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NUMERICAL STUDIES OF WAVE INTERACTION WITH RIGID VEGETATION OF DIFFERENT SUBMERGENCES

Kishore Kumar Reddy. P[1], Muni Reddy.M.G[2], Jayakumar Seelam[3]

[1]Assistant Professor, Civil Engineering, KSRM College of Engineering, YSR Kadapa, INDIA
[2]Associate Professor, Civil Engineering, Andhra University, Visakhapatnam- INDIA .
[3]Senior Principal Scientist, CSIR-National Institute of Oceanography, Goa, INDIA,

Abstract---Using linear wave theory a 2D numerical wave tank model is developed. Simulation of wave interacting with varying heights of submerged vegetation is carried to understand the wave-vegetation interaction and wave transformation for vegetation of uniform height and of different submergences. The equation of continuity and momentum are the governing equations for incompressible fluid motion, k-ε model is considered for turbulence closure of RANS equations. A multiphase model Volume Of Fluid (VOF) is applied for determining the free surface. Reflection of incident waves reaching the outlet has been reduced by introducing sponge layer. Validation of the model is done by using the analytical theory. Coastal vegetation is modeled by a series of small rigid cylinders of varying heights (lengths). Geometrical obstruction of the vegetation is taken into consideration during the simulation of flow. The simulation results shows wave transformation is happening in the presence of submerged vegetation. The average wave transmission (K_T) for submerged rigid vegetation with roots for horizontal seabed condition is 0.40, submerged rigid vegetation of uniform height is 0.55 and for varying submergences is 0.64. Wave attenuation depends on submergence of vegetation and type of configuration.

Keywords: wave attenuation, vegetation roots, k-ε turbulence model, submerged vegetation, vertically varying stems.

I. INTRODUCTION

A large part of India's population is living in coastal areas. Due to the ongoing population increase combination with the effects of climate change, such as sea level rise and increasing storm surges, the risks of coastal disasters are likely to increase in the coming decade. Engineering solutions for coastal zone management are often quite expensive; they are often harmful to ecosystems and are not a sustainable solution. One of the ecosystems that have gained attention and existing natural coastal defense is aquatic vegetation. Recent Tsunami event and coastal response to this in east coast of India witnessed the importance of the vegetation as a natural defense. The coastal vegetation can be used for cost effective, sustainable coastal defense attenuates waves and erosion and attenuates tidal currents thereby promoting sediment accretion so that coastal wetlands can keep up with sea level rise. The latter is important regarding ongoing climate change, which leads to accelerated sea level rise, increasing storm intensity, and thus increased risk for flooding and erosion of low-lying coastal areas by P. Kishore Kumar Reddy et.al, (2018). From the past two decades many numerical models have been developed for wave propagation using VOF method. Kothe and Mjolness (1992) developed RIPPLE model using VOF method to capture the free surface. Lin and Lu (1998) coupled the RIPPLE model with k-ε turbulence model and applied to calculate breaking waves on a sloping beach. Kawasaki (1998) proposed a numerical wave model for a two dimensional wave field in the vertical plane. Ketabdari et al (2008) developed the numerical model based on RANS and k-ε turbulence model to estimate wave propagation. Chen et.al, (2010) used a vertical two dimensional model with k-ε turbulence closure to simulate wave over the breakwater. In the recent years, the effects of coastal vegetation as storm barrier and sediment retention has gained more attention. Most of the published literature for wave interaction with vegetation is based on laboratory experiments. Li and Yan (2007) studied numerically the effects of regular waves on the flow through vegetation. The purpose of this study is to develop a vertical two dimensional (2D) numerical model and *k*-ε equations coupling with the VOF method for tracking the free surface to simulate the wave propagation in vegetated and non-vegetated waters. Wei-Cheng Wu (2016) simulated the attenuation of irregular waves over emergent vegetation with variations in stem heights. G. Ravi kumar et.al, (2018) regular waves without vegetation are calculated and considered for validating the model using analytical theory in MATLAB and wave transmission was studied for uniform vegetation and uniform vegetation with roots. An attempt was made to understand the wave attenuation and wave-structure interaction and its submergence on the coastal morphology.

