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WAVE TRANSFORMATION THROUGH SUBMERGED RIGID AND FLEXIBLE VEGETATION PATCHES

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ABSTRACT: The energy of coastal waves and storm surges are reduced by vegetation cover, which also helps to maintain wetlands through increased sediment deposition. Coastal regions are becoming more vulnerable to natural disasters, flooding resulting from hurricanes and other extreme storm events is a prominent risk along the coasts. Thus, understanding the effect of vegetation on the hydrodynamic impact of such waves on the coastal structures has become an important issue among the coastal engineering community. This has created a need for research into the properties of waves passing through wetland vegetation. The physical studies were carried out in the present study with rigid vegetation simulating the mangroves and flexible vegetation simulating the marshy vegetation. Experiments were conducted with regular waves of predefined amplitude and frequency on a horizontal and 1:20 bed slope with constant water depth of 0.47m. One of the key parameters to study the hydro-elastic interaction of the flow with the vegetal stem to represent real-world coastal vegetation is Young's modulus E. A convenient way to address the single effect of water depth on wave attenuation is to define the relative stem length H/lv. Wave Run-up decreases with relative water depth for different values of H/lv. Darcy's friction factor f decreases with Reynolds number in range studied up to 3 x 10^5. Predictive equations were proposed for Transmission coefficient (KT) and Runup (R_U/H_i) for three different vegetation configurations.

1.0 INTRODUCTION

In the present era of global change, sustainable coastal protection is of growing importance. Hence, knowledge about the mitigation of flooding and erosion hazards with low environmental impact structures is of great interest. Over the past decades the problem of coastal erosion has expanded and there has been noted an important retreat of the shoreline. The solutions used to confront this problem until recently have been basically constituted of 'hard' conventional methods such as emerged breakwaters, seawalls, groynes. However, environmentally friendly coastal protection methods, such as submerged breakwaters and artificial reefs, have become nowadays increasingly popular. They can be considered as a 'soft' shore protection method, provided that it does not have optical harmful effect and mainly does not prevent significantly the circulation of waters, contrary to the conventional methods.

Coastal vegetation like mangroves, salt marshes and seagrasses can play an important role in dissipating energy from waves and currents. Moreover, these ecosystems provide a very high ecological and economical value, which in part are also related to their capacity to dissipate hydrodynamic energy.

Traditional hard measures could cause environmental concerns and are quite expensive requires regular maintenance for its sustainability. The growing awareness of the potential of vegetation in contributing to coastal protection has led to a growing number of experimental and modelling studies, to get a understanding on how these vegetations interact with hydrodynamics. Important factors are the minimum and maximum water depths at which vegetation can be found, determined by wave orbital velocity, tide, and light and the maximum and minimum current velocities. The necessity of relate hydrodynamic and ecological parameters is revealed essential to understand the behaviour the ecosystems.

Understanding of wave characteristics in the vicinity of submerged vegetation is crucial to perform an hydrodynamical analysis. Although several attempts have been done in the past using an analytical approach (Dalrymple et al., 1984; Kobayashi et al.; 1993) the rigidity of the assumptions used to solve the physics produced limited application to real cases. The combined effect of wave propagation and plant induced damping has conditioned the numerical approach. Recent experimental approaches (Luhar et al., 2010) have revealed that the wave induced orbital velocity within the canopy was not significantly damped, revealing a relevant vertical motion within the plant field, pointing out the necessity of considering such aspect in the modelling. Many of the works were focused on the effect of vegetation on wave without paying attention to the flow characteristics within the vegetation field.

A proper design of the above methods requires the use of advanced mathematical models, able to simulate the complicated hydro-morphodynamical processes of the nearshore region (including swash zone), such as nonlinear wave propagation, wave-induced current, sediment transport by waves and currents and bed morphology evolution.

1.1 Importance of the Present Study

Beaches are one of our most important natural resources, and once destroyed repair is a difficult, costly and a repetitive, if not an impossible process. Until recently, shoreline protection typically involved constructing hard structures such as seawalls, groin fields, offshore detached breakwaters, and jetties to dissipate and reflect wave energy.

