IDENTIFICATION OF TSUNAMI WAVE ENERGY DAMPING PROCESS BY COASTAL VEGETATION BELT AT LABORATORY SCALE MODEL EXPERIMENT

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A laboratory scale model experiment was carried out to investigate the composition of reflected, damped and transmitted energy of tsunami by vegetation belt. A single solitary wave model was generated in the flume to simulate tsunami. The model variables include width of belt in the direction of incoming wave, tree height, volume of tree per volume unit of belt, wave height, wave length, and initial water depth in front of vegetation belt. Three non-dimensional variables were introduced to analyze the experiment results, i.e. hydraulic height of tree, hydraulic width of vegetation belt (B_L) and hydraulic density of vegetation belt (ε). The results shows that coefficient of energy reflection increases along with the increase of ($\varepsilon.B_L$), however the effect of ($\varepsilon.B_L$) is not too significant. Coefficient of energy transmission decreases along with the increase of ($\varepsilon.B_L$), where the effect of ($\varepsilon.B_L$) is very significant. Oppositely, the energy damping coefficient increases along with the increase of ($\varepsilon.B_L$).

Key Words: *tsunami energy damping, coastal vegetation, laboratory scale model*

1. INTRODUCTION

Many researchers have concluded that typical sets of coastal vegetation belt can reduce tsunami wave energy however field investigations have also found that many coastal vegetation belts were damaged by tsunami. Shuto (1987), Harada & Kawata (2004), Tanaka et al. (2007), Kerr and Baird (2007), Yanagisawa et al. (2008), and Tanaka and Iimura (2009). In order to understand the mechanism of vegetation belts damage due to tsunami forces, information on the portion of wave energy that works onto vegetation belts are necessary. The present research was carried out to understand the composition of reflected, damped and transmitted energy of tsunami flow through typical sets of vegetation belt at laboratory scale model experiment. Understanding on this composition will help better determination of the optimum sets of vegetation belt that stand against tsunami and effectively reduce tsunami energy.

2. DESCRIPTION OF THE STUDY

A laboratory scale model experiment (length scale of 1:50) was carried out to investigate the composition of reflected, dissipated and transmitted energy of tsunami flow by vegetation belt.

(1) Vegetation and wave model setup

Rhyzopora apiculata species was modeled in the present experiment. The dimension proportion of vegetation model was made in reference to the typical dimension prototype of 4 to 5 years old Rhyzopora apiculata observed in Java Island. **Fig.1** shows the sketch of this prototype.

Dimension of tree's faculties sketched in **Fig.1** as well as its respective model dimension by the model scale of $n_H=n_L=50$ are tabulated in **Table 1**. Only root, trunk and branches parts of the tree were modeled in the present experiment by using cylindrical wire. In this regard, the elasticity of vegetation was not modeled and it is assumed that vegetation will not collapse against waves.

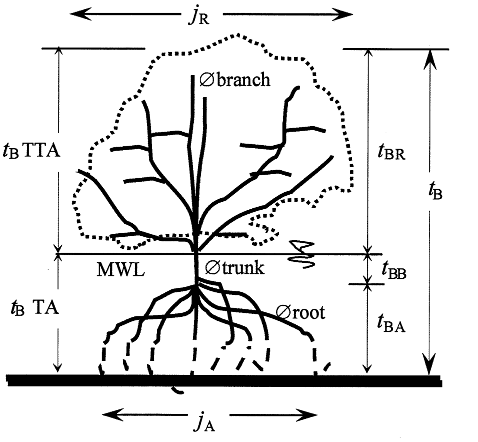

Fig.1 Sketch of 4-5 years old *Rhyzopora apiculata* prototype on which the model was developed (not scaled).