II. METHODOLOGY

The governing equations used are the vertical two-dimensional equations describing the conservation of mass and momentum. The standard *k-ε* model is used for turbulence closure of Reynolds Averaged Navier Stokes (RANS) equations

The equation of continuity is represented in equation (1)

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

The equation of momentum is shown in equation (2)

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = g_i \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \qquad (2)$$

And the *k-ε* equations are represented from equations (3-8)

$$\frac{\partial k}{\partial t} + u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\frac{\upsilon_t}{\sigma_k} + \upsilon\right)\frac{\partial k}{\partial x_j}\right] - G - \varepsilon + \eta_k F_i u_i \qquad (3)$$

$$\frac{\partial \varepsilon}{\partial t} + u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\frac{\upsilon_t}{\sigma_\varepsilon} + \upsilon\right)\frac{\partial \varepsilon}{\partial x_j}\right] - C_{1\varepsilon}\frac{\varepsilon}{k} G - C_{2\varepsilon}\frac{\varepsilon^2}{k} + C_{1\varepsilon}\frac{\varepsilon}{k}\eta_k F_i u_i \qquad (4)$$

$$\tau_{ij} = 2(\upsilon + \upsilon_t)\sigma_{ij} - \frac{2}{3} k \sigma_{ij} \qquad (5)$$

$$\upsilon_t = C_\mu \frac{k^2}{\varepsilon} \qquad (6)$$

$$G = 2\upsilon_t \sigma_{ij} \frac{\partial u_i}{\partial x_j} \qquad (7)$$

$$\sigma_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \qquad (8)$$

Where, i = 1, 2; j = 1, 2

A function F is introduced which indicates the fraction of a mesh cell that is filled with water. The function of F is governed by equation (9). If F=1, the cell is full of water; F=0 the cell is full of air and if F is in between 0 and 1, the cell must be surface cell.

$$\frac{\partial (F)}{\partial t} + \frac{\partial (u \ F)}{\partial x_i} = 0 \qquad (9)$$

The governing equations are discretized using finite difference scheme. For solving convection terms hybrid difference scheme i.e., combination of 2nd order centered difference scheme with 1st order upwind difference scheme is used. Viscosity and diffusion terms are solved using 2nd centered order difference scheme. A pressure-velocity coupling method PISO is used. A computation domain of Δx =0.04 m and Δy =0.04 m with time step size of 0.01 s and simulation period of 20 seconds is considered for all the cases. For convergence of the solution the value of order 10^{-6} is considered. For wave simulation, boundary conditions considered on the left side of the domain is velocity inlet condition, for avoiding reflections from the right side exit boundary beach treatment is provided to damp the waves. At the top of the domain pressure outlet condition is given and bottom of the domain, vegetation are considered as no-slip walls. Validation of the model is done. Series of 9 rigid cylinders were considered across the length .variation of height of cylinder are considered as 33%, 50%, 67% of water depth as shown in (Figure I) and 12 cases were simulated.

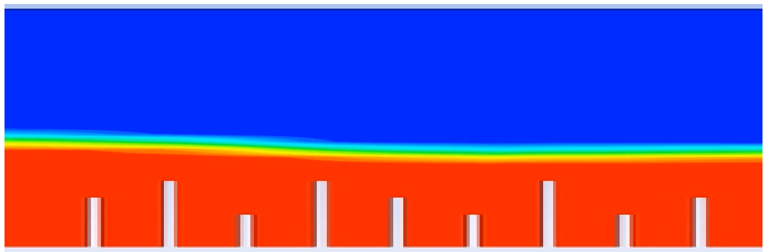

Fig. 1 VARVEG

III. RESULTS

Water surface elevations (η)

Regular waves are analyzed over three different submerged vegetation models (uniform vegetation (UNIVEG), uniform vegetation with roots (UNIVEGWR) and varying vegetation (VARVEG) in a numerical flume of length 32 m and 1.2 m deep. Case 1-12 is carried out for UNIVEG, UNIVEGWR, and VARVEG. The comparison of the time series profiles is as shown in the (Figure II) and it shows UNIVEGWR cause larger wave attenuation.

