PHYSICAL MODELING OF TSUNAMI FLOW THROUGH DISCONTINUOUS VEGETATION

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ABSTRACT

Vegetation has been recognized as an effective measure to reduce the fluid force of tsunamis and floods. Laboratory experiments were performed through emergent vegetation of discontinuous (patch type) pattern with different water depths under subcritical condition. It was observed that the flow structure is significantly affected due to the presence of discontinuous forest model (FM), the influence of which increased with the increase in initial water depth condition. The water surface was raised in the upstream region of FMs, causing a steep water surface slope within FM regions, which resulted in reduction of inundating flow depth downstream of the FMs. Thus, each FM contributed to the loss in energy by creating water level differences upstream and downstream of the FMs. The overall energy loss for both upstream and downstream FMs was observed to be 29-36%. The study found that the energy of the inland tsunami flow can significantly be reduced by the discontinuous forests as a defense system.

1. INTRODUCTION

The coastal vegetation plays the role in mitigation of tsunami in the form of debris trapping, dissipation of energy, an escape route, and a soft-landing place (Shuto, 1987; Tanaka et al., 2007). Vegetation acts as a natural protection measure as it reduces inundation depth downstream of it and dissipates the energy of flow like flood and tsunami. The previous researchers focused on modeling tsunami flow through vegetation, but no study has been reported on discontinuous vegetation as a countermeasure for tsunami mitigation. Sometimes, it may not be possible to provide full length vegetation along existing pathways; therefore, the vegetation in that case can be provided with a gap. Hence, the objective of the present study was to physically model the tsunami flow through discontinuous vegetation, and investigation of energy loss through it.

2. EXPERIMENTAL CONDITIONS

The experiments were carried in a 12m long, 0.5m wide, and 0.7m deep glass sided channel (constant bed slope of 2/1200) at Saitama University (as shown in Fig.1a). The tsunami flow in a subcritical condition in the inland region was considered, and the physical scale of FM was selected as 1/100. The layout of FMs and experimental condition are shown in Fig. 1 and Table 1. The water level was measured throughout the center of the channel using a rail mounted point gauge at an interval of 2-10cm (depending on the change in the water surface) in the flow direction.

Table 1. Vegetation configuration

Initial water depth (h_o) (cm)	**Initial Froude No. $F_r = V_o/(gh_o)^{0.5}$**	**Forest location**	**Porosity "P_r" (%)**	***G/d***	***D* (cm)**	***W* (cm)**	**Vegetation thickness "*dn*" (No. cm)**
4, 5, 6, 7, 8, 9	0.648, 0.671, 0.715, 0.727, 0.733, 0.761	Upstream	98	2.125	2.5	24.27	179.36
		Downstream	98	2.125	2.5	24.27	179.36

3. RESULTS AND DISCUSSION

3.1 Flow structure around discontinuous vegetation

The backwater rise ($\triangle h$) upstream of the FMs is raised due to reflection of vegetation, with a water surface slope ($\tan\theta$) inside the FMs (Fig.2a). Whereas, the inundation depth downstream of FMs is significantly reduced. This effect of varying flow structure became strong with the increase in initial water depth. The backwater rise is relatively higher for upstream FM (UFM) as compared to the downstream FM (DFM) for almost all the given initial water depths (Fig. 2b). This is because the UFM results in the relative reduction of water depth downstream of it by creating a water surface slope inside the vegetation model, and this consequently affects and reduces the upstream water depth of DFM. Moreover, a slightly increasing trend in backwater rise for both FMs is observed with the increase in initial water depth. The water surface slope (Fig. 2c) also increased with the increase in initial water depth condition for both the FMs. However, the magnitudes of water surface slopes of UFM are relatively smaller as compared to those of DFM. This is due to the resistance and reflection by DFM, causing the backwater rise upstream of it, which consequently affects the water surface slope as well as downstream inundating depth of UFM.

3.2 Energy loss around discontinuous vegetation

The specific energy ($E = y+\alpha V^2/(2g)$, where y is the depth of water, V is the depth averaged velocity (= Q/A, where, Q:discharge, A:cross-section area), and α is the coefficient for accounting the variations in velocity (= 1 in this study)) is defined. The total energy loss for upstream and downstream FMs is calculated by $\Delta E_1 = E_1 - E_2$ and $\Delta E_2 = E_2 - E_3$, respectively, where E_1, E_2, and E_3 are the mean specific energies at upstream of UFM, downstream of UFM where flow becomes almost stable, and the downstream

