

**DAMPING TSUNAMI AND STORM WAVES BY COASTAL FORESTS –
PARAMETERISATION AND HYDRAULIC MODEL TESTS**

von

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ABSTRACT

Motivated by the contradictory reports on the efficiency of coastal forests to attenuate waves, particularly under tsunami conditions, experimental investigations supported by numerical modelling is undertaken in the frame of the project TAPFOR in order to determine the hydraulic performance of coastal forest. On the basis of the experiments conducted in the twin-wave flumes of LWI for selected tree species (for mangroves - *Rhizophora sp.* and for pine forest - *Casuarina sp.*), wave transmission, reflection and energy dissipation will be determined, together with drag, inertia and roughness coefficients. Details of tree parameterization, construction of the required new devices/equipment and experimental set-up/programme are presented in the paper.

1. INTRODUCTION

Incident wave energy can be attenuated by coastal forests due to the flow resistance provided by a tree canopy, trunks and branches and a root system (if uncovered). As a result of wave propagation through the coastal forest vegetation, both flow velocities and wave height are reduced by drag and inertia caused by a tree, by bottom friction as well as by turbulence associated with the wave breaking and vortices. The amount of the wave energy attenuated is predominantly a function of forest type, age (tree dimensions) and density as well as the incident wave conditions, and coastal configurations, including topography and bathymetry. In the available experimental studies, several significant shortcomings can be noticed, considering the approaches adopted for tree parameterisation and tree flexibility and that no direct measurements of the forces exerted on a single tree/entire forest have been performed.

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In view of the lack of reliable studies that would allow to understand the global and local processes leading to wave damping, laboratory investigations on the hydraulic functioning of coastal forests are being performed in the frame of the project TAPFOR (Tsunami Attenuation Performance of Coastal Forests). The project is a part of the German and Thailand cooperation on Tracing Tsunami Impacts onshore and offshore in the Andaman Sea Region (TRIAS). Using the experimental/field results, the project aims at the derivation of semi-analytical formulae and the development and of a detailed numerical model that could be employed in coastal risk management as a tool for controlled-forest growth to provide the maximum protection against storm and tsunami waves. In the paper, the achieved and current stages of the project are discussed.

2. PARAMETERISATION OF COASTAL VEGETATIONS

In the present study only *Rhizophora sp.* for mangroves and *Casuarina sp.* (Fig. 1) for coastal pines are considered, since both represent the most common species in coastal regions. *Rhizophora sp.* can be easily recognised by its airy complex root system, while *Casuarina sp.* has a much more simple structure. Both species represent different habitats - *Rhizophora sp.* can be found in estuaries, tidal flats or swampy area, whereas *Casuarina sp.* grows well on dry lands (sandy beaches).