The costs of installing hard structures for coastal protection are very high; strong negative public reaction to rock emplacements along the coast often aggravates the problem (Bray *et al*., 1995; Black. K.P, 1999; van der Weide, *et.al.*, 2001). These hard structures disrupt regional and local sediment transport and alter near shore hydrodynamics and circulation patterns. Some investigators tried with low-crested barriers to alter the wave profile and thus making wave to break and dissipate the energy. These barriers will work efficiently for normal weather conditions and fail to control the wave characteristics during extreme events like storm surge and tsunamis.

The latest trends in coastal engineering are focusing on more non-intrusive forms of shore protection such as vegetation, which protects the shoreline and provides a natural habitat for many different species of fish, amphibians, insects and birds. Wetlands are one of the most productive ecosystems in the world with valuable natural resources that provide important benefits to people and the environment.

While engineered structures provide immediate stabilization and erosion abatement, they become progressively weaker over time and do not adapt to changing site conditions. V***egetation***, though ineffective when first established, becomes progressively more effective, adaptable, and self perpetuating over time. Vegetation also improves water quality, wildlife and fisheries habitat, improves aesthetics, reduces noxious weed establishment and storm water run-off, A "Bio-Structural" approach to erosion and slope stability problems; i.e., incorporating planned vegetation elements in engineering designs, can be less expensive, more effective, and more adaptable than purely structural solutions. Vegetation selected for "Bio-structural" design elements should be native whenever possible. Plants chosen should also be appropriate to the site, have wide adaptability, favourable spread and reproductive capability, superior control value, roots of high tensile strength, and be available commercially.

The presence of vegetation along an open beach can modify the run-up height and its inundation distance along the coast, the degree of which will be dependent on the characteristics of the incident waves and the vegetation. The ingress of the great Indian Ocean tsunami of 2004 has demonstrated the role of vegetation in acting as buffers in reducing the inundation heights and distance in to the land as reported by Kathiresan and Rajendran (2005). The studies of Mascarenhas and Jayakumar (2008) indicate that large stretches of the coast of Tamil Nadu (South East of Indian Peninsula) with thick casuarinas apart from coconut, mangroves and palm trees served as excellent wave attenuators. However, the phenomenon the interaction of the waves and the vegetation is not well understood. The design of vegetation as a mitigation measure for protecting the coast against natural coastal hazards necessitates a careful design, particularly in regard to the diameter and flexibility of stems of the individual trees within the plantation as well as its spacing. The width of the vegetation is also an important parameter that governs the flow. A mangrove is defined as an assemblage of trees and shrubs that grows in the intertidal areas of estuaries, deltas, backwater areas, and lagoons in tropical/sub-tropical regions.

In this regard the wave attenuation characteristics by the vegetation, when the wave approaches the beach must be studied carefully. The negative impacts on nature have made civil engineers aware of the importance of keeping the balance of natural ecosystems, and the trend of civil engineering works has been shifting from hard to soft in the last few decades. These newly added concepts are: (1) The maintenance and conservation of coastal environments and (2) The development of the coastline for public use. Thus, current civil engineers have been trying to find ways to intervene in harmony with nature. In this context, it would become more important than before to explore sustainable and cost-effective methods to protect the shoreline considering the impacts on the entire ecosystem.

In the event of a tsunami or storm surges, the ingress of water on beach and coastal areas will not be strictly oscillatory in motion. In order to study the behaviour of vegetation in steady flow conditions and to have a preliminary idea as to how the vegetal parameter influence the flow behaviour, experimental have been carried out.

The present study will have these steps: To study the wave transmission and wave run-up with relative water depth (D/Lo) for different vegetation models (rigid vegetation, rigid vegetation with roots and flexible vegetation). Darcy's friction factor f and manning's n with Reynolds's number R_e and Vegetation Flow Parameter (VFP) for different vegetation models were also presented in this study.

2.0 METHODOLGY

The mechanical characteristics of vegetation have a considerable effect on the resistance to flow of water. For tall vegetation, these properties include leaf density, shape and the general flexibility of tree species. The parameters that have been considered here include the size, elastic modulus of the vegetal stems, configuration of the vegetal patch, as well as the spacing between the individual plants. Quantification of friction factor in steady uniform flow is of primary interest and has practical relevance as far as long waves are concerned.

