EXPERIMENTAL INVESTIGATION ON DYNAMIC EQUILIBRIUM BAY SHAPE

Sutat Weesakul[1] and Somruthai Tasaduak[1]

Equilibrium bay is a bay that its shoreline is stable and does not change with time in long term. This concept can be applied for coastal protection. Experiments on dynamic equilibrium bay planform are conducted in a laboratory. There is one location of sediment supply source into a bay near upcoast headland and its magnitude vary from case to case. Wave obliquity varies from small to moderate values. These are two main parameters while wave condition is kept constant. The final bay planforms are investigated and recorded once they reach equilibrium with condition that sediment transport gradient approaches zero and no further shoreline change are observed. The parabolic equation similar to that for static equilibrium is newly proposed. The coefficients are originally derived and found to be a function of wave obliquity and the ratio of sediment supplied into bay to longshore sediment transport. The new dynamic equilibrium bay equation can be used and applied to study morphology change with variation of supplied sediment from inland.

Keywords: dynamic equilibrium bay, parabolic bay equation

INTRODUCTION

The static equilibrium bays (SEB) is the bay that its shoreline planform does not change with wave action because the longshore sediment transport in the bay is zero. The parabolic equation was proposed by Hsu and Evans (1989) to represent SEB. A number of researches have been conducted to apply SEB for coastal protection. Computer software has consequently been developed by Klein at al. (2003) to simplify the graphic part of bay so that it is a simple tool to be used for coastal engineers. However, there is another type of equilibrium which received less attention due to its complexity of coastal process in bay formation. When sediment is input into a bay such as river then wave/current transports sediment along the bay and finally the sediment transport gradient is equal to zero, this condition is so called dynamic equilibrium bay (DEB). Few researches have been conducted in laboratory to quantify its equilibrium shape and to study transition process prior to equilibrium. The first study was conducted by Tan and Chiew (1993) to investigate the DEB with unlimited sediment supply at upcoast area. The final bay planform for DEB were recorded and investigated. The DEB equation was proposed in parabolic equation and input variable was only wave obliquity. Xiem (2004) and Chatchai (2005) carried out experiments for dynamic bay planform using wave obliquity equals to 20, 30 and 40 degrees. The experimental data were used to determine a particular equation for DEB but not a generalized one due to limited number of wave obliquity. The amount of sediment supply into bay is one of parameter to govern the shape of DEB , beside the wave obliquity. In present study, the experiment in laboratory is set up and conducted to investigate the variation of DEB shape with different sediment supplies at the upcoast headland. The final equilibrium bay planforms are recorded and analyzed. The generalized equations for DEB is studied and proposed in a similar approach to SEB.

METHODOLOGY

The component of sediment budget in a bay is conceptually introduced. Continuity equation for sediment is expressed as

$$\frac{\partial y}{\partial t}+\frac{1}{D}\frac{\partial Q_{bay}}{\partial x}=0 \tag{1}$$

[1] Water Engineering and Management Program, School of Engineering and Technology
Asian Institute of Technology, Thailand

Where y is shoreline position, Q_{bay} is sediment transport rate in a bay and D is closure depth. When bay is in equilibrium, shoreline does not change with time, then $\frac{\partial y}{\partial t} = 0$

Therefore Eq.(1) can be written as $\frac{1}{D}\frac{\partial Q_{bay}}{\partial x} = 0$ (2)

Figure 1 shows sediment budget in a bay in natural condition.

