Form 2

Dissertation Abstract

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Dissertation title	Application of coastal trees as a tsunami mitigation strategy considering its possibility to be tsunami induced large driftwood （津波生成流木になる可能性を考慮した上での海岸林の津波減災対策への適用に関する研究）

Abstract

※ The abstract should be in keeping with the structure of the dissertation (objective, statement of problem, investigation, conclusion) and should convey the substance of the dissertation.

Coastal vegetation is a natural resource to a coastal community. Coastal vegetation includes coconut plantations (*Cocos nucifera* L.), oil palms (*Elaeis guineensis* Jacq.) and rubber plantations (*Hevea brasiliensis* Muell. Arg.). The benefit in these trees are not only its natural resource it provides to the community; it also provides a tsunami mitigation benefit. Vegetation has been extensively shown to mitigate tsunami damage. This includes a drag force against the wave, induce turbulence and traps debris. A thick forest patch, therefore, reduces the tsunami's run-up height and reduces its fluid forces.

However, these trees are at risk of being damaged by a tsunami, and therefore, become tsunami induced large driftwood (TLD). This aspect reduces the applicability of coastal vegetation as a tsunami mitigation strategy. When a massive tsunami breaks near the coastline, bores, that travel in high velocity, damage, and uproot trees. Much floating TLD, were noticed after the 2004 Indian ocean tsunami and the more recent 2011 great east Japan tsunami. These damaged trees can create additional point loads, pose a hazard to people and risk igniting fires. It was observed that after the 1998 Papua New Guinea tsunami, the battering effect of the debris caused most of the tsunami related damage. These point loads can, potentially colliding on schools, hospitals, and government buildings, structures that are essential to accelerate the recovery process of a tsunami.

TLD is generated because of different factors. They include the tsunami wave itself (high drag force, or sudden impact by water), weak tree condition (its critical shear strength, or weak root to substrate anchorage strength), aggravated by structures (worsening the flow condition, or inducing erosion) and or the additional force as a result of entrained debris. Studies have shown that improving the forest patch by growing stronger trees (trees that are high in its critical shear stress), improving the strength of the substrate by growing a secondary vegetation (i.e. perennial grass reducing the effect of erosion) and reducing the tsunami's energy before impact against the tree (strong shoreline structures such as seawalls) may reduce the generation of TLD. However, maintenance and site-investigation are encouraged to better guarantee that no TLD is produced in an event of a tsunami. Therefore, there is encouragement to understand how TLD can be controlled to reduce the additional damage that TLD can create.

Reduction of TLD's impact force and impact moment, delay in impact time and the ability to retain any TLD withing a designated area will control any generated TLD. This thesis provides new insights into

mechanisms that can control TLD, considering the influence of the crown, trunk, and roots of the TLD. In certain situations, the TLD will only have its crown and trunk only (broken condition – without its roots - WOR) and in other situations it will have all three aspects (washed-out condition – with roots - WR). Consideration of these factors are important as it effects the behaviour of the TLD in terms of movement and forces. Eco-disaster risk reduction methodologies (Eco-DRR), were considered, on the bases that application of coastal vegetation is a very positive Eco-DRR therefore, as best as possible the controlling strategies must follow a similar principle. Suitable model scale experiments, equations and theorical methodologies were used to achieve these objectives.

Modern research is showing that hybrid defence structures provide a more optimal solution against mitigating tsunami-related damages. These methods include vegetation (V) patch with moat (M) and an embankment (E), working in combination. A study showed that, given a fixed area, a hybrid structure shows more reduction in damage capability than just vegetation alone. This includes reduction in the overflow volume, runup distance, velocity of the flow, inundation height, and delaying the tsunami wave. Therefore, the application of a hybrid structure is growing, considering different aspects such as modifying the hydraulic jump to achieve optimum energy reduction capability yet showing the least damage potential to the hybrid structure. This study considers the benefits of a hybrid design and then elucidates the controlling mechanism of TLD given structures downstream of a forest patch.

A model scale coniferous plant (*Juniperus Chinensis* Linnaeus), considering the three different aspects of TLD was used in a suitable model scale experiment. The tree height to trunk height ratio was investigated (defined as H_{TruTre} values investigated in this study were 0.3, 0.6 and 0.8, respectively), the TLD with and without its roots (defined as WR or WOR, respectively), and the height of the TLD (model scale of 0.1, 0.2 and 0.3 m) were investigated. Using a flume channel (0.7 m wide and 5 m long with a bed slope of 1/500) three different *Fr* were pumped through the channel. When the condition was only the channel bed the flow produced *Fr* of 0.65, 0.70 and 0.75, respectively. Five different hybrid cases were considered. They were respectively VNN, VEN, VMN, VME, VEM (N represent nothing i.e. a bare-land scenario, V represent a vegetation model, M a moat model and E an embankment model, respectively). Each respective model was added onto the flow, and video camera was used to measure the TLD's movement. The experiment was repeated ten times to account for any randomness that can occur.