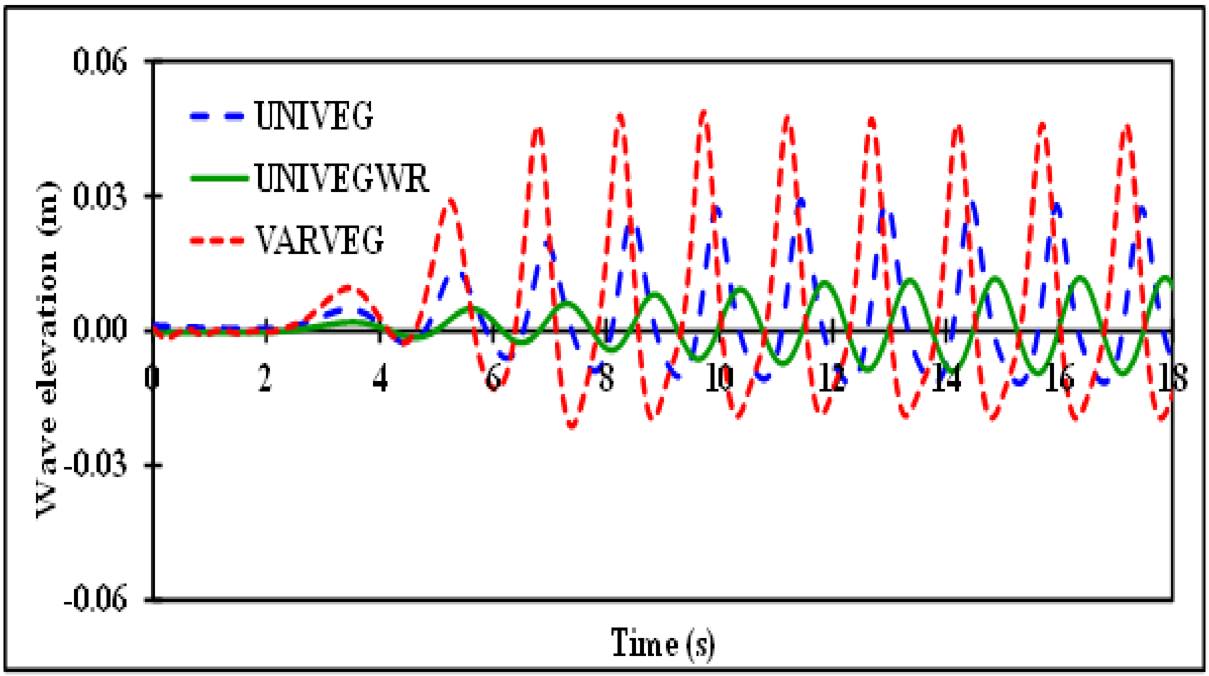

Fig. II Wave attenuation over rigid and rigid with roots vegetation for wave period of T= 1.5 s of wave height 0.15m and water depth 0.50m

Variation of Transmission Coefficient with relative water depth d/L;

The wave transmission performance of varying submerged vegetation is studied by examining the transmission coefficients. For a given water depth, the effect of the wave period is represented by relative water depth. The Transmission coefficient K_T is plotted against relative water depth d/L for UNIVEG, UNIVEGWR, VARVEG and it is shown in (Figure III) Transmission coefficient (K_T) decreases with increase in d/L for rigid vegetation with roots.

Variation of Transmission Coefficient with Wave steepness (H/L)

For a given water depth, the effect of the wave height is represented by wave steepness (H/L). The Transmission coefficient K_T is plotted against relative water depth H/L for three different models and presented in (Figure.4) Below Fig.IV shows the variation of transmission coefficienct K_T with wave steepness (H/L). Transmission coefficient (K_T) decreases with increase in H/L. for rigid vegetation with roots.

