Form 2

Dissertation Abstract

Report no.	(Course-based) No.1074	Name	GHUFRAN AHMED PASHA
Dissertation title	**Role of Vegetation in Dissipation of Tsunami Energy and Entrapment of Tsunami-Borne Wood Debris (植生の津波エネルギー減少と津波生成流木の捕捉に関する研究)**		

Abstract

A large tsunami is one of the most dreadful natural disasters in the world. The 2011 Great East Japan tsunami opened new challenges for researchers to find better ways to prevent tsunami disasters across the globe. The effectiveness of coastal forest as a natural method in reducing the disastrous fluid force of a tsunami has received increased attention since the 1998 Papua New Guinea tsunami, the 2004 Indian Ocean tsunami, and the 2011 Great East Japan tsunami. The objective of this study is to investigate the role of vegetation/forest to trap tsunami-borne wood debris and to dissipate the energy of flowing water. During tsunami events, destruction of coastal forests may produce significant amount of driftwood or large wood debris (LWD). These wood debris can cause secondary damage to buildings by collision. To limit such destruction, the trapping action of a finite-length forest was examined in a flume considering the effects of ‘forest density’, ‘debris length to forest width ratio’ and ‘forest width-length ratio (aspect ratio)’. The investigation was done to figure out the optimum forest design which would trap the maximum driftwood at the foot of trees because the trapping height greatly affects the rate of damage to the forest itself. Higher forest density and a higher aspect ratio decrease the velocity in front of the forest. Debris having a specific gravity up to 0.80 floated after collision but oscillated vertically as forest density was increased. With debris of a higher specific gravity (0.90–1.05), increased forest density resulted in debris attachment closer to the ground, which reached a plateau beyond a forest density of 0.48 cylinders/cm^2. In sparse forest, when debris was longer than the forest width; most debris fell at the foot of trees, while it was caught in the upper half of water depth in dense forest. It was deducted that the inland forest with a density of 0.48 cylinders/cm^2 and an aspect ratio of 1.7 trapped most of the debris of all lengths at the foot of trees.

Experiments with double row forests with alternate gaps were also carried out having different ‘forest densities’ and ‘forest length-width ratio (aspect ratio)’. The flow structure in front of and around a forest highly influenced the driftwood trapping

capacity. It was observed that in dense forest the flow velocity increased between the forests i.e. in the gaps, while it decreased in front of the forest. Due to the higher difference of velocity at forest front and gap in dense forest, the driftwood attachment height was higher, while in sparse forest, favorable trapping results near ground were seen with a series of smaller aspect ratio forests with alternate gaps.

Floods resulting from extreme events like tsunamis may inundate widespread inland areas and vegetation can act as a natural buffer zone to reduce the inundation area and dissipate the energy of flowing water. The second part of this study summarizes a series of laboratory experiments in which the energy loss through emergent vegetation in a steady sub-critical flow was investigated. The energy loss was determined against vegetation of variable thickness (dn, where d=diameter of cylinder, n=number of cylinders in a stream-wise direction per unit of cross-stream width), non-dimensional vegetation density (G/d, where G=spacing of each cylinder in cross-stream direction, d=diameter of cylinder) and initial Froude number. On the upstream side of vegetation, the backwater rise increased by increasing both vegetation thickness and density. Contrarily, on the downstream side a breaking undular jump with lateral shock wave was observed in a dense vegetation arrangement (G/d=0.25), whereas a non-breaking undular jump with and without air bubbles was identified for intermediate (G/d=1.09) and sparse (G/d=2.13) vegetation conditions, respectively. Under these present conditions, the maximum energy reduction due to a jump reached 6.4% for dense vegetation, and was reduced to 1.7% and 1.4% for intermediate and sparse vegetation, respectively. Hence, denser vegetation offers larger resistance thus causes significant energy loss.

Since the 2011 Great East Japan tsunami, many improvements have been made in both hard and soft solutions for tsunami mitigation. One of the Japan tsunami disaster affected sites was Soma Port in Fukushima Prefecture, where high acceleration of tsunami currents caused trees to break and wash away resulting in extensive damage to inland houses. Contrarily, some of the houses located inland and away from vegetation with a dropping step survived. This shows a possibility that a step along with the vegetation offers greater tsunami energy reduction by providing additional resistance. Laboratory experiments were conducted to investigate the energy reduction through a compound defense system (vegetation and a backward-facing step). Vegetation with a step (VS) showed greater energy reduction compared to that of only vegetation without a step (OV) due to additional loss by collision with the bed surface. However, the relative energy reduction in OV remained almost constant with the increase in the initial Froude number (Fr_o, where the Froude number is obtained from a model without vegetation in a flume), whereas the relative energy reduction in VS showed a decreasing trend with increasing Fr_o because the energy reduction due to collision decreases with increases in water depth or Fr_o.

Like the critical velocity and slope, the study also introduced the concept of ‘critical resistance’ which is defined as ‘resistance offered by vegetation to transform the subcritical flow to supercritical’. An analytical approach for finding the water depths upstream, inside and downstream of vegetation was introduced and validated well with the laboratory experiments. The classification was done against vegetation of variable density (G/d), thickness (dn) and initial Froude number (Fr_o). The subcritical flow (Fr_o ~ 0.55-0.75, without vegetation) was transformed to supercritical flow (downstream vegetation) with a range of Froude number of 1.5-1.8, 1.1-1.3 and 0.85-0.89 against G/d ratio of 0.25, 1.09 and 2.13, respectively, thus defining G/d~1.0 as critical condition. However, changing vegetation thickness didn’t produce changing results.

The energy dissipation through vegetation in a supercritical state was also investigated in this study. The initial Froude number without vegetation model (Fr_o) in channel was selected from 1.67-1.83, representing extreme tsunami conditions. Contrary to the sub-critical flow while all the other conditions remain same, in a super-critical flow (Fr_o-1.67-1.83), a weak hydraulic jump was formed on the upstream side of vegetation. The height of jump, its location and the resulting energy loss were increased by increasing both the vegetation density and thickness. Due to less reflection at vegetation front, drag force against sparse vegetation (G/d=2.13) was higher as compared to intermediate (G/d=1.09) and dense (G/d=0.25) vegetation. Under these conditions, the maximum energy reduction due to a weak hydraulic jump reached 9.4% for dense vegetation, and was reduced to 8.1% and 7.8% for intermediate and sparse vegetations, respectively.

The findings are important for design of inland forest to trap wood debris and energy dissipation of tsunami flow. The trapping height of debris greatly affects the damage to the forest itself. In case of single row continuous forest, increasing forest density resulted in all lengths of driftwood to attach near the ground. However, with debris length larger than the forest length, even with sparse forest, favorable trapping results were seen with a series of smaller aspect ratio forests with alternate gaps (double rows forest). Greater the vegetation density and thickness, greater the energy reduction. Depending upon the resistance offered by the vegetation, in a sub-critical flow, hydraulic jump is formed on the downstream vegetation, while in a super-critical flow, jump is produced on the upstream vegetation which also contributed to energy reduction. This study has classified the flow pattern considering the generated jump and quantified the contribution of energy reduction by vegetation and hydraulic jump in relation to the hydraulic parameters and vegetation characteristics.