Table 1 Dimension of prototypes tree's faculties and their respective model dimension (n_H=n_L=50)

Tree faculties	Prototype (averaged assumed)	Model
t_B	5 m	10.0 cm
t_{BR}	2/3 t_B	6.5 cm
t_{BA}	1/4 t_B	2.5 cm
t_{BB}	$t_B - (t_{BR} + t_{BA})$	1.0 cm
j_R	3 cm	3.4 cm
j_A	1.9 cm	3.4 cm
∅ branch	5 cm	0.1 cm
∅ trunk	12 cm	0.6 cm
∅ root	5 cm	0.1cm

In reference to the previous researches conclusion on the significant variables affecting tsunami attenuation by vegetation belt, e.g. Shuto (1987), Harada & Kawata (2004), Tanaka et al. (2007), the main variables of vegetation belt selected in the present experiment include width of belt in the direction of incoming wave (B), tree height (t_B), and the volume of tree per volume unit of belt (K). Four variations of forest composition were set in terms of B ($B1$ and $B2$) and K ($K1$ and $K2$) combination, where $K1$ is 2cm and $K2$ is 4cm tree distance, while $B1$ is 100cm and $B2$ is 50cm forest width. **Fig.2** shows the model composition of $K1$ and $K2$.

A single solitary wave model was generated to simulate tsunami-like wave flow toward vegetation belt model. The variables of wave model include wave height (H), wave length (L), and initial water depth in front of vegetation belt (d). The reflection, damping, and transmission performances were analyzed by using wave height data recorded at six locations. **Fig.3** shows the setup of vegetation model in the flume, including the positions of wave height-meter gauges.

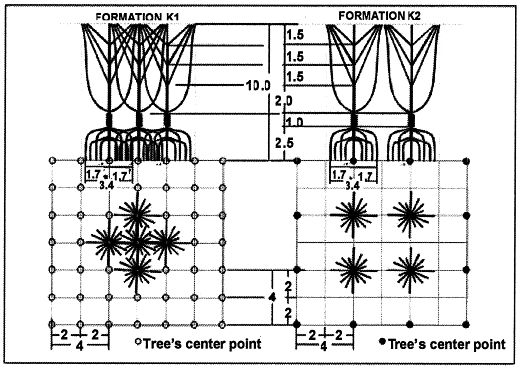

Fig.2 Model tree composition $K1$ (left) and $K2$ (right) in the experiment which determine the volume of tree per volume unit of belt (Utomo et al., 2003)

(2) Analysis method

Three non-dimensional variables are introduced to analyze the experiment results, *i.e.* hydraulic height of tree (δ), hydraulic width of vegetation belt (B_L) and hydraulic density of vegetation belt (ε). Here, $\delta = (d+H)/t_B$ and $B_L = B/L$, whereas $\varepsilon = f(K,\delta)$ was determined in advanced for combination values of K and δ. Here, K is summed area of vertical projection of all tree faculties. The experiment result is provided in the form of energy reflection (KE_R), damping (KE_L) and transmission (KE_T) coefficients in terms of ($\varepsilon.B_L$). Combination of ($\varepsilon.B_L$) was selected as the control variable since it gives the highest value of statistical determinant coefficient (r^2) comparing to other combinations of variables. The effect of B_L as a control variable on KE_R, KE_L and KE_T coefficients was also check to understand the effectiveness of vegetation belt width in reducing tsunami wave energy in terms of tsunami wave length.

The coefficients of wave height reflection (K_R) and transmission (K_T) by a hydraulic structure are referred to Horikawa (1978)

$$K_R = \frac{H_R}{H_I} \quad \text{and} \quad K_T = \frac{H_T}{H_I} \qquad (1)$$

where H_R is reflected wave height, H_T is transmitted wave height and H_I is incident wave height. Here, $0 \leq K_R \leq 1$ and $0 \leq K_T \leq 1$.

In the context of energy damping formulation, the coefficients of wave energy reflection (KE_R) and transmission (KE_T) follows

$$KE_R = \frac{E_R}{E_I} \quad \text{and} \quad KE_T = \frac{E_T}{E_I} \qquad (2)$$

where E_R is reflected wave energy, E_T is transmitted wave energy and E_I is incident wave energy. Here, $0 \leq E_R \leq 1$ and $0 \leq E_T \leq 1$.

