MORPHOLOGICAL CHANGE IN BEACH CUSP FORMATION

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1. INTRODUCTION

Beach cusps can be described as alongshore sequences of crescentic shapes developing in the swash zone. An individual beach cusp is characterized by two raised horns, protruding in the offshore direction, separated by a more gently sloping bay. Beach cusps presence has puzzled scientists for decades. This longshore pattern probably the most visually obvious and intriguing of the nearshore patterns, have also been the subject of the greatest controversy concerning many different approaches. Recently, there are two methods have been used to approach beach cusp research, edge wave theory and self-organization theory. Most of research based on edge wave theory is a laboratory experiment or field observation while self-organization theory is a numerical simulation based on "cellular automata rules" (Coco and Murray, 2007). In this present study, we attempt to use numerical simulation based on established differential equations representing conservation momentum. We use nonlinear wave equation for describing hydrodynamic model and applying sediment transport model.

2. NUMERICAL MODEL

A 2DH finite difference Boussinesq model coupled with sediment transport modeling was used to simulate the pattern formation processes. Boussinesq equation is the non-linear amplitude wave theory, which can be used to analyze the variations of wave height in surf zone. This equation allows accurate modeling of surface waves from intermediate depth to shallow water. Numerical model in this study was carried out using FUNWAVE 1.0, a code developed by The Center for Applied Coastal Research, University of Delaware. The sediment transport model is based on Grant and Madsen (1979) formulae as described by Ontowirjo et al. (2005) with some improvement for this present study.

2.1. Hydrodynamic model

Boussinesq equation is the non-linear amplitude wave theory which used to analyze the variations of wave height and current in surf zone. The conservation of mass is defined as

$$\eta_t + \nabla\cdot\left[(h+\eta)\left[u_\alpha + \left(z_\alpha + \frac{1}{2}(h-\eta)\right)\nabla\left(\nabla\cdot\left(hu_\alpha\right)\right)\right] + \left(\frac{z_\alpha^{\,2}}{2} - \frac{1}{6}\left(h^2 - h\eta + \eta^2\right)\nabla\left[\nabla\cdot(u)hu\right]\right)\right] = 0 \tag{1}$$

where η is the surface elevation, h is the still water depth, u_α is the horizontal velocity vector at the water depth $z = z_\alpha = -0.531h$ and subscript t is the partial derivative with respect to time. The governing equation is expressed at reference depth as a dependent variable. The conservation of momentum is

$$u_t + (u\cdot\nabla)u + g\nabla\eta + V_1 + V_2 + V_3 - F_{br} - F_m + F_b = 0 \tag{2}$$

where terms V for dispersive and F_{br}, F_m, and F_b are for wave breaking, lateral momentum fixing and bottom friction.

2.2. Sediment transport model

Bed load sediment transport in nearshore zone area is very complex because of wave and current interaction. Tanaka and Thu (1994) proposed a simple formula for calculating the instantaneous bottom shear stress under waves and current crossing at an arbitrary angle. The shear stress is approximated using the following formula

$$\tau_{\max} = \rho\frac{\left[f_c + 2\sqrt{f_c\beta f_w}\cos\phi + \beta f_w\right]}{2}|u_w|u_w \tag{3}$$

where ρ is water density and u_w is wave velocity, f_{cw} is the friction factor. Current friction factor, f_c , is given in Eq. (4) and wave friction factor, f_w , is given in Eq. (5). β is a coefficient given in Eq. (5) and ϕ is the angle between waves and current.

$$f_c = \frac{2\kappa^2}{\left\{\ln\left(z_h/z_0\right)-1\right\}^2}\left(\frac{u_c}{u_w}\right)^2 \tag{4}$$

$$f_w = \exp\left\{-7.53 + 8.07\left(\frac{u_w}{\sigma z_0}\right)^{-0.100}\right\} \tag{5}$$

$$\beta = \frac{1}{0.769\left[\dfrac{1}{\ln\left(z_h/z_0\right)-1}\dfrac{|u_c|}{|u_w|}\right]^{0.83}+1}\left\{1 + 0.863\alpha\exp(-1.43\alpha)\left(\frac{2\phi}{\pi}\right)^2\right\} \tag{6}$$

with z_0 is roughness height, z_h is total depth of flow, and κ is Karman constant (=0.4). Sediment transport formula by Grant and Madsen (1979) is

$$q = w_0 d\,12.5\left(\frac{\tau}{\rho Sgd}\right)^3 \tag{7}$$

Where w_0 is settling velocity, d is mean grain size, and S is relatives density. Bed deformation is approximated by this following

$$\frac{\partial h}{\partial t} = -\frac{1}{(1-n)}\left(\frac{\partial q_{bx}}{\partial x} + \frac{\partial q_{by}}{\partial y}\right) \tag{8}$$

