

ANALYSIS OF DRAG FORCE CHARACTERISTICS OF REAL TREES WITH THREE DIFFERENT TYPES OF VEGETATION FOR BIOSHIELD IN COAST

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Abstract: This paper presents the experimental investigations on drag force characteristics of vegetation in mitigating the impact of tsunami and other surge effects by the resistance offered to the flow. The experiment was conducted in a laboratory towing tank of 50m x 2m x 2m. Three types of vegetation species used were the trees with small thin broad leaves (Wetakeyya), large broad leaves (Kottamba) and stick type leaves (Kasa). The drag force characteristics of the vegetations mainly depend on the differences in the distribution of foliage, different streamlining mechanism of the leaves against flow, the roughness and the shape of the tree trunk. Drag coefficient of vegetation varies with the flow velocity; the lower flow velocities show higher drag coefficients because of the maximum frontal projected area of the plant.

The drag coefficients for the canopies show higher values for the Reynolds numbers less than 10^6 . For canopies with large broad leaves (Kottamba), it ranges from 0.02 to 0.2. The drag coefficients for small thin broad leaves (Wetakeyya) and stick type leaves (Kasa) range from 0.1 to 1.7 and 0.18 to 0.7. Comparatively the drag coefficient of Wetakeyya is greater than Kottamba and Kasa at larger Reynolds numbers ($Re > 10^6$).

Previous studies on vegetal drag are mainly focused on the single rigid cylinders and colony of rigid cylinders. The studies with single rigid cylinders show an almost linear relationship between drag force and square of the mean velocity of flow. However, the limited studies with natural flexible vegetation show a linear relationship between drag force and mean velocity. Drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder for the region of $Re > 60000$. For this region the drag coefficient for Kasa trunk ranged in between 0.9 to 1.0 while for the smooth PVC pipe it ranged in between 1.2 – 1.4. For Kottamba it was in between 0.8 – 0.9 and for Wetakeyya it was around 0.6.

Keywords: Vegetation, Drag Coefficient, Roughness, Foliation, Towing tank, Tsunami protection

1 Introduction

There are several evidences in favor of coastal vegetation to mitigate tsunami effects. The tree vegetation reduces wave amplitude and energy (Massel et al., 1999). In the case of a coastal forest, energy is progressively absorbed as the tsunami wave passes through it. Once the tsunami comes on shore, the amount of reduction in water depth, velocity, and force depends on how much water is reflected and energy adsorbed by the coastal forest (Keith Forbes, 2007). Without the forest barrier, the

tsunami will run-up to a maximum height determined by the magnitude and nature of the seismic event that created the tsunami.

It is also recorded, based on satellite images that the coastal areas with tree vegetation were markedly less damaged than areas without them (Kandasamy et al. 2005). Shuto (1987) quantitatively estimated the effectiveness of coastal forests against tsunami by statistically analyzing the physical damage suffered by pine trees in Japan. In addition, Hamzah et al. (1999) demonstrated the effects of model mangrove stands against tsunami attack in experiments from the viewpoint of hydraulic resistance, and emphasized that such vegetation provides effective protection against tsunamis. Therefore it is very important to find out the most appropriate species to exert high hydraulic resistance by coastal canopies (Tanaka et al. 2007). This research is conducted to investigate the drag force characteristics of three different species. They are the trees with small thin broad leaves (Wetakeyya - *Pandanus odoratissimus*), large broad leaves (Kottamba - *Terminalia catappa*) and stick type leaves (Kasa - *Casuarina equisetifolia*). Findings of this study will be very useful in future landscape planning in the coastal regions.

The drag force characteristics of the vegetation mainly depend on the frontal area of the leaves. Vogel (1984) suggested that frontal area is the most influential parameter for streamlined objects at high Reynolds numbers as the drag is proportional to the dynamic pressure times the frontal area of the object. Different streamlining mechanism of the leaves can significantly affect hydraulic resistance of flexible plants. For vegetation with constant leaf mass, the product of the drag coefficient and the frontal projected area decreases with increasing velocity (Armanini et al. 2005, Wilson et al. 2008). The leaf area is not an appropriate surrogate measure for the frontal projected area as the frontal projected area depends on both leaf mass and flow velocity (Schoneboom 2008). The frontal projected area of flexible elements reduces with the increasing drag force due to reshaping and streamlining of branches and leaves (Vogel 1994). Distinct contribution of foliage to the total plant drag at different velocities particularly at lower velocities where the foliage is not streamlined and compressed is observed (Wilson 2008). The length and flexural rigidity (EI) of the trunk and the branches also affect the projected area and consequently the streamlining mechanism. The shape of the leaves become important in changing the drag characteristics of the trees. Leaves of different shapes can be classified into small thin and broad leaves, large and broad leaves and stick type leaves.

