INVESTIGATION OF SPECTRAL ENERGY DISTRIBUTION IN WAVE GROUPS DUE TO PRESENCE OF VEGETATION

N Hari Ram[1], V Sriram[2] and K Murali[3]

This work presents an experimental study of long-period waves passing over modelled vegetation belts, focusing on the energy attenuation process through vegetation belts and their characteristics. The wave passing over a slope and interacting with vegetation has complex flow characteristics. Thus, the process of energy attenuation by the vegetation has been investigated in this study. Monochromatic waves were considered, and the attenuation characteristics over vegetation belts of different lengths have been discussed in detail. The wave characteristics were discussed in the spectral domain considering the primary frequency and higher harmonics of incident waves to understand the attenuation process of vegetation. The attenuation by vegetation consists of shifting of energy from primary frequencies to higher harmonics and the dissipation of energy from the higher harmonics. The importance of vegetation belt length in energy attenuation has been proved through this investigation in detail.

Keywords: wave-vegetation study; spectral energy distribution; wave attenuation; vegetation belt.

Introduction

The wave – vegetation study has been discussed by many researchers especially as coastal protection from coastal calamities like storms and tsunamis. The post – tsunmai field investigation studies showed coastal vegetation protecting the coastline (Danielsen and Sørensen 2005; Kathiresan and Rajendran 2005; Sundar et al. 2007; Mascarenhas and Jayakumar 2008). The protection provided by the wetlands against huricane storms has been showed by Barbier et al. (2013). The effective attenuation of waves by the mangrove patches along the north coast of Singapore has been reported by Lee et al. (2021). Thus, it is important to understand the wave – vegetation interaction to effectively utilise the coastal vegetation as coastal buffers against such extreme events. Apart from the aspect of coastal protection from waves the vegetation also helps in preventing soil erosion (Thampanya 2006; Montakhab et al. 2012). Further, the vegetation helps in carbon sequestration, as reported by Bianchi et al. (2013); Ward (2020).

Dalrymple et al. (1984) carried out the earlier work on wave height attenuation by vegetation considering array of cylinders. He derived the analytical equation of wave damping across the vegetation belt. The work following which was extented by Mendez el al. (2004) by accoundting the bed variation for breaking and non-breaking waves consists of regular and irregular waves. The study on drag, turbulence and diffusion within emergent vegetation is reported by Nepf (1999). The process of energy dissipation through dense vegetation was due to the mechanical obstruction of the flow, whereas the sparce vegetation is through turbulence drag. Tanaka (2009) made a review on the advantanges and the shortcomings of coastal vegetation as protection measures against extreme events. The effect of friction factor for different vegetation arrangents, density and stem size was studied and reported by Noarayanan et al. (2012). The study showed that the staggered vegetation was more effective in terms of energy dissipation. Simailar observation was obsereved by Hashim and Catherine (2013). The works by Wu et al. (2016) reported the influence of variation in vertical density of vegetation. But this influence was obsereved in relatively higher water depth than shallow depths. He et al. (2019) investiagted on wave attenuation considering stem, root and canopy. The combined effect of all three was observed to be higher. It has been reported that the dissipation provided by the roots and canopy was higher compared to the stem alone. The experimental study on the influence of arrangement patterns of vegetation patches on solitary waves was carried out by Maza et al. (2016). The importance of the vegetation submergence was obsereved. The investigation by Hari Ram et al. (2022) showed that the energy reduction property of vegetation belt was not influenced by the profile of long wave models like solitary and elongated solitary waves. Subsequently, the empircal equation for wave attenuation for such long wave models over vegetation belt with modified submergence ratio was propesed considering the flow characteristics.

[1] Ocean Engineering Department, Indian Institute of Technology Madras, India.
[2] Ocean Engineering Department, Indian Institute of Technology Madras, India.
[3] Ocean Engineering Department, Indian Institute of Technology Madras, India.