Motivated by the need to study the hydro-elastic interaction of the flow with vegetal stems, a suitable material for model had to be identified to represent coastal vegetation in real world. One of the guiding parameters for this purpose is the Young's modulus, E. The common timber would have an E value in the range from 10.05 GPa to 15 GPa. The mangrove has one of the highest E values of 20.03 GPa. In order to cover this wide range of E, a reference value has to be assumed for the field which had to be modeled for laboratory tests. Hence for the laboratory tests the reference E value is taken as 0.35 GPa and the material with this E value is identified. uPVC pipes which has E value of 0.35 GPa were used to make the vegetation models. uPVC pipes are relatively light. Their specific weight 1.43 is one-fifth that of steel pipes. The physical properties of the plant, such as the density and stiffness, are important in order to study the wave interaction, the bending of the leaves and the resulting wave damping efficiently. Each stem of the artificial plant was 35 cm long. The stems were inserted in a stiff 3.5 cm wooden board, which was then placed in a wave flume forming the artificial meadow. The schematic diagram of 2-D wave flume is shown in Fig.1, 2 and 3 for seabed slope such as a 1:20. Model tests were conducted at Department of Civil Engineering, Andhra University College of Engineering (A), Andhra University, Visakhapatnam, Andhra Pradesh. After processing the data obtained from the tests, the results were presented in the form of graphs represented by different dimensionless parameters. These graphs were explained elaborately relating it to its physical phenomena in the real field situations and their physical significance.

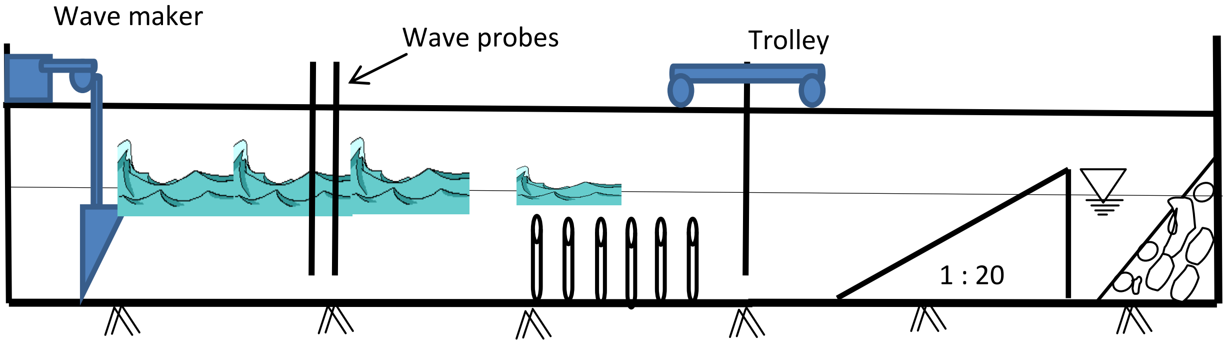

Figure.1 Schematic diagram of experimental set-up of rigid submerged vegetation on horizontal seabed in a 2-D wave flume (not to scale).

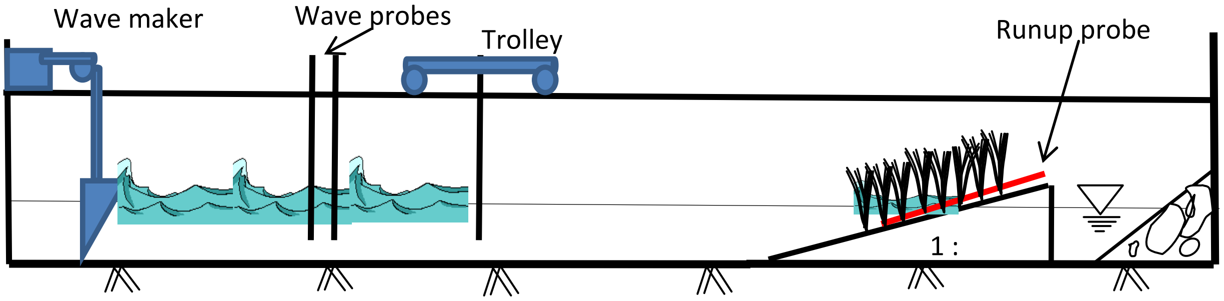

Figure.2 Schematic diagram of experimental set-up of flexible vegetation on a seabed slope of 1 : 20 in a 2-D wave flume (not to scale).

