/d = 0.525*

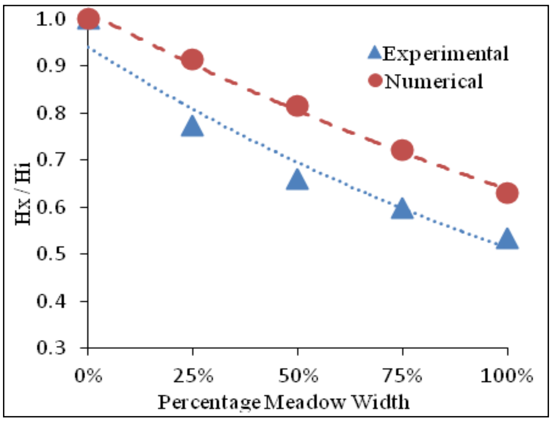
For hs/d = 0.525 and T=1.8 sec, the wave height observed at the end of the vegetation in experimental case is 38.40%, 46.90%, and 52.80% and in numerical case is 55.60%, 57.50% and 62.50% for an incident wave height of 0.08m, 0.12m and 0.16m respectively.



(a)



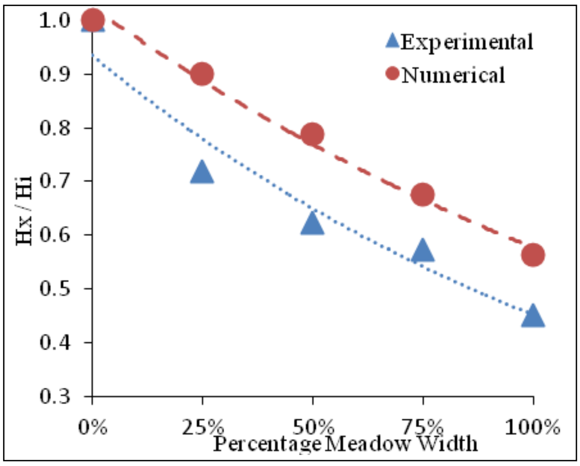
(b)



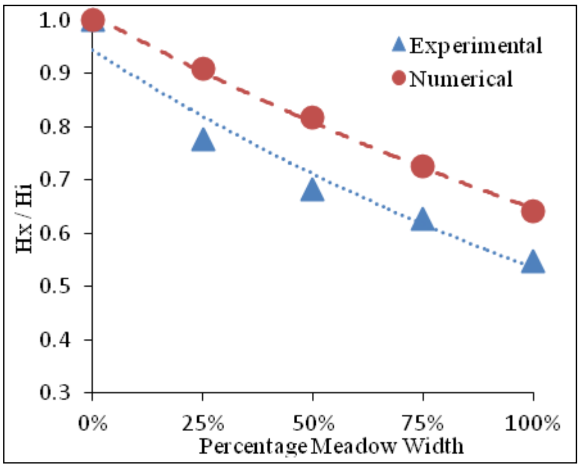
(c)

Figure 8. *Relative wave height (H_s/H_i) measured along the submerged vegetation meadow for a) h = 0.08m, T = 2 s, hs/d = 0.525, b) h = 0.12m, T = 2 s, hs/d = 0.525, c) h = 0.16 m, T = 2 s, h_s/d = 0.525.*
For hs/d = 0.525 and T=2 sec

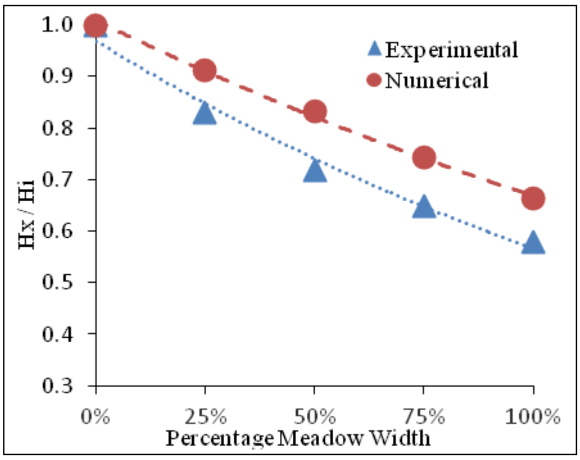
The wave height observed at the end of the vegetation meadow in experimental case is 39.30%, 47.70%, and 53.30% and in numerical case is 48.80%, 57.60% and 63.30% for an incident wave height of 0.08m, 0.12m and 0.16m respectively.



