Form 2

Dissertation Abstract

Report no.	(Course-based) No.1227	Name	**Anjum Naveed (S18-DE-156)**
Dissertation title	**Study on the effects of discontinuous and vertically layered vegetation against tsunami inundations and river flow hydrodynamics** (不連続かつ鉛直方向に層をなす植生が津波浸水や河川の水流特性に与える影響に関する研究)		

The disastrous events of tsunamis or floods in the past revealed the effectiveness of coastal forest. In tsunami mitigation strategies, interest in a multiple defense system is increasing rather than a single defense structure focused on reducing the energy of tsunami currents and vulnerability of the defense systems. This shift to a strong bioshield or a multiple defense system is because the tsunami inundation could sufficiently be delayed, and the overflow volume could be reduced compared to that of a weak or a single defense system.

In the present study, the flow resistance and velocity structures around vertically double-layered vegetation (VDLV) and single-layered vegetation (SLV) against the tsunami inundations were explored computationally using a Reynolds stress turbulence model in a computational fluid dynamics (CFD) software FLUENT. The flow response was simulated under the steady subcritical flows of an inland tsunami while considering the varying initial Froude number (F_r) condition. In VDLV flows, an inflection in the profiles of streamwise velocities i.e. the mixing-layer with an approximate length of 1cm (using a model scale of 1/100), was found around the top of short vegetation height. Due to high porosity (P_r = 98%) of the upper vegetation layer, the flow velocity reduced significantly in comparison to that within the region of lower vegetation layer of relatively low porosity i.e. P_r = 91%. The flow resistance through VDLV observed an increasing trend with the rise in F_r condition (F_r = 0.67, 0.70, and 0.73. On the contrary, the flow resistance through the vertical column of SLV was comparatively low. The numerical model predicted the complex flow structures around the mixed culture of short and tall vegetation structures, and found a relatively reduced bed shear stress through VDLV. The 3D simulation data of velocity and shear stress around the mixing layer was also used to derive important information, like mixing length and shear stress deriving non-dimensional parameter for analytical approach, that could be used in 2D modeling of flows through layered vegetated flows. The turbulent kinetic energy production in the flow and loss of turbulent flow energy through VDLV was observed to be reasonably very high as compared to that through SLV. Thus, the outcomes demonstrated that the incorporation of short submerged vegetation within a coastal forest of sparse tall vegetation can significantly increase the flow resistance against the tsunami currents.

The study was extended to experimentally investigate the mitigation effects of continuous and discontinuous emergent inland coastal forest, focused mainly on

energy reduction of the inundating tsunami current under the subcritical flow conditions. An experiment about exploring the influence of gap length between the forest models was initially performed. To improve the effectiveness of the coastal forest, a layer of short submerged trees with the varying condition of porosity (P_r= 98%, 95%, 91%, and 79%) was coupled/incorporated and tested with the tall emergent trees (with a model scale of 1/100). The results revealed that the forest in discontinuous placement effectively produced resistance to the flow by notably increasing the backwater rise in the upstream and reducing the energy of the tsunami current in the downstream region, rather than a continuous forest belt. The incorporation of short submerged tree layer within an emergent tall tree forest further increased the flow resistance by causing a large water level difference between the upstream and downstream regions of the forest, which consequently resulted in a significant amount of energy loss i.e. 30-50% higher, in comparison to that of single layered emergent tree configuration. Moreover, the critical zone of high shear stress and large turbulence hydraulic jump formation zone was observed to significantly move in the further downstream region for discontinuous and layered tree forest configurations, that could possibly save the direct collision of water with the ground just behind the forest. The outcomes predicted by the statistical analysis approach also showed a strong inverse correlation between the energy dissipation of flow and forest porosity. The results demonstrate that this type of discontinuous forest with the appropriate configuration and a minimum possible gap i.e. 0.5m, could be as effective as a continuous forest belt in mitigating the tsunami hazards.

Based on the forest strength and vulnerability, the research was further extended for the proper management of inland coastal forest. The relation of tree crown height to that of the trunk part using the moveable bed condition was explored. Flume experiments were performed with varying parameters like changing the crown height from the ground (highest h'_t=0.7, medium h'_t=0.5, and lowest h'_t=0.3; where $h'_t=h_c/h_t$: h_c is the crown height and h_t is the tree height), forest thickness i.e. L and $L/2$ (where L is the forest length), and initial Froude conditions (F_r) ranging from 0.668 to 0.732. The study found that the flow structures are influenced significantly with the low crown height i.e. h'_t= 0.3 which caused the maximum energy reduction i.e. 40-43%. On the other hand, the production of scour around the forest became excessive because of the large impact force of the overflowing water, that can destroy the forest defense system. The optimal results of significant flow energy reduction and minimum susceptibility (permissible scouring) around the forest have been observed with the medium crown height i.e. h'_t=0.5, and large possible thickness of the coastal forest.