The experiment showed that embankment structure provided a retaining function. Case VEN, VEM, and VME showed retaining of TLD. Case VEM showed that of the ten times the model was added onto the flow there was a probability as high as approximately 70% of the TLD being retained withing the hybrid structure. The retaining function of the embankment seems to be a function of the overtopping depth, the length of the TLD and the TLD's H_{TruTre} condition. The general pattern includes the lower the overtopping depth and greater the length of the driftwood, the lower the chance of overtopping of driftwood over the embankment and, therefore, the greater the retention function. Inclusion of the moat upstream of the embankment, case VME, reduced the overtopping depth, and, therefore, the retaining function was increased. Placing the moat downstream of the embankment, case VEM, showed a secondary reflection of wave that encouraged retention of TLD. It was observed that the TLD with low H_{TruTre} condition, there was a greater probability of the TLD being retained within the hybrid structure. In a *Fr* of 0.65 H_{TruTre} of 0.3 there is a 70% of retention within the hybrid structure. For the same *Fr* and an H_{TruTre} of 0.6 the retention probability was approximately 48%. The low drag effect because of the smaller crown attributed to this difference. Moreover, for any overtopped TLD a reduction in velocity of around 6~8% was observed, compared to that of a just vegetation only scenario, case VNN. Retention means 100% reduction in damage potential and a velocity reduction allowed for decrease in the impact force.

Additionally, any overtopped TLD, especially in the case of VEM, rotation of TLD against the streamlines were observed. Rotation as high as 70˚ against the streamlines were observed in the experimental study. The benefit of this is explained in the following paragraphs.

Inland forest (IF) can be blended into a coastal community to both improve social aspects as well as protect critical infrastructure, for example, protect hospitals and schools, against the wind loading and provide shade to surrounding environment. IF can also be used to trap any overtopped TLD. The protection of, for example, hospitals and schools may assist in providing a faster recovery after a tsunami disaster has occurred. One aspect that allows the IF to trap TLD rather than the forest itself being TLD is since the IF is located inland the tsunami has decreased in wave energy and the ground condition can be more suited for stronger anchorage, therefore, a lower risk in being damaged.

Through a suitable laboratory experiment, in a flume channel (0.5 m wide and 14 m long with a slope of 1/1000) with a model scale conifer plant (*Chamaecyparis lawsoniana* (A. Murray) Parl.), the applicability of an IF for trapping was investigated. An IF considering the inland forest design, driftwood's flow depth condition and the forces associated when driftwood attacks an inland forest was investigated. The study aimed to not only improve the inland communities against tsunami damage but also understand the factors of the upstream forest, that can become TLD, has on the impact force and trapping function against an IF. Varying IF properties such as the tree spacing (made non-dimensionless by the tree's cross-stream width, S_{Trap} = ratio of TLD's cross stream width and the trees cross stream spacing), number of rows of trees (one, two and three rows respectively) and varying the floating condition were investigated (just floating JF and fully floating FF, respectively). JF means the TLD was brushing the ground while FF meant the TLD was fully buoyant.

Wooden poles of 0.01 m in diameter were used to represent the average trunk diameter of an IF. The centre pole in the first row of the respective IF was attached to a 10N force-gauge. The TLD was released 2 m upstream of the IF at a streamwise direction. Additionally, the driftwood was initiated at a rotated angle (45˚ and 90˚ to the streamlines). This was done to investigate the effect of a rotated driftwood.

This study showed that four distinct trapping types exist. They are Type Br: branches getting caught in the trunk; Type Rt: roots getting caught in the trunk; Type PR: partial rotation before two or more trunks, prevented the driftwood from flowing downstream; Type FC: trapping at the front face of IF in a cross-stream position by one or more trunk(s). Each of these trapping types occurrence varied by the IF properties and the TLD's properties and each of these trapping types showed different force patterns. Variation in the trapping type observed varied based on the factors investigated.

For encouraging trapping, the greater the S_{Trap}, the higher the trapping function. Small cross-stream spacing increased the probability of Type Br and Type FC trapping. Type Br had a lower average maximum force, against the IF, compared with Type FC. However, by reducing the cross-stream spacing, this not only increased trapping, but it also allowed for two or more trunks in the IF to support Type FC. This allowed to decrease the *FI* (ratio of max force after trapping by force before trapping) from 13.64 to

9.17. Using a modified equation of Gardiner et al. (2000) it showed that given a *Fr* of 0.8 and the TLD supported by two trunks (possible when Type FC was observed) a critical diameter at breast height ($d_{BH\text{-}crit}$) of around 0.46 m is required rather than 0.55 m if the TLD is supported by one trunk. Moreover, it also encouraged the possibility of the lower force trapping, Type Br, to occur. Increasing the probability of Type Br to occur can decrease the critical strength of the tree species to trap the TLD safely. In the WR scenario, there was an average force of 5.3 N in Type FC, however, for Type Br it was approximately 3.9 N.

This study showed that increasing S_{Trap} can be achieved by rotating the driftwood against the streamlines. Rotation of TLD can be achieved when the TLD overtops hybrid design VEM. Rotation as high as 70˚ against the streamlines were observed. Given low H_{TruTre} an S_{Trap} of 2.1 or greater showed a 90% probability in trapping of TLD by an IF irrespective of the floating condition or its condition of with or without its roots (data was derived for IF only having two rows, S_{Trap} for higher trapping is expected to decrease with increasing the number of rows).

Once safe trapping was observed, Trapped TLD by an IF created a horseshoe type flow pattern downstream of the IF. This trapped TLD acted as a shield against any downstream structures, reducing the fluid force index (the multiplication of flow velocity squared and flow depth). Reduction of the fluid force index decreases the probability of structures being washout. A reduction of fluid force index was observed in dense IF conditions. A reduction of around 40% was achieved in *Fr* of around 0.65. Therefore, dense IF not only provides a higher trapping function, this trapping function then further increases the mitigation capability of the IF.

Further research includes variations to the embankment and moat designs. By steepening the landward face of the moat structure, a stronger reflected wave may be induced, increasing the retention function.