(a)



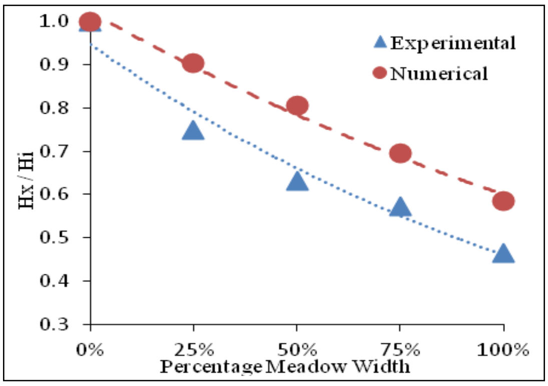
(b)



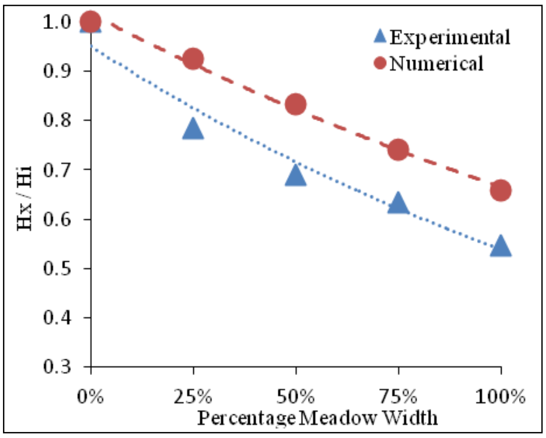
(c)

Figure 9. *Relative wave height (H_s/H_i) measured along the submerged vegetation meadow for a) h = 0.08m, T = 1.8 s, hs/d = 0.467, b) h = 0.12m, T = 1.8 s, hs/d = 0. 467, c) h = 0.16 m, T = 1.8 s, h_s/d = 0. 467*

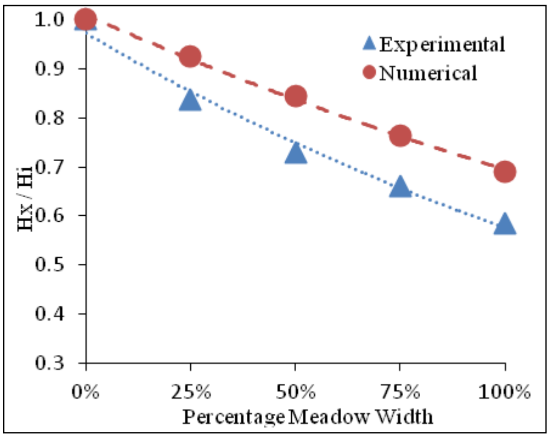
For hs/d = 0.467 and T=1.8sec, the wave height recorded at the end of the vegetation meadow in experimental case is 45.10%, 54.80%, and 57.90% and in numerical case is 56.30%, 64.20% and 66.30% for an incident wave height of 0.08m, 0.12m and 0.16m respectively.



(a)



(b)



(c)

Figure 10. *Relative wave height (H_s/H_i) measured along the submerged vegetation meadow for a) h = 0.08m, T = 2 s, hs/d = 0.467, b) h = 0.12m, T = 2 s, hs/d = 0. 467, c) h = 0.16 m, T = 2 s, h_s/d = 0. 467.* For h_S/d = 0.467 and T=2sec

The wave height recorded at the end of the vegetation meadow in experimental case is 46.40%, 54.80%, and 58.50% and in numerical case is 58.50%, 65.80% and 68.90% for an incident wave height of 0.08m, 0.12m and 0.16m respectively.

4.1 Summary of Results and discussion

It is observed that the wave attenuation along the vegetation cover is following the exponential trend. Wave attenuation due to rigid submerged vegetation is mainly due to the captivation of orbital velocities of the propagating waves resulting in building up of turbulence, which in turn gives rise to loss of wave energy, thus reduction in wave heights.

The wave attenuation in case of numerical study for rigid submerged vegetation, achieved an average of 74.5% agreement with experimental results. The variation between experimental results and numerical results are probably due to the assumptions based on which models are simulated, i.e. vegetation are assumed to be rigid and do not move in any direction for the action of waves.