The energy dissipation by salt marshes during tropical storm was reported by Jadhave et al. (2013). The reduction of non – linearity in the shallow waters was observed due to the presence of the salt marches. The importance of submergence height and the density was reported by Anderson and Smith (2014) considering irregular waves over modelled vegetation field of *Spartina alteriflora*. In which the effect of wave height in wave attenuation was reported but the influence of period was not observerd. This is due to the fact of multiple frequency interactions and energy shift. Thus, in this paper dissipation trend is observed and explained by considering regular waves interacting with vegetation belts of different length. The effects of vegetation belt in reducing the non – linerity of the incident wave is also discussed. Further, the importance of length of the vegetation belt are discussed.

This paper is organized as follows. Section 2 provides the details regarding the experimental setup for the present study. Section 3 provides the details of the waves and the analysis procedure followed and the repeatability cases for the waves considered. In section 4, the attenuation characteristics of monochromatic waves over different vegetation belts and finally, the importance of length of the vegetation belt has been discussed in detail.

2. Experimental setup

The experiments were conducted in a wave-cum-current flume at the Department of Ocean engineering, Indian Institute of Technology Madras, India. The flume is 2 m wide, 30 m long, and 1.8 m in height. Fig.1 (a) shows the schematic drawing of the experimental setup. The false bottom was created with a slope of 1:10, followed by a flat region and slope on the rear side. The long-period monochromatic waves were generated using piston type wave maker. The waves were generated using “IITM WaveGen software”, in house developed software. Second order wave maker theory was used for the wave generation. The far end of the flume has been filled with rubble stones for wave absorption. In this study the vegetation was modelled as an array of cylinders. The cylinders were made of polyethylene. The model scale (λ) of 1:40 has been adopted. Froude’s law and Cauchy’s similitude were adopted in the study. The Young’s modulus (E) of timber ranges from 10.5 to 15 GPa. The adopted diameter of the trunk ranges from 100 to 400 mm in the prototype. Thus the vegetation model fabricated as cylinders of diameter 10 mm. The Young’s modulus of the polypropylene is 3.8 GPa. Thus considering rigidity scale factor for the model is λ^5, the base diameter of the vegetation was fixed as 5 mm (Noarayanan et al., 2012). Fig. 2 (a) and (b) shows the drawing of the vegetation model and the fabricated polypropylene cylinder used in the experiment respectively. The vegetation was arranged in staggered manner with c/c spacing between the cylinders were maintained at 75 mm, and the height of the vegetation cylinders (h_v) of 300 mm was used. The vegetation model was fixed to the flat region of the false bottom covering the whole width of the flume. In this study, four different vegetation belts namely WB1, WB2, Wb3 and WB4 of lengths (L_v) 0.225, 0.45, 0.6 and 0.975 respectively, were considered.

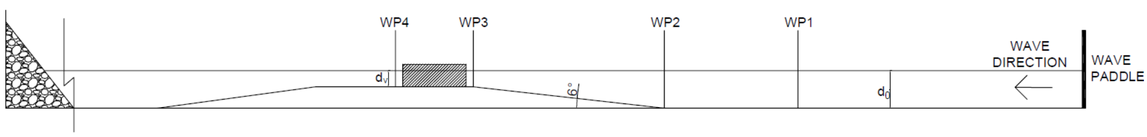


Figure 1. Schematic diagram of experimental setup.

Figure 2. Vegetation model considered in the study.

The water depth near the wave paddle (d_0) was 0.58 m. The water depth near the vegetation flat over the slope (d_v) was 0.25 m. The long-period waves of four different periods of wave height of 0.05 m were considered in this study. The details and wave parameters are given in Table 1. The data were sampled at 100Hz using resistance-type wave probes. These are placed at 4.38 m (WP1), 6.44 m (WP2), 9.38 m (WP3) and 10.58 m (WP4) from the zero position of the wave paddle as seen in Fig.1.(b). The wave profile of the generated waves was verified using the wave probe WP1. The wave probe WP2 was placed at the begining of the slope. The WP3 was placed close to the frontal vegetation for all the vegetation width. The WP4 was placed positioning behind the last row of WB4 vegetation belt. All the wave probes and the wave paddle were synchronized through *IITM WaveGen software*. From our experience, the waves in this flume are highly repeatable in nature. Nevertheless, order to validate this all the wave cases were repeated thrice. Fig 3. shows the repeatability validation for the wave case M2 from the WP1 gauge.