Experimental studies with single rigid cylinders show an almost linear relationship between drag force and squared mean velocity (Nepf 1999). On the other hand, studies with natural flexible vegetation show an almost linear relationship between drag force and mean velocity (Armanini et al., 2005, Schoneboom, et al. 2008). One reason for the difference of the behaviors of rigid and flexible vegetation is associated with the streaming effects (Schoneboom et al. 2008). Another reason is the difference in the surface roughness of the natural vegetation and the rigid cylinders. The surface roughness plays an important role in the behavior of single cylinders (Xianzhi Lui et al. 2007). Within this range of Reynolds number, drag crisis as a result of the boundary layer of the cylinder surface changes from laminar to turbulent.

In addition, to surface roughness and flexibility, existence of leaves, self oscillations are also needed to be considered (Sina Wunder, 2009). In the arrangement with the rigid cylinders, it is shown that primitive Kármán vortex streets are generated behind the cylinders for small Reynolds numbers ($Re < 10^6$) (Takemura et al. 2006). In the wake behind the living tree, reverse flow was found at further downstream region than the case of a circular cylinder (Ishikawa et al. 2006).

Therefore it is clear that further studies are required to ascertain the similarity of tests with the natural trees and apply the drag coefficient in the natural environment. In this study the previous studies on rigid cylinders are extended to model the natural flexible tree trunks and canopies. Then these results can be scaled up for the natural trees and hence the drag force characteristics of an entire landscaping unit can be predicted.

2 Objectives and Methodology

The main objective is to investigate drag force characteristics of three different types of trees and to find out the potential to protect the coastal region against tsunami natural disasters

The following methodology was used:

1. Testing the model samples of trees in the towing tank in a range of higher Reynolds numbers (Reynolds number = Ud/ν ; where, U is the mean velocity of carriage fixed with sample, d is the characteristics length obtained as square root of total wetted area of the sample and ν is the kinetic viscosity of water). Then obtain the variation of the drag coefficient with Re Numbers ($10^5 - 6 \times 10^6$)
2. Scale up the results to obtain the drag force characteristics of the trees.

3 Experimental set up

The experiments were conducted in the laboratory towing tank of 50m x 2m x 2m. Experiment 1 was conducted to investigate the effect of leaf mass (leaves density in a projected plane) and shape of leaves on drag force characteristics. Three samples (Table 1) from each species were tested while changing the velocities from 0.25 m/s to 2.5 m/s in 0.25 m/s intervals. The tests were repeated for the same canopies without leaves in order to estimate the influence of the foliage. For analyzing the effect of leaves, β is defined as the ratio between total drag force and drag force by only branches without leaves (Takenaka et al, 2010).

Table 1; Sample characteristics of the canopies used in Experiment 1

The specie	Leave area	Branch area	Frontal projected leave area	Frontal projected branch area	Projected leave area /projected branch area
Kottamba	4.70	0.163	1.569	0.052	30.2
Wetakeyya	3.38	0.132	0.135	0.042	3.2
Kasa	1.23	0.553	0.205	0.176	1.2

The experiment 2 was to investigate the effect of surface roughness of tree trunks on the drag coefficient at Reynolds numbers range from 10^4 to 2×10^5 . Three trunk samples of species (Table 2) were investigated at the velocities from 0.25 m/s to 2.5 m/s in 0.25 m/s intervals.

Table 2; Sample characteristics of trunks and PVC pipe used in Experiment 2

The specie	Trunk diameter	Surface condition
Kottamba	0.106	Rough surface
Wetakeyya	0.050	Emergent roughness lines in lateral direction in smooth surface
Kasa	0.063	Cracks and trenches available in longitudinal direction in rough surface
PVC Pipe	0.075	Smooth surface

The methodology of calculation is based on study of Linder (1982) and Pasche (1984). Basis for their calculation system is the formula for drag force of an element inside a stream;

$$W_D = 0.5 C_D \rho V_m^2 A_{veg}$$

Where W_D = drag force, V_m = averaged flow velocity; A_{veg} = projected vegetation area, C_D = drag coefficient of the element, ρ = fluid density.