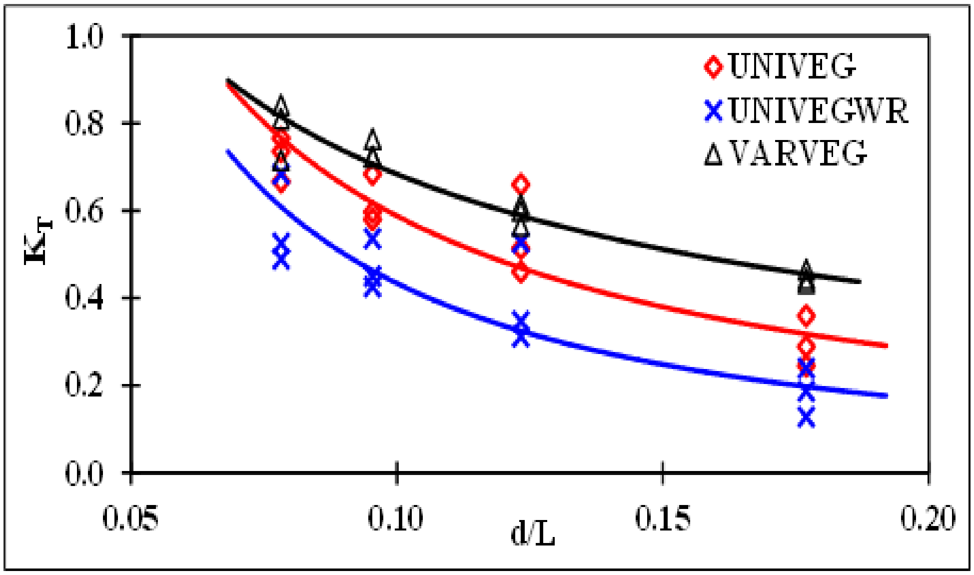

Fig. III Variation of Transmission coefficient K_T with relative water depth (d/L)

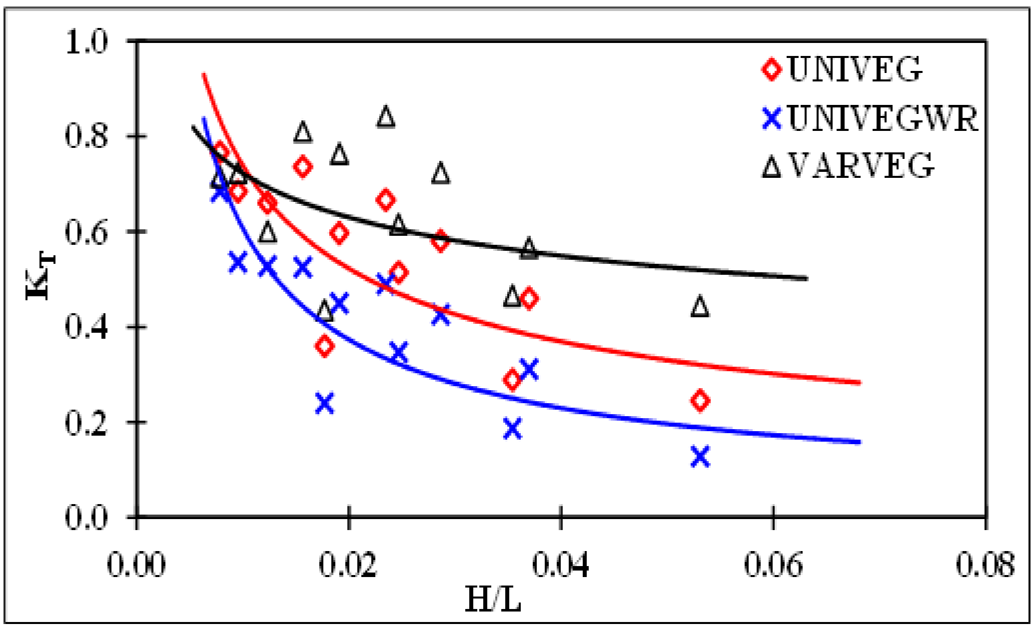

Fig. IV Variation of Transmission coefficient K_T with wave steepness (H/L)

IV. CONCLUSIONS

From the water surface elevations measured in the presence of varying submerged vegetation the wave is transforming and becoming steep near the crest and broader near the trough due to the interaction of wave with submerged vegetation and leads to better understanding of wave attenuation. The simulation results shows that original pattern of the wave behaves as non-linear. The average value of Transmission coefficient (K_T) for VARVEG for horizontal seabed condition is 0.64 , UNIVEG is 0.55, UNIVEGWR is 0.40. Wave attenuation was more for the case of vegetation with roots due to the greater lateral obstruction created for the incident wave to pass through the structure. The average reduction in 0.05 m wave height is 0.019 m, 0.10m is 0.033 m and 0.15 m is 0.053 m for VARVEG. The average reduction in 0.05 m wave height is 0.019 m, 0.10m is 0.0464 m and 0.15 m is 0.0765 m for UNIVEG. The average reduction in 0.05 m wave height is 0.025 m, 0.10m is 0.0621 m and 0.15 m is 0.0989 m for UNIVEGWR.

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