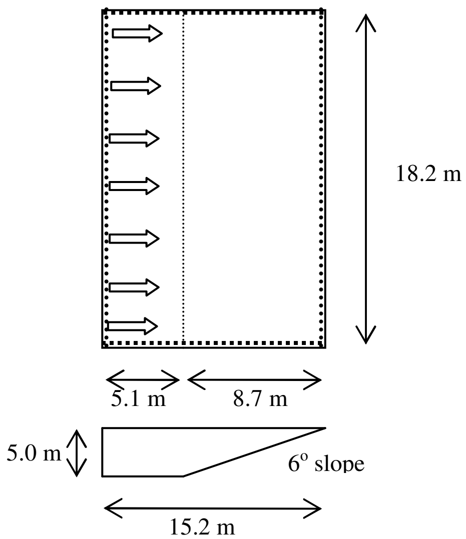

Figure 1. Basin in laboratory experiment

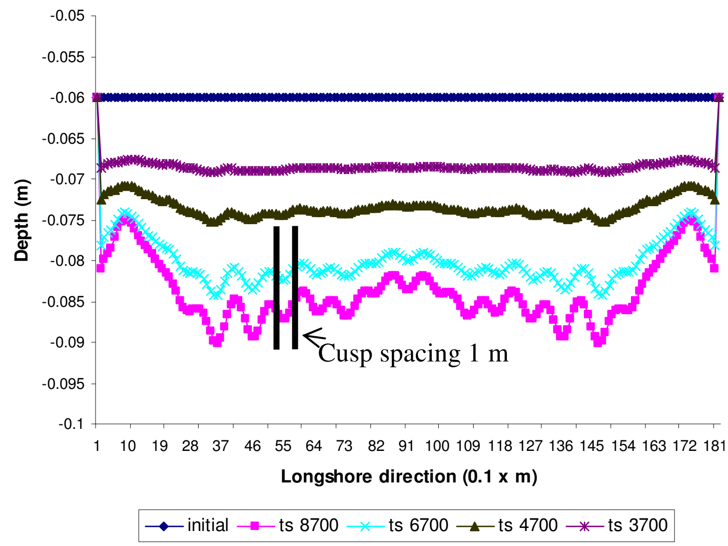

Figure 2. Beach cusp formation in longshore direction. Initial formation (solid line), simulation formation(solid-dot line)

3. LABORATORY EXPERIMENT

A laboratory experiment of beach cusp and edge wave is use to validate numerical model. An experiment by Guza and Inman (1975) was conducted in the 15.2 m x 18.2 m (Figure 1.) wave basin at the Hydraulics Laboratory at Scripps Institution of Oceanography. The beach was a concrete variable sloping section extending from the shoreline end of the basin for 8.7 m, the depth being constant 5.1 m between the toe of the beach and the plunger-type wave maker. The sides of basin were lined with wave absorbers. Edge waves excitation was studied by sending normally incident low-amplitude waves onto the beach. The synchronous edge waves with wave period 2.7 second and wave amplitude 2.5 cm was formed small cusps spaced about 1 m apart.

4. RESULT AND DISCUSSION

Figure 2 show us morphodynamic change from early simulation until beach cusp pattern arise. Horizontal axis is in longshore direction (in meter x 0.1) while vertical axis is depth. Each graph shows one longshore intersection. Solid line is initial contour line before simulation and solid-dot line is after simulation. There is an interesting process when beach cusp begins to form. In time step 3700 before beach cusp form in swash zone, the crescentic form is forms in submerged surfzone area. This crescentic formation is form into a submerged longshore sandbar. When a sandbar forms, there will be a non-uniformity of breaking pattern, pressure gradient, and these processes will form a circulation current pattern in the nearshore (Kurniadi and Tanaka, 2007). At time step 6700 the erosion and deposition occur in the straight shoreline, and later at time step 8700 we get the beach cusp pattern with average spacing 1 m (Figure 2.).

5. CONCLUSION

Guza and Inman experiment has stressed that beach cusps is response to normally incident, strongly reflected, incident waves. A numerical computation based on conservation of momentum coupled with sediment transport model was applied to simulate laboratory experiment result and show agreement. A rhythmical pattern both in hydrodynamic and morphology is easily from during high energy with shore-parallel wave conditions.

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