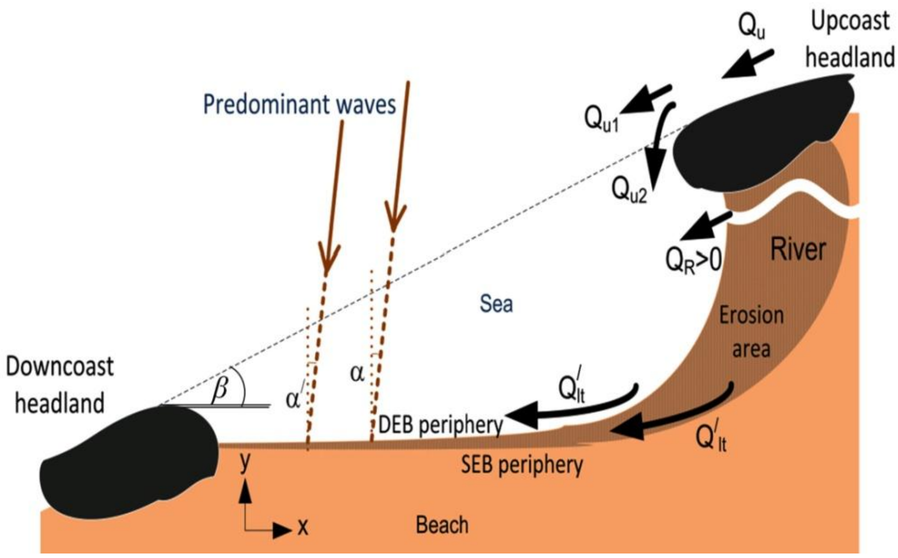


Figure 1. Sediment budget in a bay

Sediment budget in a bay is introduced and can be expressed as follows

$$Q_{bay} = Q_{u2} + Q_R - Q'_{lt} \quad (3)$$

Where Q_{bay} is a sediment available in a bay. There are two sources of sediment supply into bay which are Q_{u2} and Q_R. Q_{u2} is bypassed sediment from upcoast area. The sediment transport in the upcoast headland is represented by Q_2. Part of sediment is transported outside the bay which is Q_{u1} while some of them transport into bay which is Q_{u2}. Q_R is sediment supply from river or inland into a bay and Q'_{lt} is longshore sediment transported by wave and current, so that sediment can be transported outside bays. For static equilibrium case, Q_{bay} equals to zero , there is no sediment supply to bay, it means that Q_{u2} and Q_R equal to zero. Then bay is gradually reshape until $Q_{lt} = 0$ Longshore sediment transport in a bay equals to zero.

For dynamic equilibrium condition, substituting sediment budget in a bay Eq.(3) into Eq.(2), yields

$$\frac{\partial Q_{bay}}{\partial x} = \frac{\partial}{\partial x}(Q_{u2} + Q_R - Q'_{lt}) = 0 \quad (4)$$

In experiment condition, there is no sediment bypass from upcoast area or $Q_{u2} = 0$ and there is only one source of sediment supply in upcoast headland, which is Q_R

Therefore Eq. (5) is expressed as

$$\frac{\partial}{\partial x}(Q_R - Q'_{lt}) = 0 \tag{5}$$

It means that rate of sediment coming into a bay (Q_R) is equal to rate of sediment outgoing from the bay (Q'_{lt}). Q_R can be predetermined as rate of sediment supply in experiment. A nondimensional sediment supply or sediment supply ration is newly introduced as SSR. $SSR = Q_R / Q_{lt}$ where Q_{lt} is potential longshore sediment transport at wave obliquity (β) as shown in Figure 1. Ratio (SSR) is used as a variable in the analysis. In case of large amount of sediment supply and it exceeds the capacity or potential of wave to transport from the bay. Sediment is deposited and form a sand spit as investigated by Vithana et al (2000).

EXPERIMENTAL PROCEDURE

A wave basin as illustrated in Figure 2 is employed to study the chronological development of the bay. The basin is 14 m long, 12 m wide equipped with regular wave generators. The shoreline was set up between two headlands with 2 m distance. The tip of the wave guide serves as the inner tip of the upcoast headland. Sediment supply apparatus are designed to supply sand at hook zone near the upcoast tip similarity to sediment supply from a river. Water depth is constant at 20 cm. The initial slope at the seaward side of the beach is set at 1:4. The wave height is fixed as 4.3 cm and wave period is 2 s. This condition are the same as experiment conducted by Xiem (2004) and Chatchai (2005). Wave obliquity varies from 25 to 45 degrees. Fine sand having the average size d_{50} =0.3 mm is used as beach material. Sediment supply varies between 70 to 475 g/min. The ratios of sediment supply to longshore sediment transport (SSR) are varied from 0.055 to 0.268. The shapes of bays are recorded regularly. It takes at least 45 hours until bay approaches equilibrium while sediment is continuously supplied at constant rate. The image of shoreline are recorded using photograph system mounted in a frame stand 4.4 m high above the ground as shown in Figure 3. The shoreline data should be adjusted and rectified from the recorded photo because the shooting focus point does not align in vertical at all shoreline position. The point A depicted in Figure 3 are then adjusted to be point A'. Figure 4 shows an example of shoreline position before and after adjustment. In addition, the longshore sediment transport rate at wave obliquity (β) can be determined using a procedure proposed by Kamphuis (1991). The sediment is continuously supplied to maintain the initial shoreline position for a fixed wave obliquity . It takes 3 to 4 hours until the shoreline does not change its orientation and sediment rate is measured from a downcoast sand trap. Experiment is repeated 6 times to get the average longshore sediment transport rate (LST) for that wave obliquity. Figure 5 shows the relationship of LST with wave obliquity.