Keywords: Tsunami, Flow structure, Vegetation, Backwater rise, Energy loss
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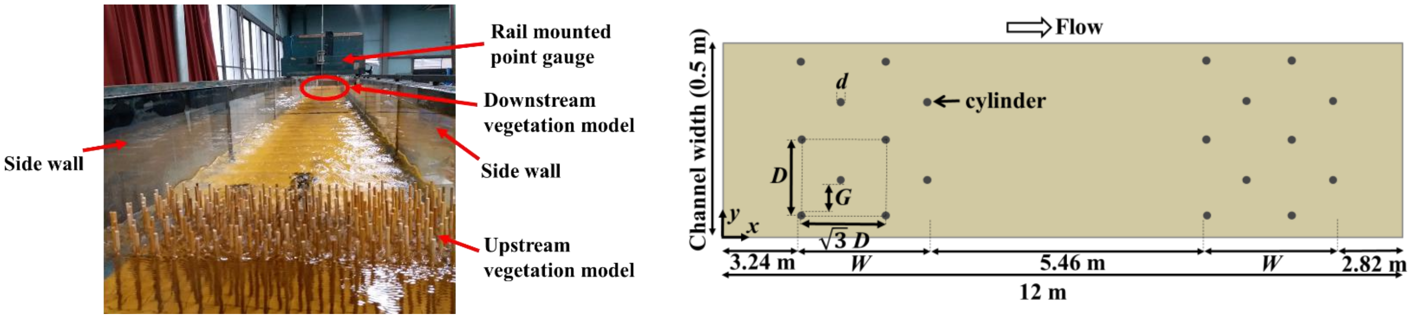
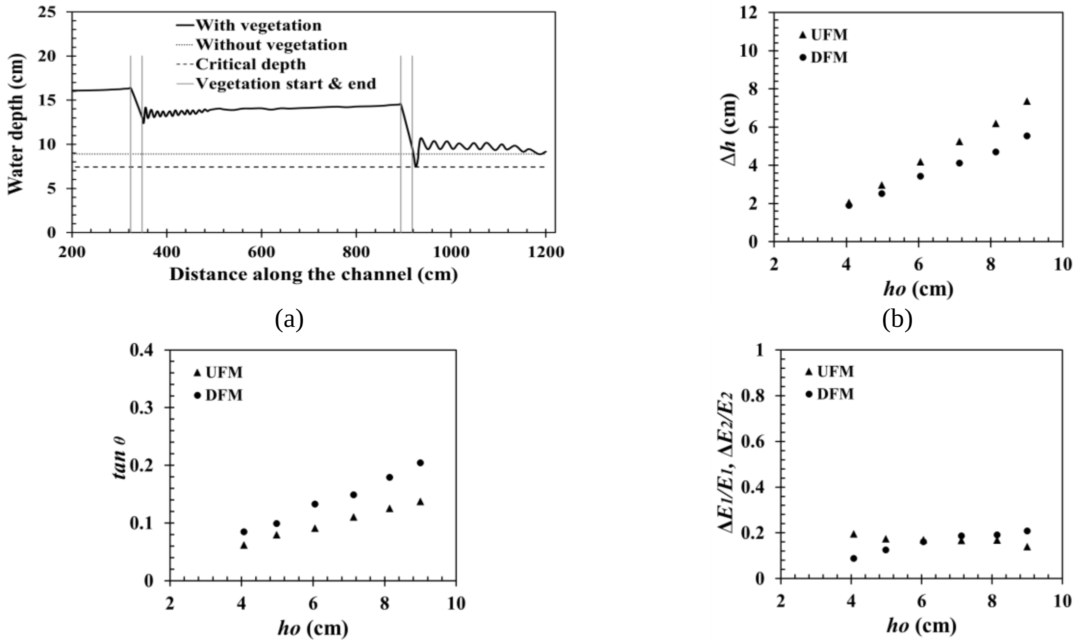


(a) (b)

Fig. 1: (a) Experimental channel, and (b) top view of schematic diagram of channel showing vegetation configuration.



(a) (b) (c) (d)

Fig. 2: (a) water surface profile at highest initial water depth i.e. h_o= 9cm, (b) backwater rise "Δh" against various initial water depths, (c) water surface slope "*tan θ*" within the forest models, and (d) relative total energy losses ($\Delta E_1/E_1$ and $\Delta E_2/E_2$).

of DFM, respectively. Fig. 2d shows the relative total energy loss by the individual FMs. A significant amount of energy is lost due to the resistance offered by discontinuous vegetation. The relative total energy losses show almost non-varying trend with the increase in initial water depth, pointing out that the initial water depth or initial Froude number has no significant effect on relative total energy loss by the individual FMs. The overall total energy loss ($\Delta E_1/E_1 + \Delta E_2/E_2$) due to both UFM and DFM is observed to be 29-36% for the given initial water depths. This relative energy loss due to sparse vegetation i.e. G/d= 2.125, of discontinuous pattern is comparatively higher as compared to that found by Pasha and Tanaka (2017) in their sparse (G/d= 2.125) as well as intermediate (G/d= 1.09) arrangement of vegetation thickness $dn \approx 180$, for which they found maximum loss of energy to be 28.1% and 31.7%, respectively, under subcritical flow conditions.

4. CONCLUSIONS

The present study revealed that the flow structure is greatly influenced due to the presence of discontinuous vegetation in the form of patch type forests. The vegetation affects backwater rise in front of and water surface slope inside vegetation. DFM also affects UFM flow structure. Due to the flow resistance offered by discontinuous vegetation, a significant dissipation in overall total energy results. The outcomes show the importance of discontinuous vegetation as defense system.

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