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Effect of river vegetation with timber piling on ship wave attenuation: Investigation by field survey and numerical modeling

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ABSTRACT

The objective of this study is to investigate the effects of river vegetation and timber piling on the attenuation of ship-generated waves that cause erosion at river bank. A numerical model based on two-dimensional Boussinesq-type equations was developed to predict the ship wave prorogation through river vegetation and timber piling. The model was validated with the field data and found that the model can reproduce well the field data when the disturbances from tides and winds were minimal. The numerical model was then used to simulate ship wave propagation through a belt of river vegetation consist of *Rhizophora apiculata,* a dominant type of mangroves planted in the Ca Mau River in the south Vietnam, and a timber piling. A 200 m long timber piling, parallel to the river bank, at 10 m from the bank reduced 51% and 89% of run-up height and wave force at the bank, respectively. If the timber piling combined with 20 m width of the vegetation the run-up height and wave force were reduced further 61% and 95%, respectively.

1. Introduction

Ship-generated waves (ship waves) have been researched for a long time in both theoretical and practical aspects with different aims. Since the middle of the nineteenth century, many scientists and engineers had studied about waves generated by ships (Rankine, 1868; Froude, 1877; Kelvin, 1887a, 1887b). After that, Havelock (1908), Johnson (1958), Sorensen (1969), Kofoed-Hansen et al. (1999), and Whittaker et al. (2001) developed ship wave theory and also conducted model experiments to validate their theories. A number of scientists have been using Boussinesq-type models for simulating ship waves in shallow water. Tanimoto et al. (2000) developed a simulation method to calculate ship waves in shallow water and studied ship waves in a channel restricted by vertical walls. Dam et al. (2006) investigated the transformation of ship waves on sloping bottom by a Boussinesq model and suggested that the refraction on slope is similar to the ordinary wind waves have. Dam et al. (2008) discussed the effect of Froude number on the characteristics of ship waves in a narrow channel restricted by vertical walls, based on observed data and the results computed by a two-dimensional model in which wave breaking was considered.

Ship waves, depending mainly on their energy possessed, have been recognized as a threat to the environment. Kirkegaard et al. (1998) reported that a large number of vessels moving at high speed caused a danger to recreational use of beaches. Regarding environmental aspects, Nakase et al. (1999) concluded that the ship waves have a great impact on the activities in aquaculture. By using Michell's thin-ship theory, Dong et al. (2009) studied the impact of ship waves on marine structures and pointed out that the forces induced by ship waves are an important factor contributing to the damage to coastal structures and offshore structures as well.

Both aquatic vegetation and timber piling have been shown to be effective in minimizing wave energy. Coops et al. (1996) conducted an experiment to investigate wave forces that affected by bank slope and water depth, and that interfered with the emerged vegetation as well. Their results showed that the waves transmitted through the vegetation lose energy due to the resistance offered by the vegetation and bottom surface. Although a 4 m wide-band of vegetation can be regarded as a

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strip, wave height measurements in did show wave attenuation to occur. Roo and Troch (2010) evaluated reduction in the force by ship waves through the off-bank timber piling along the river Lys (Zulte, Belgium) by field observation data. They showed that a single row of off-bank piling cannot reduce the height of the primary wave system but only 20% reduction in the secondary wave system. Based on field data of river-bank erosion caused by boat-generated waves, Nanson et al. (1994) reported that the major threshold in erosive energy of ship waves is associated with the peak waves. Very recently, Trung et al. (2015), based on the field investigation in the Ca Mau River, Vietnam, pointed out that two types of vegetation *Rhizophora apiculata* (*R. apiculata*) and *Nypa fruticans* (*N. fruticans*) are able to dissipate wave energy and therefore have a high potential for riverbank protection. They found further that *R. apiculata* is more effective than *N. fruticans* in wave height reduction, although its porosity is greater. It is evident that those studies have been based mainly on field surveys and/or experimental studies. There is lack of numerical modeling studies which may help explore this problem at prototype scale.