There are 8 experiments conducted in the present study and 10 experiments for small wave angle taken from Xiem (2004) and Chatchai (2005). In total, there are 18 data sets as shown in Table 1.

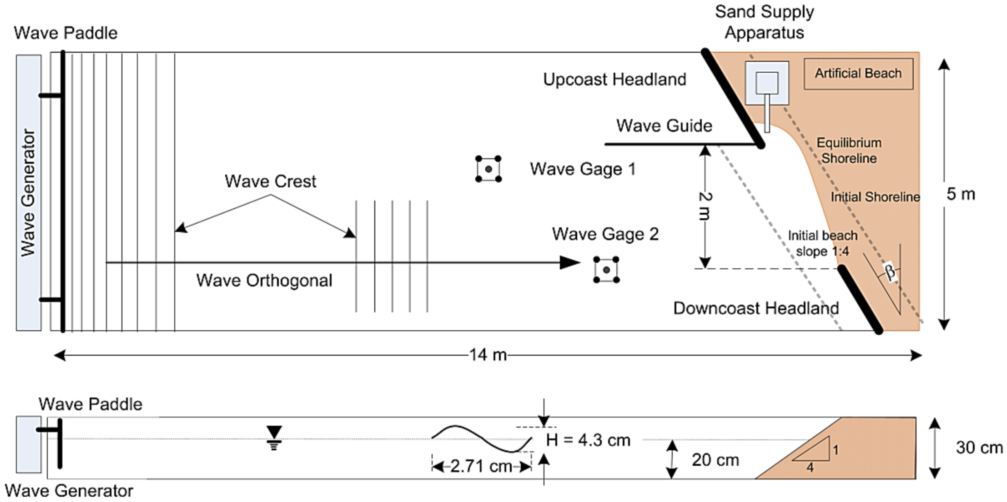


Figure 2. Experimental set up in a wave basin

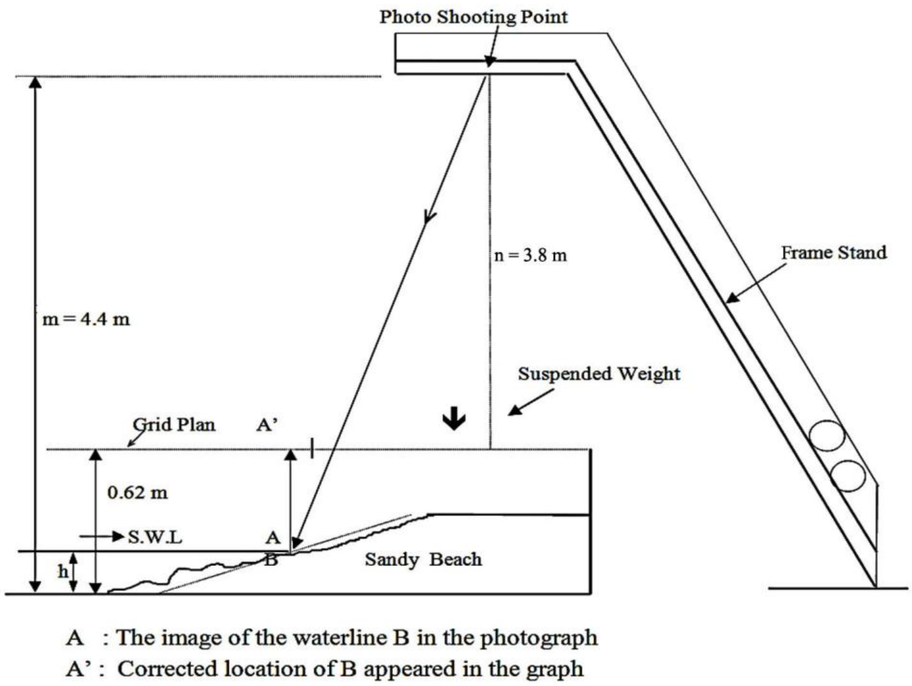