The flow features and morphology of open channels like rivers are significantly influenced by forms of vegetation. The vegetation in the riparian environment does not only affect the flow carrying capacity of the channel, but also play substantial roles in the management, restoration and rehabilitation of rivers.

The present study examined the effects of river vegetation with a pattern of discontinued i.e. patch type, vertically layered configurations on the complex flow

structures in an open channel. This computational study was performed using a k-epsilon (k-ε) model in a CFD code software FLUENT (ANSYS). The validation of the numerical model was first performed with the experimental data, and then the effects of patch type canopies on the flow turbulence was explored while considering the varying conditions of vegetation density and patch length. The results showed large spatial velocity fluctuations in the regions just upstream and downstream of the vegetation structures, while sharp inflection in the vertical velocity profiles wase observed at the top edge of submerged vegetation i.e. z/h_s= 1 (where z is the water depth and h_s is the height of small vegetation). The turbulent flow features experienced large flow disturbance and turbulence (with an approximately 13% of turbulent intensity) within the patch regions for the case of dense vegetation i.e. S_s/d= 4; and S_t/d= 8 (where S_s/d and S_t/d are the small and tall vegetation spacings, respectively; and d is the cylinder diameter) as compared to relatively sparse vegetation i.e. S_s/d= 8; and S_t/d= 16 (with an approximately 9% of turbulent intensity). The turbulent flow in case of large patch and gap length (while keeping the ratio of patch to gap length equal to 1) appeared to be more stable than the case of small patch and gap length. In addition to this, the variation in the distribution form i.e. increasing the patch length although the flow turbulence experienced no significant influence, the extent of variation in the flow structures was low. The flow passing through the patch regions experienced a noteworthy rise in the turbulence flow properties like turbulent kinetic energy and turbulent intensity. Thus, a non-uniformity in the flow exists as it approaches the discontinuous and layered vegetation configuration.

The river vegetated numerical flows study was extended to examine the flow structure variations around longitudinally discontinuous and vertically two layered vegetated canopies occupied in half channel width. A three-dimensional Reynolds stress model was utilized for flow simulation. The outcomes demonstrated visibly lower flow velocities in the gap regions as compared to that in the vegetation patch regions. Along the channel cross-section, the lateral flow instability occurred by the flow shear because of the partly distributed canopies. The channel flow carrying capacity in the free (non-vegetated) region was significantly influenced by the vegetation resistance along the patch areas. The flow discharge passing through the non-vegetated part of the channel was found to be 144-525% larger than the flow through vegetated part of the channel. The results found a significant increase in flow resistance in case of high vegetation density, which decreased while short and tall vegetation layers were in submerged condition. Moreover, providing a large gap length between the patches (patch to gap length ratio=0.5) made the flow structures more stable than that in the small gaps (patch to gap length ratio=1). Thus, the results showed a strong influence on the flow structures and flow resistance by the discontinuous and partially placed vegetation.

The research was further extended to numerically investigate the turbulent flow behavior through longitudinally discontinued vegetation covering half channel width. The vertical formation of vegetation configuration was varied in this study while

considering double layered vegetation (DLV), submerged vegetation (SV) and emergent vegetation (EV) with the similar vegetation density. The results found a complex flow distribution through DLV and SV, followed by multiple inflectional instabilities in the vertical velocity structure profiles. On the contrary, the flow through EV experienced a uniform flow distribution over the vertical canopy column. The flow resistance through the canopy zone was high in DLV arrangement that the velocities reduced by approximately 42% and 37% in comparison to those of SV and EV arrangements, respectively. The length of mixing layer over the interface zone of vegetated and non-vegetated parts was estimated from the inflectional instabilities of flow, which suggested a strong exchange of momentum in lateral direction for the DLV configuration as compared to that of the SV and EV. The study found remarkably reduced flow velocity and turbulence in the gaps between the patches because of the sheltering effects, while highlighting the flow response to be positive and beneficial for aquatic life and sediment deposition around such environment.