(a) Monochromatic wave – M2

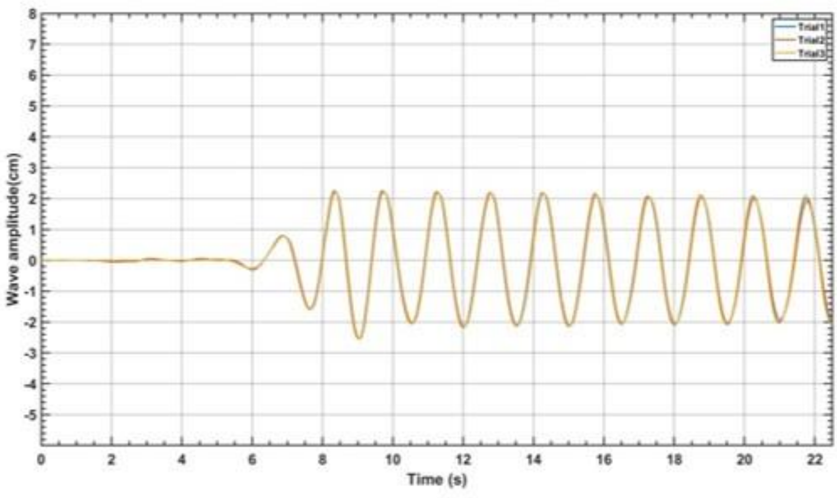


Figure 3. Wave profile recorded in wave gauges and its corresponding FFT.

3. Methodology

The wave profile measured in the time domain was analysised to the frequency domain through FFT analysis. To understand the effects of vegetation belts of different length on the wave characteristics, the wave cases were compared with and without the vegetation cylinders. Thus a total of 20 cases were studied. For the analysis, steady part of the waves was only considered in the analysis. Fig. 4. shows the wave profile variation for the regular wave (M3) at different wave gauge locations. The steady waves were tracked with the time-synchronized signal.

The energy being directly proportional to the square of the wave amplitude, the energy dissipation trend is studied by looking into the amplitude of the frequencies contained in the wave groups. Fig. 5 shows the amplitute of the frequency contents of the waves at the corresponding wave gauge. It is well known that higher nonlinarity leads to higher amplitude in the higher harmonics. Reduction in amplitude of the frequency component refers to the reduction in energy contributed from the corresponding frequency and vice versa.

Regular wave (M3)

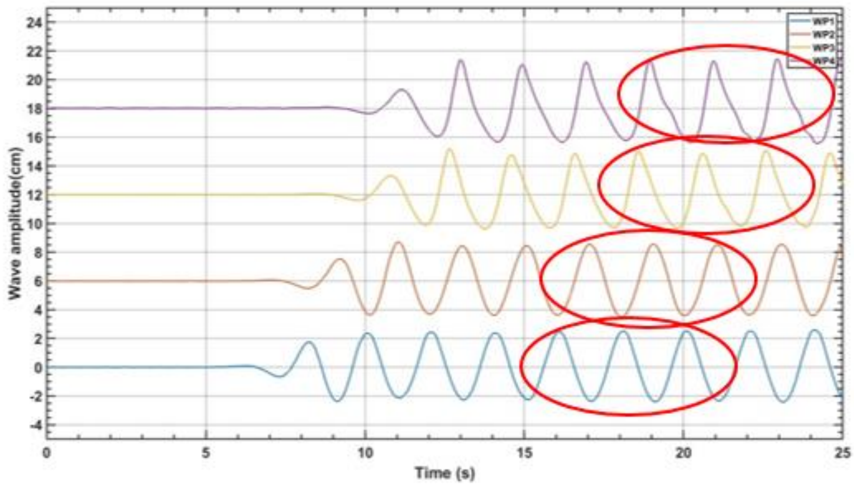


Figure 4. Wave profile recorded in wave gauges and its corresponding FFT.