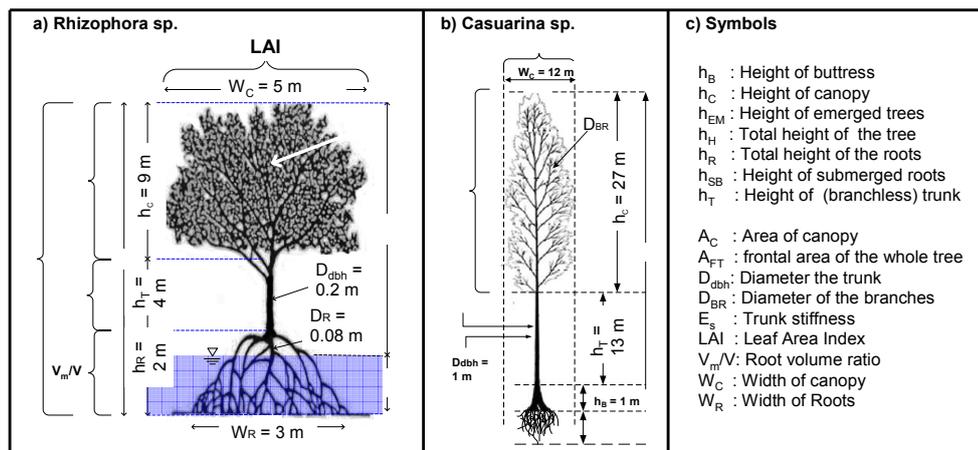


Fig.1: Definition of parameters for mangroves and coastal pines

Efforts to parameterize coastal forest vegetation have been carried out by considering mostly the dimensions and density of the tree (Latief et al., 1999; Istiyanto et al., 2003; Imai and Matsutomi, 2005). However, none of the publications considered the importance of tree flexibility in attenuating tsunamis. Therefore, studies on the parameterisation of forest vegetation will be divided into two approaches based on the vegetation structures and material characteristics:

- stiff structure assumption considering only bottom part of the tree (root system) and the trunk, adopted for mangrove forest,
- flexible structure assumption considering the whole part of tree structures (root system - trunk - canopy), adopted for both mangrove and pine forest.

Due to the complexity of mangrove tree structures, first the stiff tree assumption will be adapted in the parameterisation - only roots and the trunk are to be parameterised. A real mangrove model was constructed at scale 1:20, as reference model (Model A) based on the concept of tree dimensions (Istiyanto, 2003) and root volume ratio (Mazda et al., 1997). The alternatives of the parameterised tree model (Model B and C) consist of a group of cylinders with different arrangements (staggered and tandem) were then constructed and tested in a flume with steady flows, employing different velocities and water depths. The results (total forces, head different losses, current velocities, and flow patterns) were compared to the same measurements performed for the reference model A.

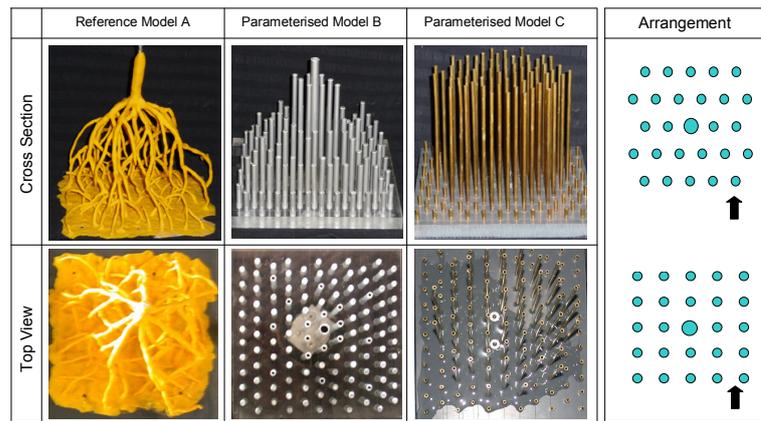


Fig. 2: Real mangrove (Model A) and parameterised mangrove models (B and C)

The results show that the parameterised models with tandem arrangement always give lower results in comparison to the models with the staggered arrangement. Therefore, further tests and analyses only consider the models with staggered arrangements. Looking at the drag coefficient (C_d) determined from force measurements, its value decreases from $C_d=3.0$ and converge to $C_d=0.6$ for all three models A, B and C. These values seem to be in a reasonable range as compared to the other previously reported values. Considering other aspects, Model B was selected for the further investigation because it has similar physical characteristics (Fig. 3a) and all hydraulic properties are quantifiable to the reference model (Model A).