Figure 1 shows the experimental set up for the measurement of drag forces of the samples. A load cell is attached at P2. Both P2 and P3 are smoothly pivoted to minimize the friction. The axial force through P2 is shown in a digital gauge (Aikoh RX IT/CB – N) attached to the load cell. By taking moments around the pivot at P3, P1 (actual drag force acting on the sample) can be calculated using the following equation;

$$P1 \times (L1 + L2) = P2 \times L1$$

Where, L1 is the distance between two pivots and L2 is the distance from P2 to the centre of area of the leaves.

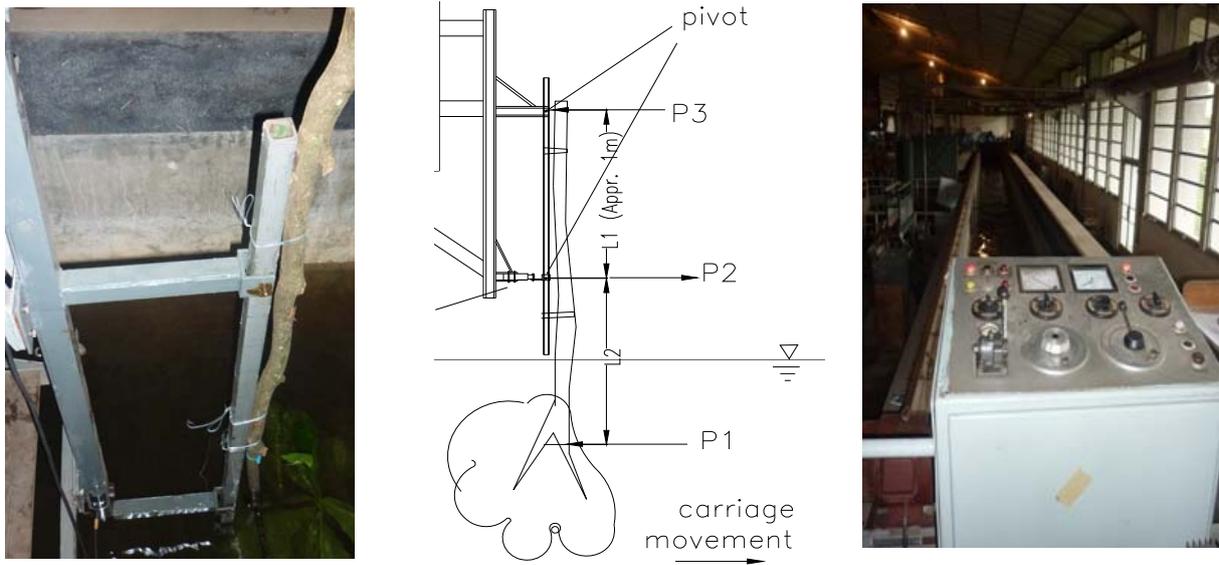


Figure 1; Experimental set up for the estimation of drag force

4 Results and Discussion

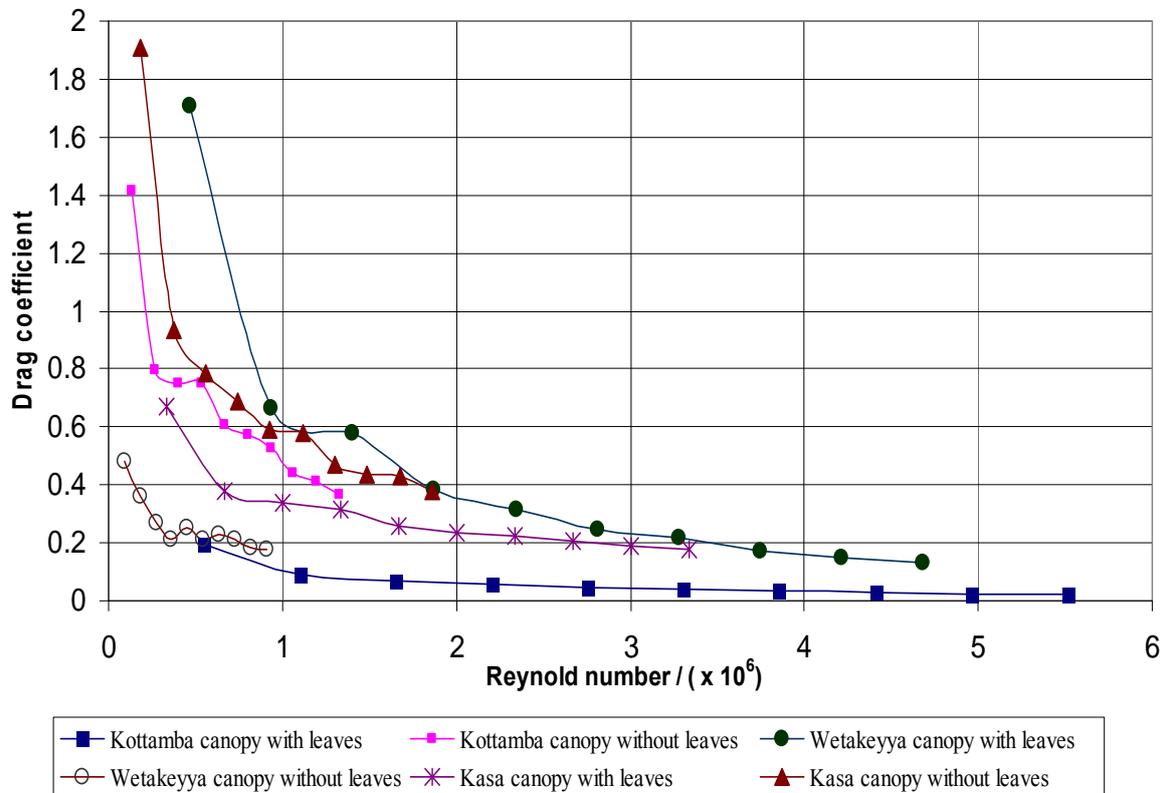


Figure 2; Variation of drag coefficient with Reynolds number for Kottamba, Wetakeyya and Kasa Canopies

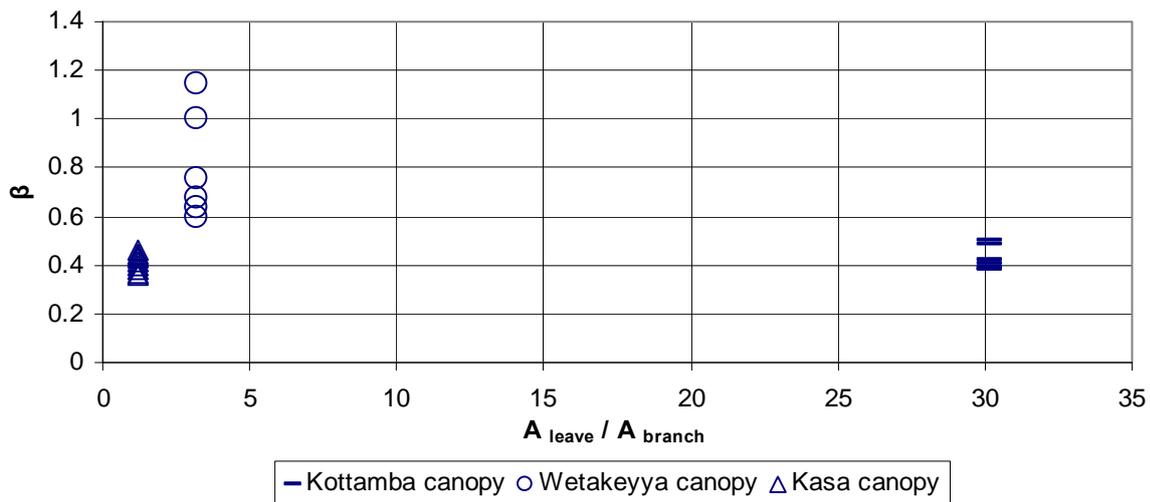


Figure 3; Relationship between β and $A_{\text{leaves}}/A_{\text{branches}}$ where β is defined as the ratio between total Drag force and drag force by only branches, A_{leaves} or A_{branch} is the projected area of leaves or branch, respectively.