Figure 3. The frame stand used in the data acquisition

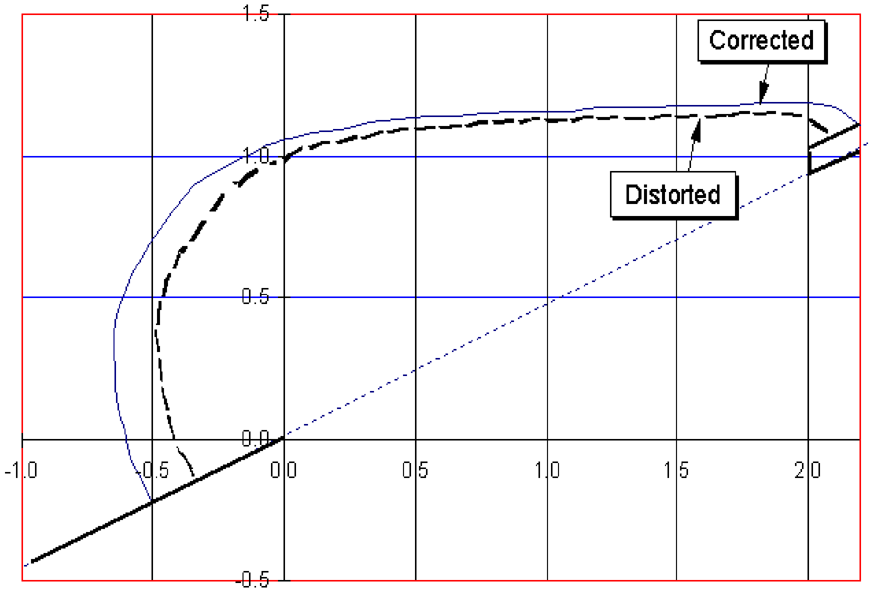


Figure 4. An example of the shoreline image before and after correcting distortion (unit :meter)

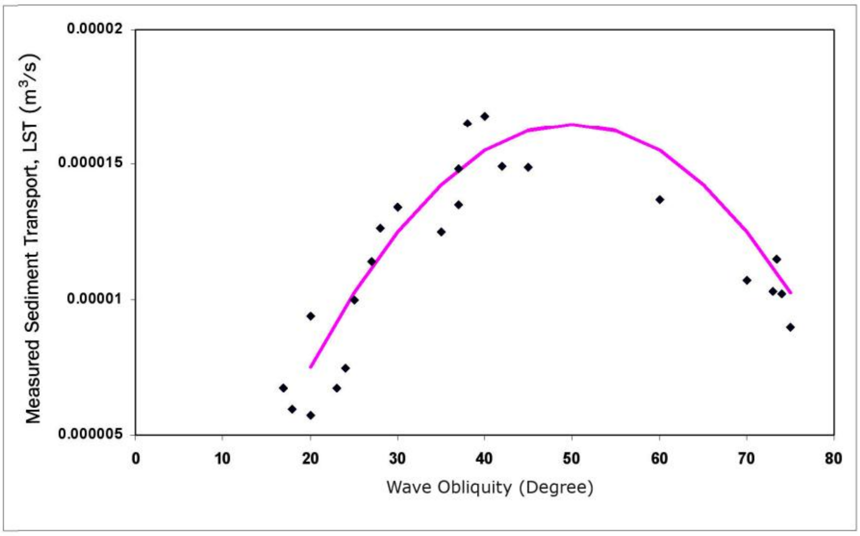


Figure 5. Relationship of measured longshore sediment transport and wave obliquity