The flexible vegetation model was prepared by using self-locking cable ties. The length and width of the tie are 30cm and 4.8mm respectively. The ties are bunched and placed into the holes of a wooden plank. The fabricated flexible vegetation model is shown in fig.3.

The experiments were carried out in a 2-D wave flume which 45m long, 1.2 m wide and 1.2m deep in the Department of Civil Engineering, Andhra University College of Engineering (A), Visakhapatnam, India. The flume bed is made up of smoothly finished concrete slab. One end of the wave flume is fitted with wave maker and the other end is provided with a rubble absorber for the elimination of wave reflection. The slope of 1:20 bed is adopted for the experiments. The water depth was maintained at 0.47 m throughout the experiment. The wave generating system can generate different kinds of 2D regular wave sequence or sea state. Electric actuator system designed for sine wave output for wave generation wave installed in the wave flume. Electromechanical linear actuator with features of dedicated computer, servo drive cum controller was the driving mechanism.

Figure.3. Flexible and rigid vegetation with roots model fixed in a 2-D wave flume

A dedicated personal computer was used for the generation of wave and the simultaneous acquisition of signals from the sensor pickups. The personal computer is interfaced to the data acquisition system for data collection from capacitance type wave probes and run-up meter. The data acquisition was done with a sampling frequency of 0.025 sec (40 Hz) and the length of the record was for 90sec. The data collected was converted to physical variables by using the corresponding calibration coefficients. The raw data was analyzed in time and frequency domain to get a clear understanding of the phenomenon under investigation. The time series of the different parameters stated earlier were viewed to pick up the part of time series with regular trend by omitting the transient part. The regular time series were then subjected to threshold crossing analysis to get the mean amplitude of the time history. The wave height and wave periods were obtained by analyzing the measured time histories of wave surface elevation using threshold-crossing analysis**.**

A series of experiments were performed for regular waves propagating over the artificial vegetation patch in intermediate and shallow waters. The wave conditions were selected in order to reproduce wave conditions of the east coast of India. The relative water depths (D/Lo) indicated that the results obtained are applicable to the shallow water conditions. Wave heights are varied from 40mm to 150mm and wave periods are varied from 1 second to 3 seconds.

3.0 RESULTS AND DISCUSSIONS

3.1 Variation of Transmission Coefficient with relative water depth D/Lo

Wave attenuation performance of vegetation is studied by examining the transmission coefficients (K_T). For a given water depth, the effect of the wave period is represented by relative water depth (D/L_0). The transmission coefficient K_T is plotted against relative water depth D/Lo for three different vegetal patches i.e., rigid, flexible and rigid vegetation with roots and a slope of 1:20 presented in figure 4, for relative stem spacing of 4.5, water depth of 0.47m and H/l_v is 0.40 and 0.267 respectively. Transmission coefficient (K_T) decreases with D/Lo for flexible vegetaion and increases for rigid vegetation patches.

At low relative water depths i.e., up to D/Lo =0.075, K_T is constant for three types of vegetation patches and an average value is 0.135. For long period waves transmission coefficient is more as the wave energy penetrates through the stems in case of rigid vegetation patches. Fully grown flexible vegetation, blade like ribbon type leafs interacts with more flow path thus become more complex interactions.