Frequency domain (M3)

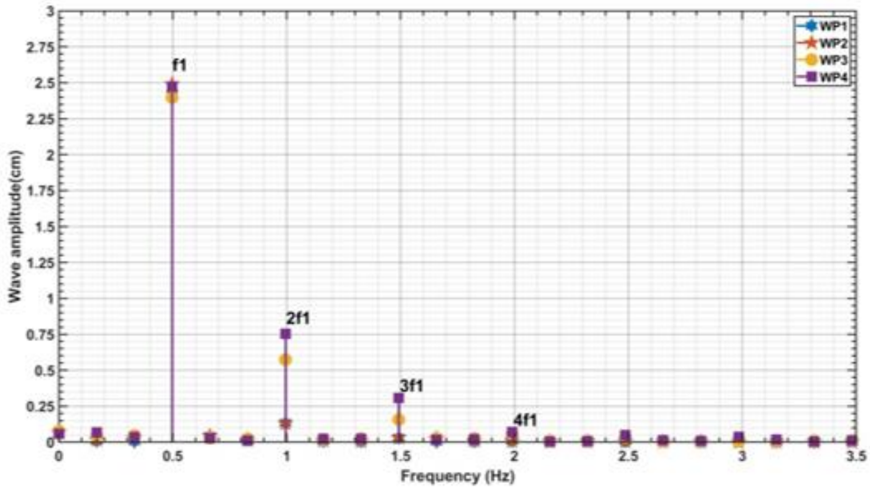


Figure 5. Frequency analysis for the waves at corresponding wave gauges.

4. Results & Discussion

As mentioned previously, the test cases were considered with and without the model to bring out the influence of the vegetation. The waves passing over the slope become non-linear, which can be observed from the comparison of the wave profile of WP1 and WP4 data, as shown in fig. 4. This can also be shown with the occurance of the higher harmonics in the frequency domain for the respective waves from WP1 and WP4 as shown in fig. 4. This shows the influence of the slope and reduced water depth over the slope in introducing the non-linearity. On comparing the wave profile in fig.4 and frequency contents in fig. 5, once can see the influence of nonlinearity in higher harmonics.

The waves after passing through the vegetation belts were also studied, considering the variation in the amplitude and its frequency contents. The variation of the amplitude ratio for different vegetation belts for case M1 is shown in fig .6. It can be observed that the amplitude of the higher harmonics getting increased for vegetation belts of shorter length and decreases as the length of the vegetation belt increases. The amplitude is reduced in every frequency component for the longest vegetation belt WB4 in this study. Fig. 7. shows the comparison of the amplitude content of the frequencies in the waves passing over different vegetation belts. A general trend of amplitude shift from the primary frequency component (f1) to the higher harmonics (f2,f3, and f4) can be observed from the WB1 and WB2 vegetation belts. Also, there is a reduction in amplitude in the higher harmonics with increasing vegetation belts (WB3 and WB4). Thus, in general the case of WB1 and WB2, the vegetation helps shift the energy to higher harmonics. The additional vegetation length found in WB3 and WB4 dissipates the energy from the higher harmonics, apart from the shifting in the energy content and thus reduces the wave energy. This also reduces the non – linearity present in the waves due to dissipation of the amplitude in the higher harmonics.