In this paper, the effect of river vegetation and timber pilling on the reduction of ship wave-generated run-up height and force on the bank of the Ca Mau River was analyzed by a new numerical model. The numerical model was based on two-dimensional Boussinesq equations (Dam et al., 2006), but was developed to simulate the wave run-up on the bank, with the resistance by vegetation and timber piling. Field surveys were conducted in a section of the Ca Mau River to measure the characteristics of ship waves (water surface fluctuation, current velocity, and run-up on the bank) for different ship speeds and those were used to validate the model. The numerical model then was applied to another section of the Ca Mau River where river vegetation and timber piling have been employed to minimize the bank erosion caused by ship waves.

2. Numerical method

2.1. Governing equations

The new numerical model (Eqs. (1)–(3)) to simulate ship wave run-up through vegetation was based on Boussinesq-type equations (Madsen and Sørensen, 1992; Dam et al., 2006). The coordinate system O_{xy} such that the origin O lies on the immobilized water-plane and the x-axis points in the direction of ship's forward motion while the y-axis perpendicular to the bank. The moving ship boundary (Chen and Sharma, 1995; Tanimoto et al., 2000; Dam et al., 2006, 2008) was used. The governing equations are written as:

$$b\frac{\partial\eta}{\partial t}+\frac{\partial Q_x}{\partial x}+\frac{\partial Q_y}{\partial y}=0 \qquad (1)$$

$$\frac{\partial Q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_x{}^2}{d}\right)+\frac{\partial}{\partial y}\left(\frac{Q_xQ_y}{d}\right)+gd\frac{\partial\eta}{\partial x}-R_{bx}+\frac{\rho g n^2}{\rho d^{7/3}}Q_x\sqrt{Q_x{}^2+Q_y{}^2}+\frac{F_x}{\rho} \qquad (2)$$

$$=\left(\beta+\frac{1}{3}\right)h^2\left(\frac{\partial^3 Q_x}{\partial t\partial x^2}+\frac{\partial^3 Q_y}{\partial t\partial x\partial y}\right)+h\frac{\partial h}{\partial y}\left(\frac{1}{6}\frac{\partial^2 Q_y}{\partial t\partial x}\right)$$

$$+\beta g h^2\left\{\frac{\partial h}{\partial x}\left(2\frac{\partial^2\eta}{\partial x^2}+\frac{\partial^2\eta}{\partial y^2}\right)+\frac{\partial h}{\partial y}\frac{\partial^2\eta}{\partial x\partial y}\right\}+\beta g h^3\left(\frac{\partial^3\eta}{\partial x^3}+\frac{\partial^3\eta}{\partial x\partial y^2}\right)$$

$$+h\frac{\partial h}{\partial x}\left(\frac{1}{3}\frac{\partial^2 Q_x}{\partial t\partial x}+\frac{1}{6}\frac{\partial^2 Q_y}{\partial t\partial y}\right)$$

$$\frac{\partial Q_y}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_xQ_y}{d}\right)+\frac{\partial}{\partial y}\left(\frac{Q_y{}^2}{d}\right)+gd\frac{\partial\eta}{\partial y}-R_{by}+\frac{\rho g n^2}{\rho d^{7/3}}Q_y\sqrt{Q_x{}^2+Q_y{}^2}+\frac{F_y}{\rho} \qquad (3)$$

$$=\left(\beta+\frac{1}{3}\right)h^2\left(\frac{\partial^3 Q_x}{\partial t\partial x\partial y}+\frac{\partial^3 Q_y}{\partial t\partial y^2}\right)+h\frac{\partial h}{\partial x}\left(\frac{1}{6}\frac{\partial^2 Q_x}{\partial t\partial y}\right)$$