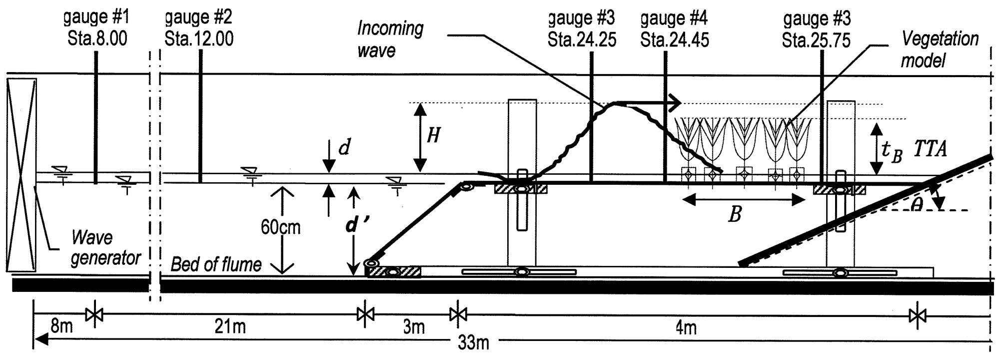

Fig.3 Setup of model and wave height-meter in the flume; H= tsunami wave height, t_B TTA= height of non-wetted mangrove part, d'= total depth of water in the flume, d= depth of water at the beach of mangrove area, B= width of mangrove area, *gauge*= wave height-meter. (not scaled).

Following the energy conservation law, the dissipated energy, here is named as KE_L, also follows $0 \leq KE_L \leq 1$, and we get the following relation,

$$KE_R + KE_T + KE_L = 1 \qquad (3)$$

Assuming that the experimental waves are close to the solitary wave form, two-dimensional theoretical solitary wave profile (η) and energy (E) approximation according to Dean and Dalrymple (1984) is written as follows,

$$\eta = H \operatorname{sech}^2 \left[\sqrt{\frac{3H}{4d^3}}\, x \right] \qquad (4)$$

$$E \approx \rho_w g d^3 \left(\frac{4H}{3d} \right)^{3/2} \qquad (5)$$

where E is total force energy per unit width of wave crest (concentrated about the wave crest), H is wave amplitude or wave height, g is gravity acceleration, ρ_w is water mass density and d water depth.

By substituting Eq.(5) into Eq.(2), the correlation between KE_R and K_R and between KE_T and K_T is obtained, i.e.

$$KE_R = \frac{E_R}{E_I} = \frac{\rho_w g d^3 (4H_R/3d)^{3/2}}{\rho_w g d^3 (4H_I/3d)^{3/2}} = \frac{H_R^{3/2}}{H_I^{3/2}} = K_R^{3/2} \qquad (6)$$

$$KE_T = \frac{E_T}{E_I} = \frac{\rho_w g d^3 (4H_T/3d)^{3/2}}{\rho_w g d^3 (4H_I/3d)^{3/2}} = \frac{H_T^{3/2}}{H_I^{3/2}} = K_T^{3/2} \qquad (7)$$

By substituting Eq.(6) and Eq.(7) into Eq.(3) the following correlation is obtained

$$K_R^{3/2} + K_T^{3/2} + KE_L = 1 \qquad (8)$$

3. EXPERIMENT RESULTS

Figure 4(a) shows the correlation between hydraulic density (ε) and coefficient of energy dissipation (KE_L), which was calculated according to the Eq.(8). Although the trend of energy dissipation increases along with the ε, but the correlation is not really clear. Further, correlation between hydraulic width, B_L, and KE_L is shown in **Fig.4(b)**. It is seen that the correlation between B_L and KE_L gives relatively clearer trend.

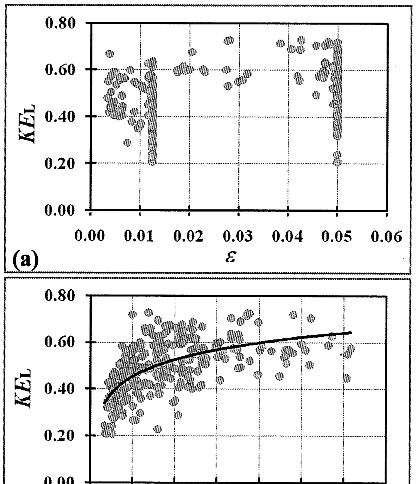

Fig.4 Plot of coefficient of energy dissipation (KE_L) in term of, respectively: a) hydraulic density (ε); b) hydraulic width (B_L) and c) product of ($\varepsilon.B_L$)

It may be said therefore that the value of coefficient of energy dissipation is more sensitive to the change of B_L rather than to the change of ε. In **Fig.4(c)**, the KE_L is plotted in term of $\varepsilon.B_L$ and it is seen that $\varepsilon.B_L$ shows better correlation with KE_L in comparison to the ε or B_L alone.