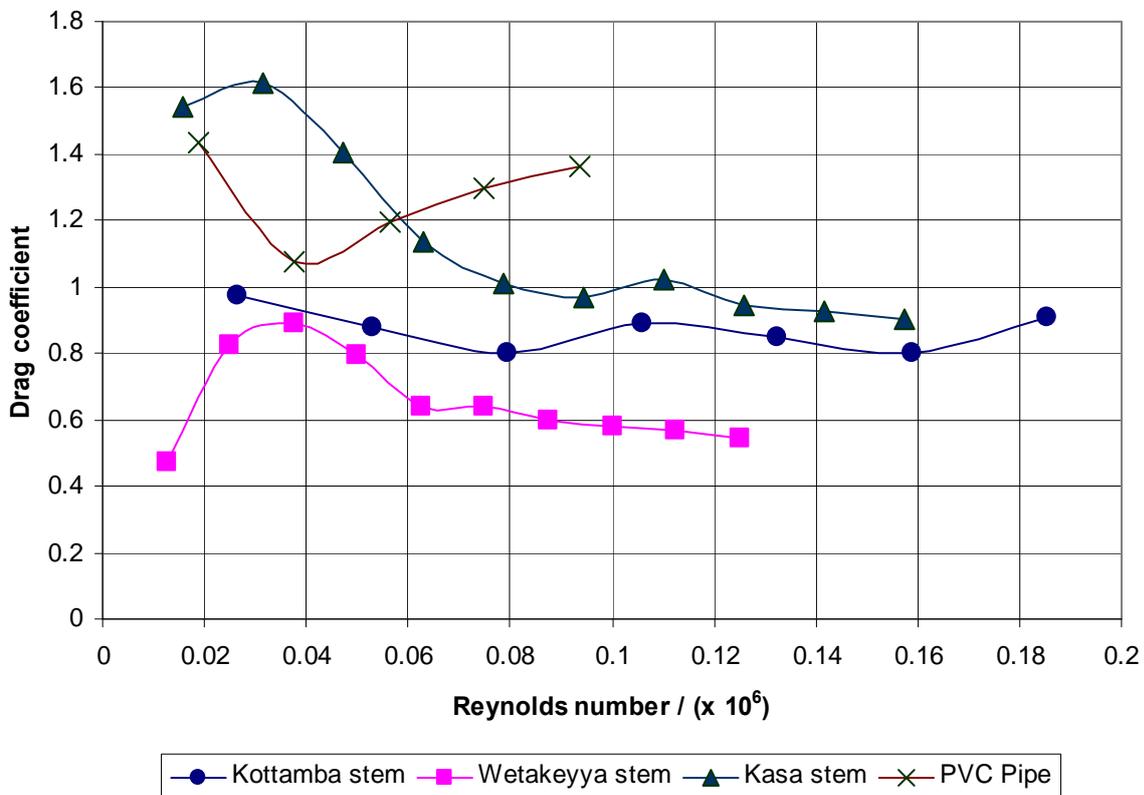


Figure 4; Variation of drag coefficient with Reynolds number for Kottamba, Wetakeyya and Kasa trunks

Figure 2 shows the experimental results obtained for the samples from Kottamba, Wetakeyya and Kasa canopies tested in towing tank. The drag coefficient of Kottamba canopies is less than 0.2, but the Kottamba canopies without leaves have higher drag coefficients. This shows the effect of foliation in drag force characteristics of vegetation. Due to the wide leaves of Kottamba and the consequent increment in the frontal projected area has reduced the drag coefficient of Kottamba canopies.

For lower Reynolds numbers ($Re < 10^6$) only Wetakeyya and Kasa show higher drag coefficients ($C_D > 0.3$). But for higher Reynolds numbers ($Re > 10^6$), both are having lower drag coefficients ($C_D < 0.2$). For Wetakeyya canopies C_D is greater than 0.2 up to the value of Reynolds number 3.5×10^6 . But for

Kasa C_D is greater than 0.2 only up to the value of Reynolds number 2.5×10^6 .

Figure 3 shows the relationship between β (ratio of drag force of canopy with leaves to the drag force of canopy without leaves) and ratio of frontal area of canopy with leaves to the frontal area of branch without leaves. It has been found that the value of β decreases with increasing Reynolds number.

Figure 4 shows the results obtained from the experiment 2. For low Reynolds numbers ($20,000 < Re < 60,000$) Kasa trunk had the highest drag coefficient than other types and the PVC pipe as well. But for the region of Reynolds number $> 60,000$, drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder. For the greater Reynolds numbers than 60,000 the drag coefficient for Kasa trunk ranged in between 0.9 to 1.0 while for the smooth PVC pipe it ranged in between 1.2 – 1.4. For Kottamba it was in between 0.8 – 0.9 and for Wetakeyya it was around 0.6.

5 Conclusions

The drag coefficients of canopies mainly depend on the type, shape size of the leaves and the way they are fixed with the trunk. These factors affect the frontal projected area and consequently the drag coefficient. The value of β (ratio of drag force of canopy with leaves to the drag force of canopy without leaves) shows less than 1 for whole Re range investigated. This shows that the effect of foliation on drag coefficient of canopies. Kottamba and Kasa canopies without leaves have greater values for the drag coefficients than with leaves. Comparatively, Wetakeyya canopies have higher drag coefficient than Kottamba and Kasa, because Wetakeyya leaves are naturally streamlined and they have minimum frontal projected area than Kasa and Kottamba. Drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder for the region of $Re > 60000$. This studies show the effect of surface roughness condition on the drag coefficient of tree trunks.

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