Table 1. Summary of experimental data

Wave Obliquity (β)	Sediment Supply Ratio (SSR) Q_R/Q_{tt}	Remark
20	0.067	Chatchai (2005b)
	0.134	
	0.201	
	0.268	
25	0.044	Present study
	0.066	
	0.088	
	0.166	
30	0.031	Xiem (2004)
	0.067	
40	0.069	Chatchai (2005)
	0.113	
	0.169	
	0.206	
45	0.074	Present study
	0.084	
	0.147	
60	0.055	Present study

RESULTS AND DISCUSSIONS

The measured shorelines of bay shape at equilibrium stage are illustrated in Figure 6 and 7 for 30 and 40 degree of wave obliquity. Variables X and Y and nondimensional variable, normalized by R_0. It is clearly shown that the shapes of DEB at different sediment supply rates are not the same. When sediment supply increases, the bay is adjusted itself and become smaller until it finally approaches equilibrium. Comparison between the measured bay in the present study with controlled sediment supply and the other two bay types, i.e., static equilibrium from Hsu and Evan (1989) and dynamic equilibrium with unlimited sediment supply from Tan and Chiew (1994) in Figure 6 and 7, shows that the present bays are in between those two extreme cases of equilibrium. It means that the present dynamic equilibrium bay varies systematically from static to dynamic condition. Figure 8 shows plot of development of shoreline every 5 hours at 20° wave obliquity. At first, shoreline is set as a straight line and waves are generated and propagate to shoreline and bay reaches static equilibrium condition as shown in Figure 8a. Then sediment is started to supply into a bay with SSR equals to 0.067 as illustrated in Figure 8b. The size of DEB is smaller than SEB. Sediment supply is increased to be 0.134, 0.201 and 0.268 respectively. The size of DEB is smaller at the time SSR increases. When wave obliquity increases to be 40°, the bay planform at DEB is changed accordingly as depicted in Figure 9. The equation for generalized DEB can be derived as shown in Eq.(6). The parabolic equation similar to SEB is found to be an appropriated one. The C coefficients are derived and found to be functions of SSR and wave obliquity as shown in Eq. (7). The exponential form in that equation is a good reasonable function because it can explain asymptotic values for both SEB and DEB with unlimited sediment supply. All coefficients will approach that for SEB when SSR equals to zero and vice versa for DEB case.