Case M1

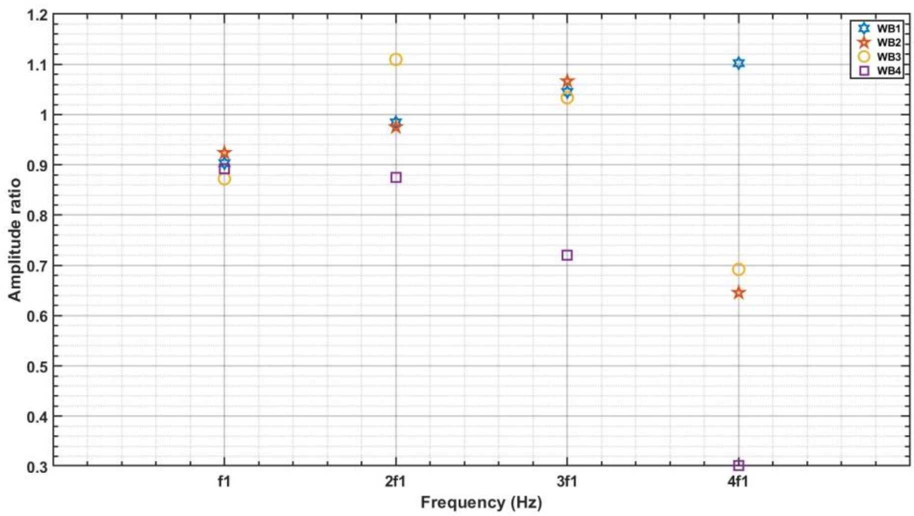
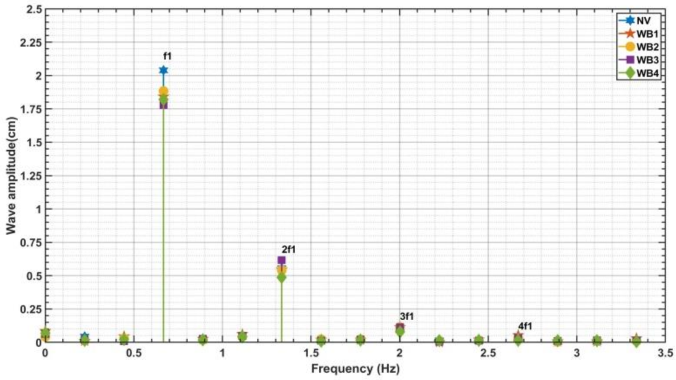


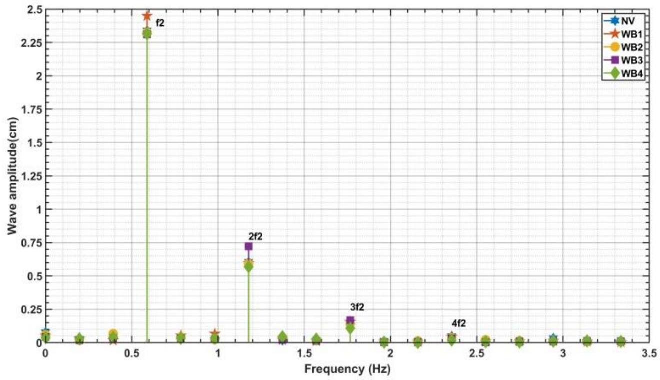
Figure 6. Amplitude ratio variation of frequency components for different vegetation .

Further, in order to understand the reduction in total energy, the energy ratio (E/E_o) for the wave cases for different vegetation lengths are compared and shown in fig .8., where E is the energy of wave without vegetation and E_o is the wave energy after passing over the vegetation belt measured at WP4. The energy of the waves was estimated from the frequency domain. It can be seen that with the increase in vegetation belt length, the energy ratio is decreasing. For short vegetation belts WB1 and WB2, we could observe a marginal increase in energy ratio which can be due to increased height of the incident wave. This could be due to the partial reflection from the vegetation and insufficient length of the vegetation belt to attenuate the increased height. This effect of a partial increase in height due to front rows of vegetation has been reported by Phan et al. (2019), Zhao et al. (2021) and Hari Ram et al. (2022).