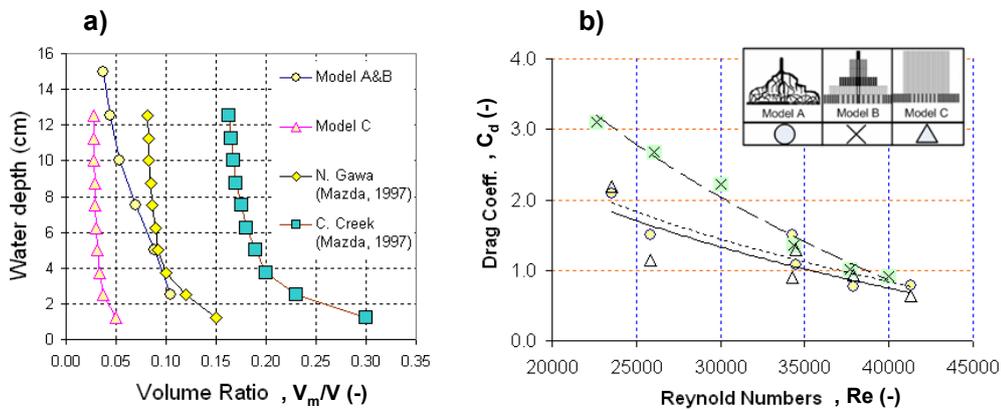


Fig. 3: (a) Comparison of physical properties of models and field measurements (b) Drag coefficient (C_d) from experiments

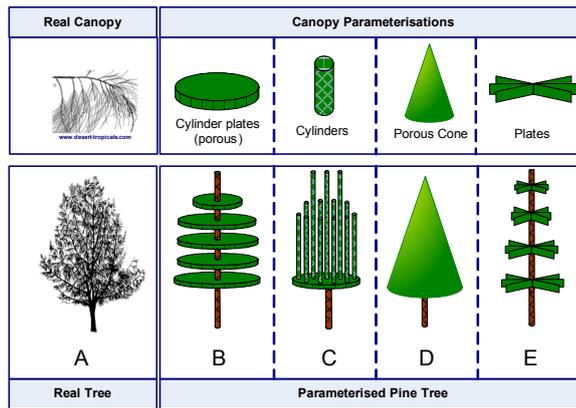


Fig. 4: Parameterised tree model for coastal pines

In case of the pine forest, several alternatives were analysed by considering dimensions, age of tree, flexible behaviour, canopy density, frontal area, energy losses, numerical adaptation, and practical considerations. The parameterised model utilising a cylinder for the trunk and square plates for the canopy was selected to be investigated further in the experiments (Fig. 4e).

3. EXPERIMENTS ON DAMPING PERFORMANCE OF COASTAL FORESTS

Parallel measurements on storm/tsunami wave attenuation by coastal forests are being performed in the twin-wave flumes of LWI, with the mangrove models placed in the 2m wide flume on a structure representing a typical beach profile. In the 1m wide flume, the beach without the forest model was constructed to investigate the influence of the forest width on the global/local processes (Fig. 5). The scale adopted in the experiments is 1:25. The beach made of plywood plates and was equipped with a constant slope (approx. 1:20) and a horizontal part of height $h_r=0.415m$, where the tree models were placed.