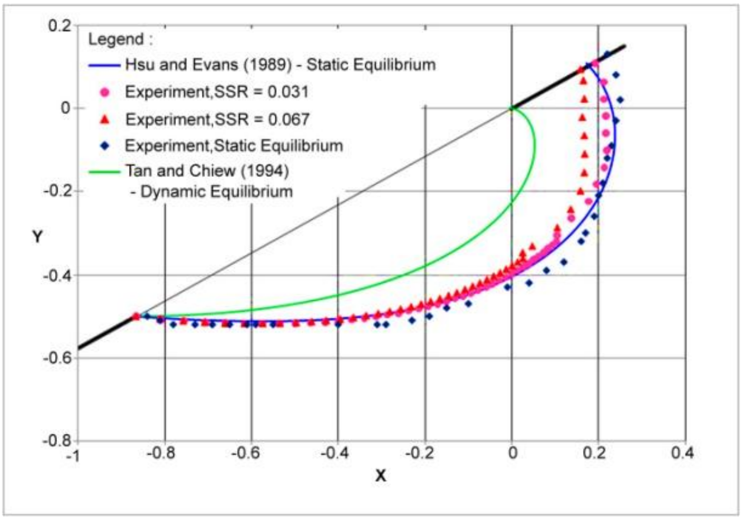


Figure 6. Measured DEB at 30 degree wave obliquity

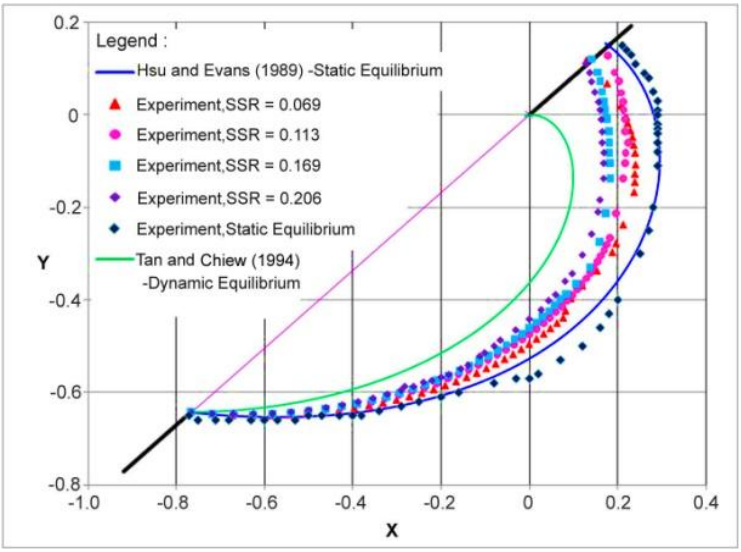
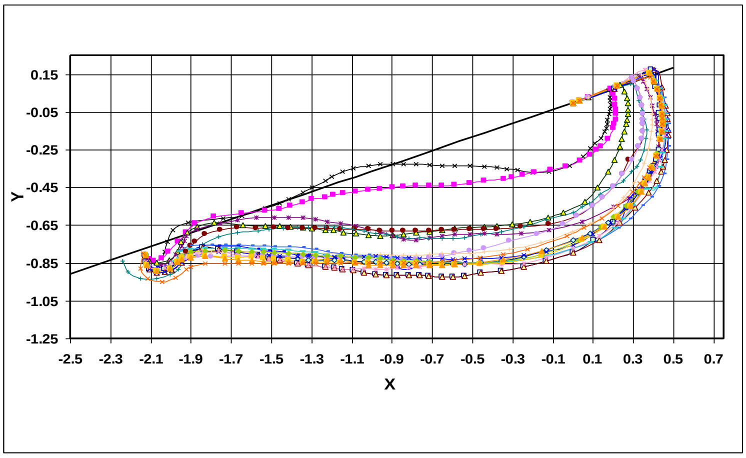
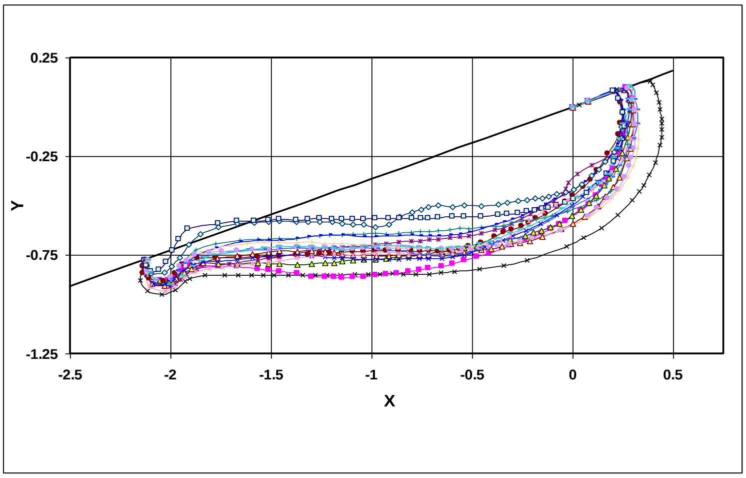


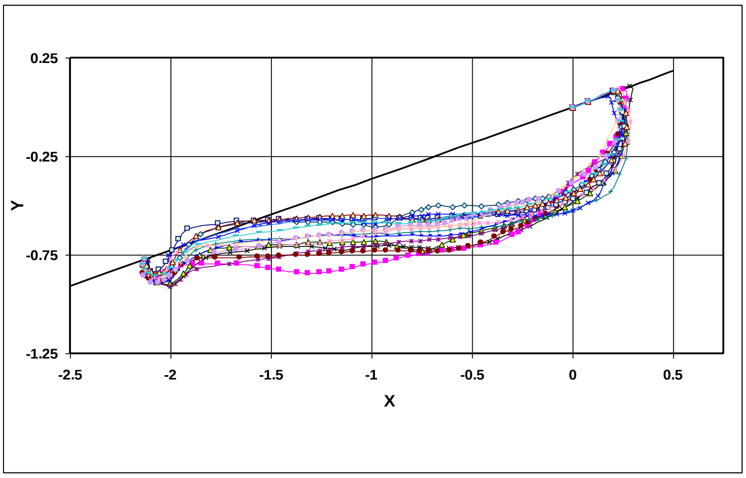
Figure 7. Measured DEB at 40 degree wave obliquity