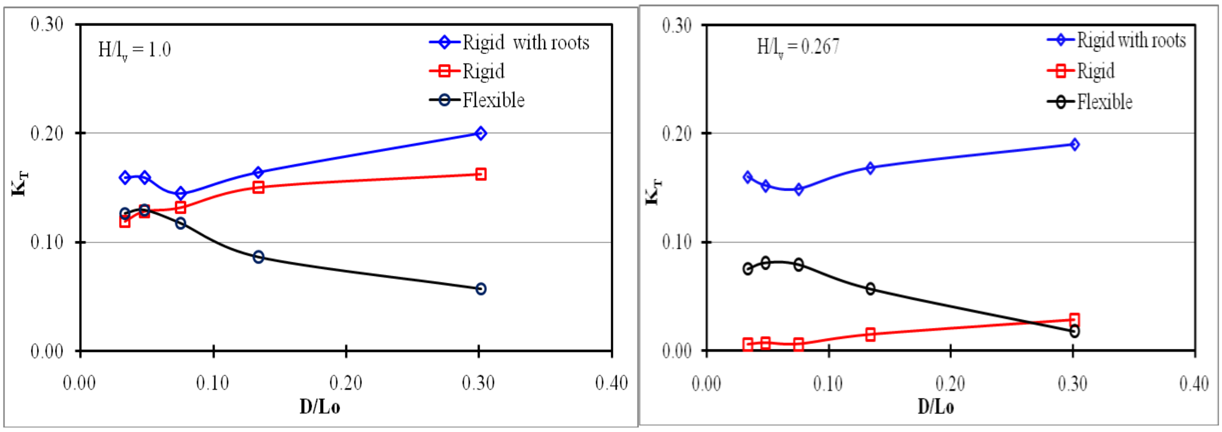

Figure.4 Variation of Transmission Coefficient K_T with relative water depth (D/Lo) for H/l_v is 1.0, 0.267 and three different vegetal patches

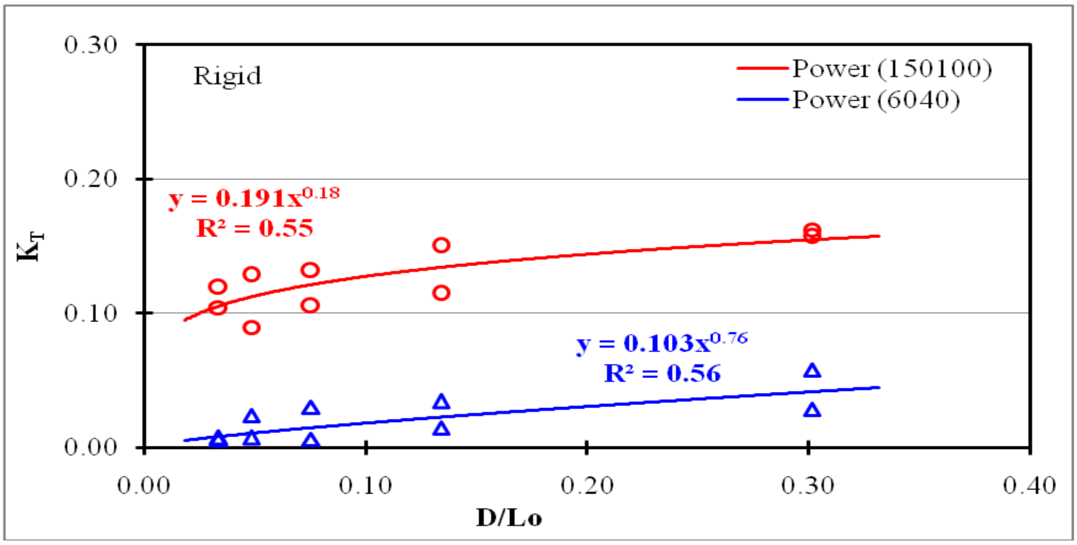

Figure 5: Variation of Transmission Coefficient K_T with relative water depth (D/Lo) for rigid vegetation. slope is 1:20, D is 0.47m and l_v is 0.30m.