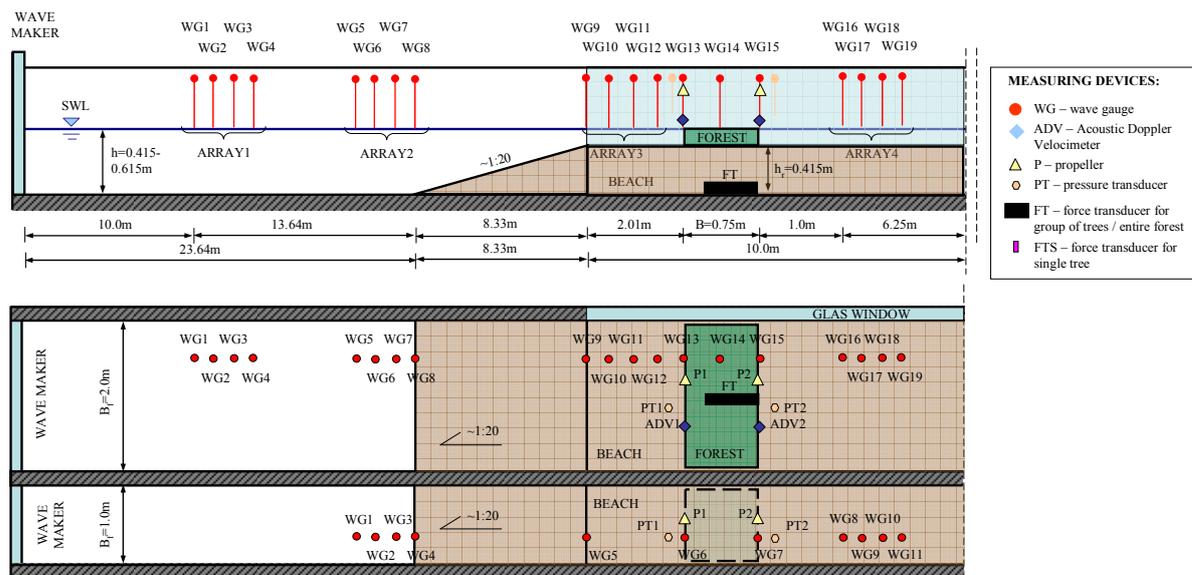


Fig. 5: Experimental set-up in twin-wave flumes of LWI

Storm waves are generated as regular and irregular waves (JONSWAP spectrum) of incident wave heights $H_i=H_{s,i}=0.04-0.20\text{m}$ and incident wave periods $T_i=T_{p,i}=1.0-6.0\text{s}$ at varying water depth $h=0.415-0.615\text{m}$. Tsunami is reproduced under the laboratory conditions as solitary waves of incident heights $H_i=0.04-0.20\text{m}$ at the same water depth conditions as in case of the storm waves, and more realistically – as bores for whose generation a special gate mechanism is required to be constructed. Different forest widths will be examined: $B=0, 0.75, 1.5, 2.25, 3.0\text{m}$.

The instrumentations used in the tests are shown in Figs. 5 and 6. Water free surface elevation, measured by means of wave gauges, will indicate the rate of wave transmission and reflection. Flow velocities measured in front of and behind the forest using propellers and Acoustic Doppler Velocimeter (ADV) will determine, together with the forces exerted on a single tree/ group of trees, the drag and inertia coefficients.

4. OUTLOOK

The experiments on the attenuation performance of both mangroves and pine trees for tsunami/storm waves will be continued by implementing more detailed and systematic investigations, including Particle Image Velocimetry (PIV) technique for visualization of the flow through the forest. Procedure of bore generation will be developed after construction of the required gates in both wave flumes. On the basis of the laboratory data, semi-empirical formulae allowing to predict wave attenuation for the given forest parameters and wave conditions will be derived and implemented in a numerical model. Both experimental and numerical results will be verified by field measurements for the 2004 Indian Ocean Tsunami, which will be provided by the Thailand partners in the TRIAS project.

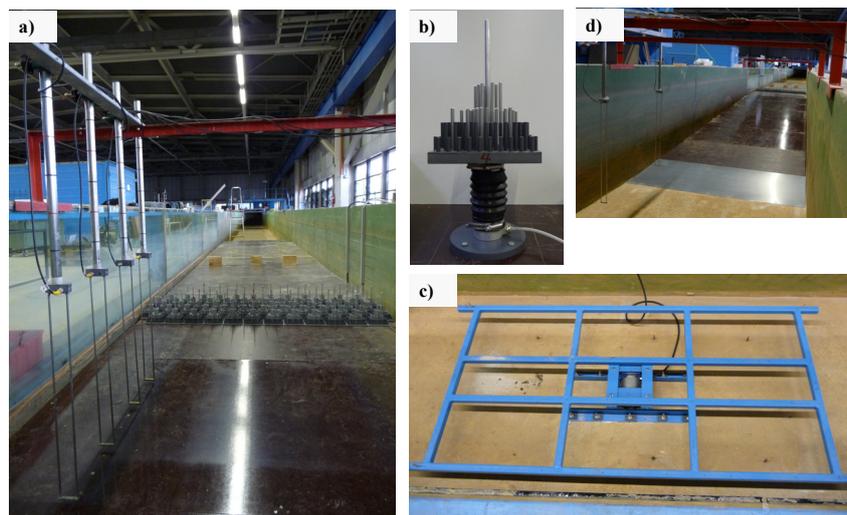


Fig. 6: Model set-up and instrumentations: a) wave gauges, b) force transducer for single tree, c) force transducer for group of trees, d) beach profile

5. LITERATURE

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