a) SSR=0

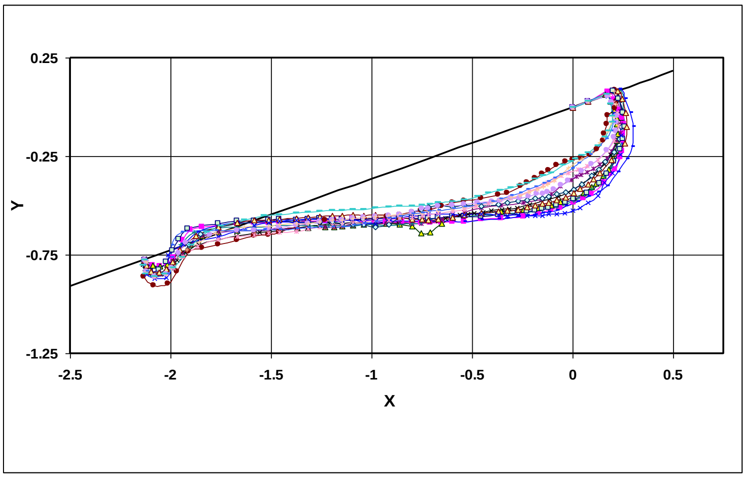


b) SSR=0.067

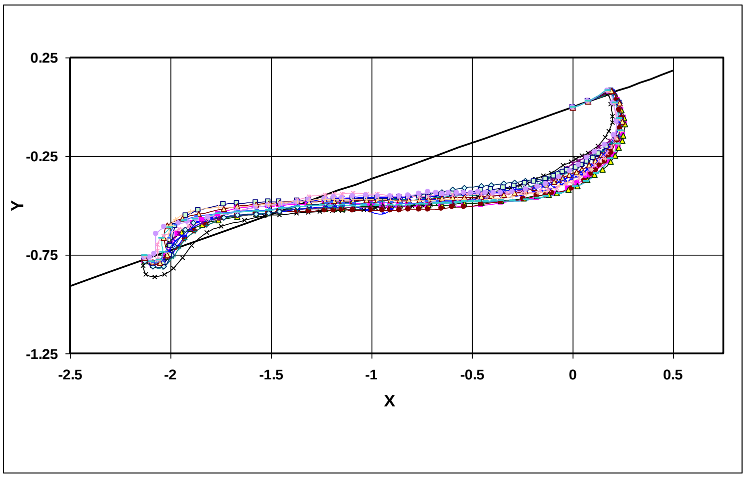


c) SSR= 0.134

Figure 8. Measured shoreline at 20 wave obliquity



d) SSR = 0.201



e) SSR= 0.268

Figure 8. Measured shoreline at 20 wave obliquity (Con't)

$$\frac{R}{R_0} = C_0 + C_1\left[\frac{\beta}{\theta}\right] + C_2\left[\frac{\beta}{\theta}\right]^2 \quad (6)$$

$$C_0 = \left(-0.00062 + 0.00041e^{-4SSR}\right)\beta^2 + \left(0.0338 - 0.024e^{-3.6SSR}\right)\beta + \left(-0.7154 + 0.6572e^{-4.4SSR}\right) \quad \text{… (7a)}$$

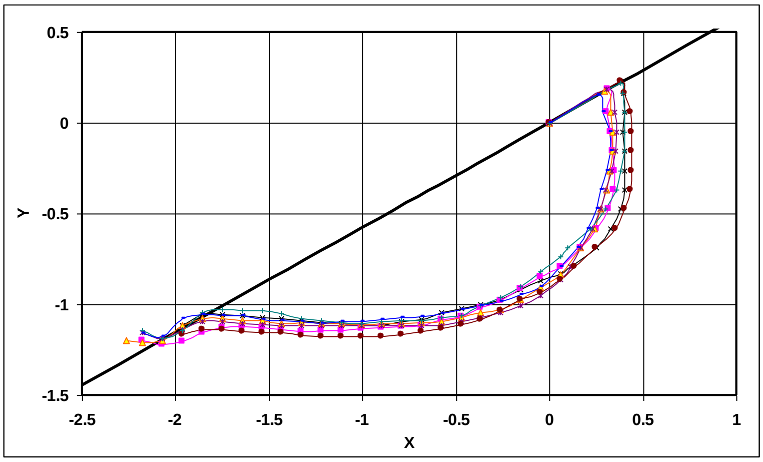
$$C_1 = \left(0.0014 - 0.0012e^{-7.5SSR}\right)\beta^2 + \left(-0.0703 + 0.0759e^{-8SSR}\right)\beta + \left(2.4895 - 1.7015e^{-7.5SSR}\right) \quad \text{… (7b)}$$