Fig.5 shows the variation of transmission coefficienct K_T with relative water depth D/Lo for relative stem spacing of 4.5, water depth of 0.47m. In this figure an predictive equation was proposed for *rigid* vegetation.

$$K_T = 0.191(D/Lo)^{0.18} \quad \text{for H/D= 0.638 and 0.425} \qquad (1)$$

$$K_T = 0.103(D/Lo)^{0.76} \qquad \text{for H/D= 0.255 and 0.170} \qquad (2)$$

3.2 Variation of Wave Run-up (R_U/H_i) *with relative water depth D/Lo*

Wave Run-up (R_U/H_i**)** is plotted against relative water depth D/Lo for rigid, flexible and rigid vegetation with roots and is shown in figure.6 for D/Lo, H/l_v =1.0 and 0.267 and slope 1:20. It was observed that the (R_U/H_i) is more for flexible vegetation than rigid vegetation patches. It also observed that the wave run-up (R_U/H_i) decreases with D/Lo. Figure indicates that rigid vegetation with and without roots was behaving almost similar in terms of wave run-up for H/l_v =1.0. It may be concluded that long period waves result into less wave run-up (R_U/H_i) than the short period waves.

Fig.6 shows the variation of wave run-up (R_U/H_i) with relative water depth D/Lo for rigid vegetation of bed slope of 1:20, water depth of 0.47m and H/l_v = 1.0, 0.667, 0.40 and 0.267. An predictive equation was proposed for *rigid* vegetation.

$$R_U/H_i = 0.02(D/L_o)^{-0.40} \qquad \text{for H/D= 0.638 and 0.425} \qquad (3)$$

$$R_U/H_i = 0.06(D/L_o)^{-0.08} \qquad \text{for H/D= 0.255 and 0.170} \qquad (4)$$

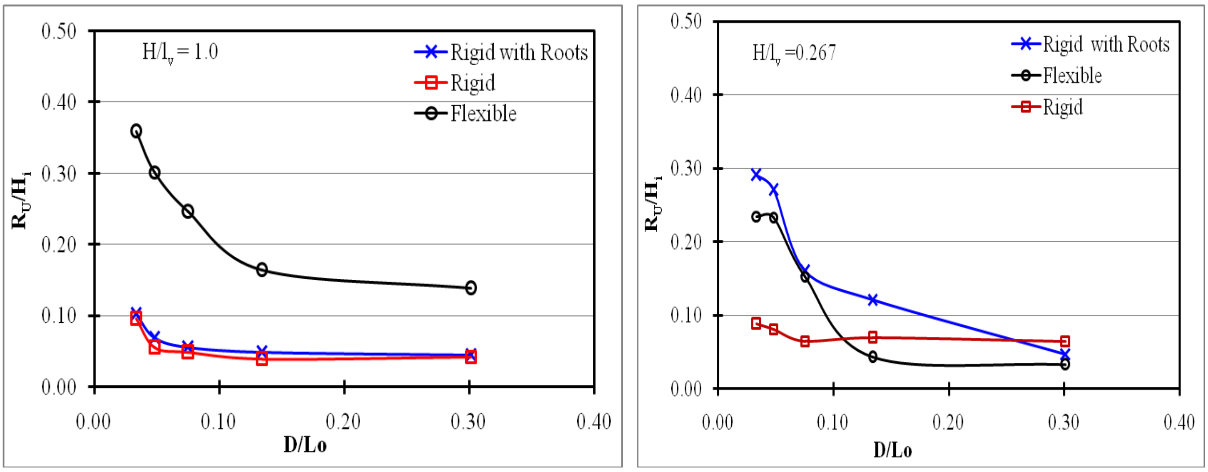

Figure 6. Variation of wave run-up (R_U/H_i) with relative water depth D/Lo for H/l_v = 1.0 and0.267for three vegetal patches. Slope is 1:20, D=0.47m and l_v is 0.30m