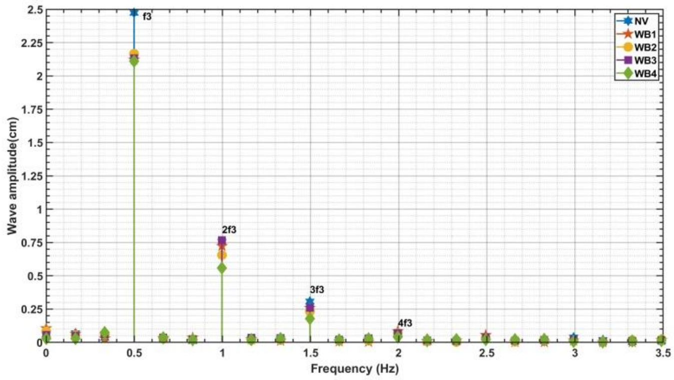
(a) Case M1



(b) Case M2



(c) Case M3



(d) Case M4

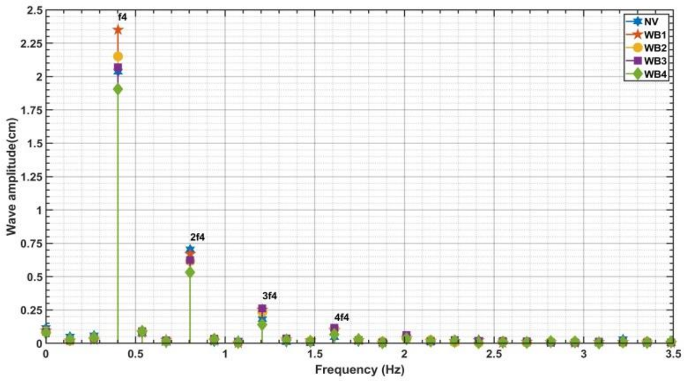


Figure 7. Amplitute variation in the frequency harmonics for different vegetation belts.

Case M1 – M4

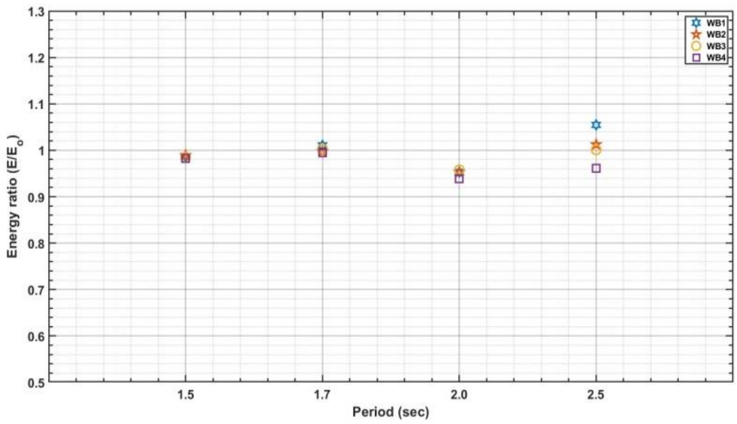


Figure 8. Variation of energy ratio for different vegetation belts.

Conclusions

The present experimental study investigated energy dissipation considering different vegetation belt lengths. The long-period waves interacting with the vegetation belt over the slope were investigated. The observations from this study showed that energy dissipation through vegetation occurs during the transfer of energy from the primary frequency to its higher harmonics, and then the dissipation of the energy in high frequency during the presence of vegetation. The results shows that the front row of vegetation aids in the former process, and the rear rows aids in the latter process. A sufficient length of vegetation belt is required for dissipating energy. A short vegetation belt does not support reducing the energy in the cases of long-period waves. This proves that a sufficient length of vegetation belt is required for energy dissipation, as observed in the field by many researchers in the past (Magdalena et al., 2022; Hari Ram et al., 2022,). The results from the frequency analysis also showed the involvement of the larger vegetation in reducing the non – linearity in the waves by means of dissipating the energy from the higher harmonics. In the actual coastal region, waves are irregular in nature along with the current, and it will be challenging to understand this phenomenon. In future, the aspect of tuning this dissipation factor needs to be studied much more in detail and further looking into the aspects of the different spacing of the vegetation.

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