Figure 5 shows trend of change of energy dissipation coefficient (KE_L) in terms of hydraulic depth, $\delta = (d+H)/t_B$. In all model cases, the rate of energy dissipation decrease with the increase of hydraulic depth. The model cases (its combination is written within attached bracket) are named as RFM11 (K1, B1), RFM12 (K1, B2), RFM21 (K2, B1) and RFM22 (K2, B2).

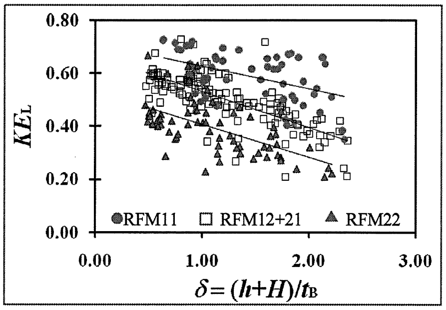

Fig.5 Trend of change of energy dissipation coefficient (KE_L) in terms of hydraulic depth, $\delta = (d+H)/t_B$ for all model cases run in the experiment.

Finally, **Fig.6** shows plots of coefficient of energy reflection (KE_R), energy transmission (KE_T) and energy dissipation (KE_L), each respectively in terms of $\varepsilon.B_L$. As shown in **Fig.6(a), coefficient** of energy reflection (KE_R) increases along with the increase of ($\varepsilon.B_L$), however the effect of ($\varepsilon.B_L$) on KE_R is not too significant as shown by the low slope of the curve, especially for the high value of ($\varepsilon.B_L$). **Fig.6(b)** shows that the effect of change of ($\varepsilon.B_L$) is very significant on the change of KE_T. Coefficient of energy transmission (KE_T) decreases along with the increase of ($\varepsilon.B_L$). This phenomenon is related to the significancy effect of ($\varepsilon.B_L$) on the change of KE_L, which also significantly increases along with the increase of ($\varepsilon.B_L$) as shown in **Fig.6(c).**

4. CONCLUSIONS

This laboratory experiment results shows the composition of reflected, dissipated and transmitted energy of tsunami flow by vegetation belt with no consideration on the elasticity of vegetation model and under assumption that vegetation will not collapse against waves.

Under the present model experiment's conditions, it is known that tsunami energy reduction by reflection process are less than 30%, while by dissipation process may reach 60% depends on the combination of forest density, forest width, tree height and wave height, which are combined in the variable of $\varepsilon.B_L$.

This experiment result needs further verification in relation with the actual vegetation elasticity and threshold capacity against tsunami force.

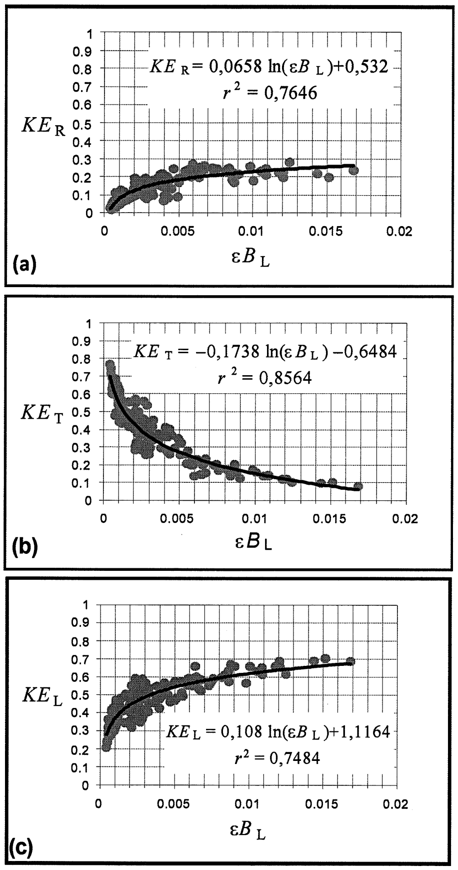

Fig.6 Plot of a) energy reflection (KE_R), b) transmission (KE_T) and (c) dissipation (KE_L) coefficients in terms of ($\varepsilon.B_L$); Here, $\varepsilon = f(K,\delta)$ where $\delta = (d+H)/t_B$ and $B_L = B/L$.

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