5. Conclusions

The open source CFD tool REF3D is used for simulation and assessment of wave attenuation over submerged rigid coastal vegetation. The influence of water depth, incident wave height and wave period on wave attenuation is investigated numerically. Numerical results are in good agreement with the experimental results and the wave attenuation due to submerged vegetation is following the similar trend as experimental for the variation of wave height, wave period and water depth.

REF3D being an open source software has the potential to be a usable CFD tool for the detailed investigation of wave attenuation due to coastal rigid vegetation and wave interaction with structures.

6. Acknowledgements

The authors are grateful to the Department of Applied Mechanics and Hydraulics, NITK Surathkal, for providing the computational resource and experimental data for the study.

References

[1] Arun Kamath, 2012 "*Wave Forces On Structures Using REEF3D*". Norwegian University of Science and Technology, Norway.

[2] Barbier, E B., Hacker,Sd., Kennedy, C J., Koch, E w., stier, A C Siliman, B R.,(2011). *The valueof estuarine and coastal ecosystem services.Ecol*. Monogar. 81920, 169-193.

[3] Beena Mary John, Kiran G Shirlal, Subba Rao, (2016). *Experimental investigation of wave attenuation through artificial vegetation meadow, ISH - HYDRO.*

[4] Bouma TJ, De Vries MB, Low E, Peralta G, Tánczos IC, van de Koppel J, Herman PJ (2005) *Trade-offs related to ecosystem engineering: A case study on stiffness of emerging macrophytes*. Ecology 86(8): 2187-2199.

[5] Coops, H., Geilen, N., Verheij, H.J., Boeters and van der Velde. (1996). *Interaction between waves, bank erosion and emergent vegetation: an ex-perimental study in a wave tank.Aquatic* Botany, 53: 187198.

[6] Das S, Vincent JR (2009) *Mangroves protected villages and reduced death toll during Indian*

super cyclone. Proc Natl Acad Sci USA 106 (18): 7357-7360.

[7] Eldina F, Ahmad K. Wahab, Hadibah I, (2008) *Numerical modeling approach of an artificial mangrove root system (ArMS) submerged breakwater as wetland habitat protector* COPEDEC VII, 2008, Dubai, UAE

[8] Halpern, B S., Meleod, K L., Rosenberg, A., Crowder. L B., (2008). *Managing for cumulative impacts in ecosystem-based management through ocean zoning*. Ocean coast. Manag. 51, 203-211.

[9] Husrin S, Strusińska A, Oumeraci H (2012) *Experimental study on tsunami attenuation by mangrove forest.* Earth, planets and space 64(10): 973-989.

[10] Lotze H K, Lenihan H S, Bourque B J, Bradbury R H, Cooke R G, Kay M C, Kidwell SM, Kirby M X, Peterson C H, Jackson J B.(2006) "*Depletion, degradation, and recovery potential of estuaries and coastal seas*". Science. Jun 23; 312(5781):1806-9.

[11] NIO (2005) *Observations of post tsunami reconnaissance investigations along eastern coastal tract of India following the devastating tsunami of 26th December 2004.* National Institute of Oceanography Technical Report no. NIO/TR-08/2005.

[12] Rosman JH, Denny MW, Zeller RB, Monismith SG, Koseff JR (2013*) Interaction of waves and currents with kelp forests (Macrocystis pyrifera): Insights from a dynamically scaled laboratory model*. Limnology and Oceanography 58(3): 790-802.

[13] Strusinska-Correia A, Husrin S, Oumeraci H (2013) *Tsunami damping by mangrove forest: a laboratory study using parameterized trees.* Natural Hazards and Earth System Sciences 13(2): 483.

[14] Struve J, Falconer RA, Wu Y (2003) *Influence of model mangrove trees on the hydrodynamics in a flume.* Estuarine Coastal and Shelf Science 58: 163-171.

[15] Sundar V, Murali K, Noarayanan L (2011) *Effect of vegetation on run-up and wall pressures due to cnoidal waves.* Journal of Hydraulic Research 49(4): 562-567.

[16] Vo-Luong P, Massel S (2008) *Energy dissipation in non-uniform mangrove forests of arbitrary depth.* Journal of Marine Systems 74(1):603-622.

[17] Zeller RB, Weitzman JS, Abbett ME, Zarama FJ, Fringer OB, Koseff JR (2014) *Improved parameterization of sea grass blade dynamics and wave attenuation based on numerical and laboratory experiments*. Limnology and Oceanography 59(1): 251-266.