$$+\beta g h^2\left\{\frac{\partial h}{\partial y}\left(\frac{\partial^2\eta}{\partial x^2}+2\frac{\partial^2\eta}{\partial y^2}\right)+\frac{\partial h}{\partial x}\frac{\partial^2\eta}{\partial x\partial y}\right\}+\beta g h^3\left(\frac{\partial^3\eta}{\partial x^2\partial y}+\frac{\partial^3\eta}{\partial y^3}\right)$$

$$+h\frac{\partial h}{\partial y}\left(\frac{1}{6}\frac{\partial^2 Q_x}{\partial t\partial x}+\frac{1}{3}\frac{\partial^2 Q_y}{\partial t\partial y}\right)$$

where η (x, y, t) is the water surface elevation, Q_x (x, y, t) and Q_y (x, y, t) the depth-integrated velocity components in x and y directions, respectively, t the time, h (x, y) the still water depth, g the gravitational acceleration, β the correction factor of the dispersion term (β=1/15), $d(x,y,t)$ the total water depth (d=η+h), and $b(x,y,t)$ the slot width parameter which was described in detail in the Section 2.2. R_{bx} and R_{by} are the eddy viscosity terms (Kennedy et al., 2000; Dam et al., 2006) as:

$$R_{bx}=\frac{\partial}{\partial x}\left(\nu\frac{\partial Qx}{\partial x}\right)+\frac{1}{2}\left[\frac{\partial}{\partial y}\left(\nu\frac{\partial Qx}{\partial y}\right)+\frac{\partial}{\partial y}\left(\nu\frac{\partial Qy}{\partial x}\right)\right] \qquad (4)$$

$$R_{by}=\frac{\partial}{\partial y}\left(\nu\frac{\partial Qy}{\partial y}\right)+\frac{1}{2}\left[\frac{\partial}{\partial x}\left(\nu\frac{\partial Qx}{\partial y}\right)+\frac{\partial}{\partial x}\left(\nu\frac{\partial Qy}{\partial x}\right)\right] \qquad (5)$$

Where ν is the kinematic viscosity.

F_x, F_y the drag resistance due to the presence of vegetation in x and y directions, respectively. F_x, F_y are written as:

$$F_x=\frac{1}{2}\gamma C_{D-all}b_{ref}d\frac{Q_x\sqrt{Q_x^2+Q_y^2}}{d} \qquad (6)$$

$$F_y=\frac{1}{2}\gamma C_{D-all}b_{ref}d\frac{Q_y\sqrt{Q_x^2+Q_y^2}}{d} \qquad (7)$$

where, γ is the tree density (number of trees/m^2), and C_{D-all} the depth-averaged equivalent drag coefficient considering the vertical stand structure of tree, which was defined by Tanaka et al. (2007) as:

$$C_{D-all}(d)=C_{D-ref}\frac{1}{d}\int\alpha(z_G)\beta(z_G)dz_G \qquad (8)$$

$$\alpha(z_G)=\frac{b(z_G)}{b_{ref}} \qquad (9)$$

$$\beta(z_G)=\frac{C_D(z_G)}{C_{D-ref}} \qquad (10)$$

where $b(z_G)$ and $C_D(z_G)$ are the projected width (diameter) on a vertical plane perpendicular to flow direction and drag coefficient of a tree at the height z_G from the ground surface, respectively, and b_{ref} and C_{D-ref} are the reference projected width at z_G=1.2 m and reference drag coefficient of the trunk (=1.0), respectively.

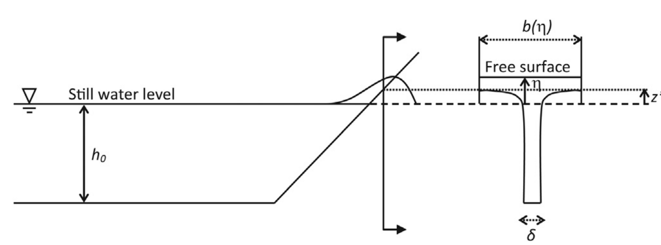

Fig. 1. A schematic view of a channel with the presence of a narrow slot (modified from Kennedy et al., 2000).