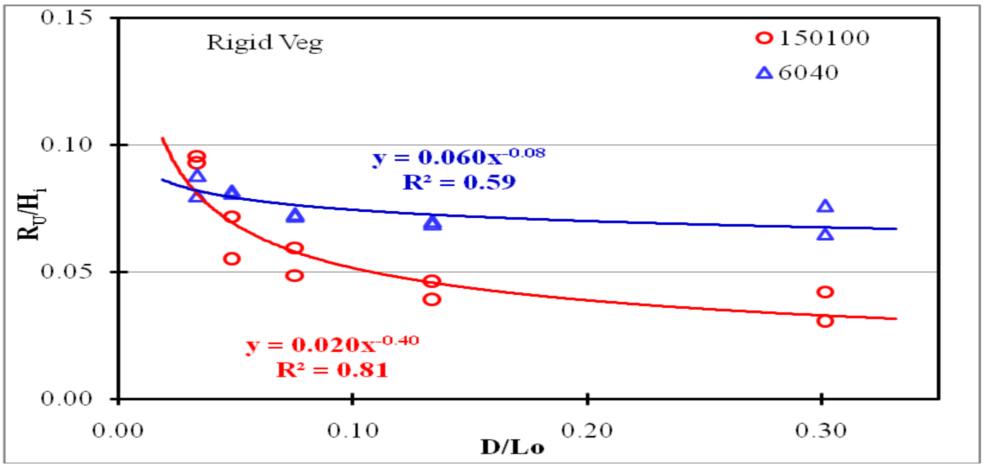

Figure 7. Variation of wave run-up (R_U/H_i) with relative water depth D/Lo for rigid vegetation, slope is 1:20, D=0.47m and l_v is 0.30m.

3.3 Determination and quantification of resistance due to Vegetation

Froude model law is usually employed for studying open channel hydraulics. However, the dependence of *f* with respect to $\boldsymbol{R_e}$ is considered for the purpose of validation of the results with that in the literature. Jarvela (2004) has measured the *f* for sedges for a wide range of $\boldsymbol{R_e}$ in a flow depth of 0.2m, the results of which are superposed with the present results for *f*, for flow depth ranging between 0.19m and 0.2m, in Fig.8.

This comparison validates the measurements with that of Jarvela (2004), Noarayanan (2009) and Sobhan raj (2014) in the range of $\boldsymbol{R_e}$ considered. The present experiments were carried out $\boldsymbol{R_e}$ in the range of 0 to 3 x 10^5, beyond the ranges covered by Jarvela (2004), Noarayanan (2009) and Sobhan raj (2014).

It was observed from the results that the Darcy's friction factor *f* decreases with Reynolds number in range studied up to 3 x 10^5. The present study covers the range 0 – 5.0x10^4 and 1.5x10^4 – 3.0x10^5, comparing with previous results and covered beyond the ranges of earlier investigations.

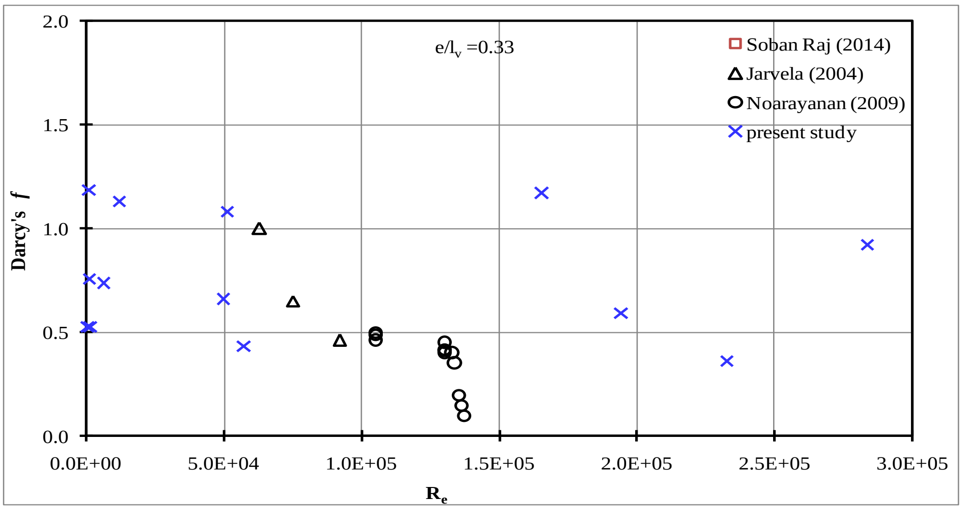

Figure 8. Variation of Darcy's friction factor *f* with Reynolds number R_e for three different vegetal patches

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