$$C_2 = \left(-0.00072 + 0.000704e^{-12SSR}\right)\beta^2 + \left(0.032 - 0.048e^{-15SSR}\right)\beta + \left(-0.6227 + 0.904e^{-15SSR}\right) \quad \text{…(7c)}$$

Where SSR is sediment supply ratio (Q_s/Q_{lt}) and β is wave obliquity

A series of C coefficients C_0, C_1 and C_2 are illustrated in Figure 10,11 and 12. It shows that all values are systematically and uniformly changed between coefficients of SEB from Hsu and Evan

(1980) and DEB with unlimited sediment supply from Tan and Chiew (1994). Comparison plot of DEB with variation of SSR is shown in Figure 13.



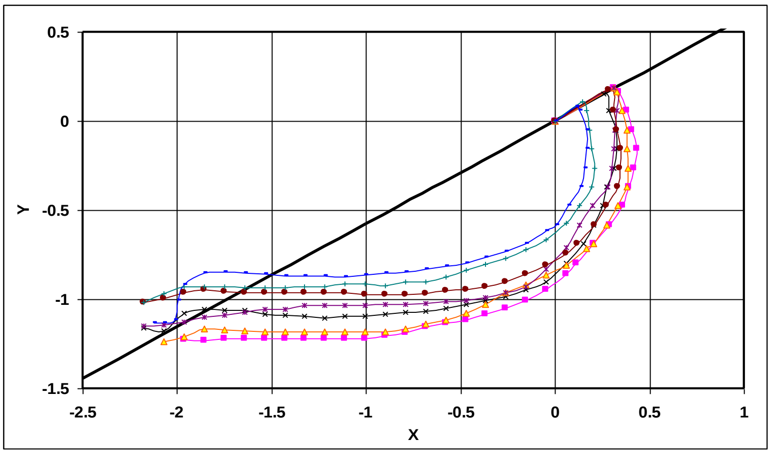


Figure 9. Development of dynamic equilibrium bay for 40 degree wave obliquity with sediment supply ratio = 0.103 and 0.229

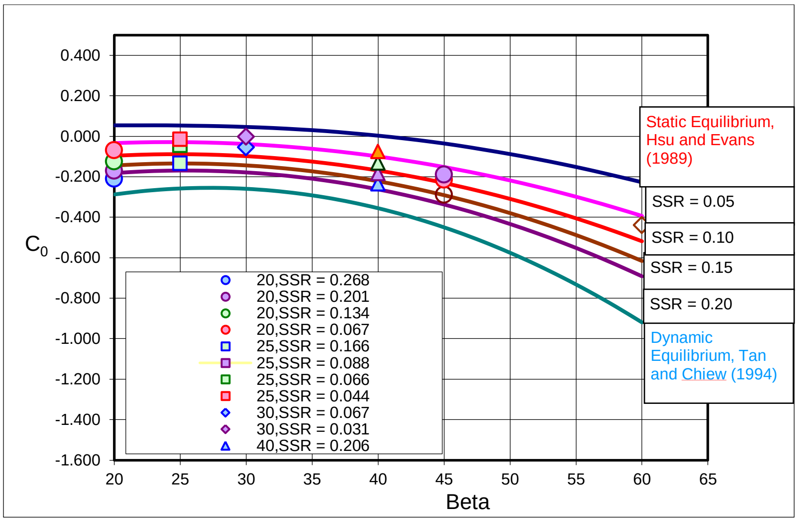


Figure 10. Proposed C_0 coefficient for dynamic equilibrium bay shape

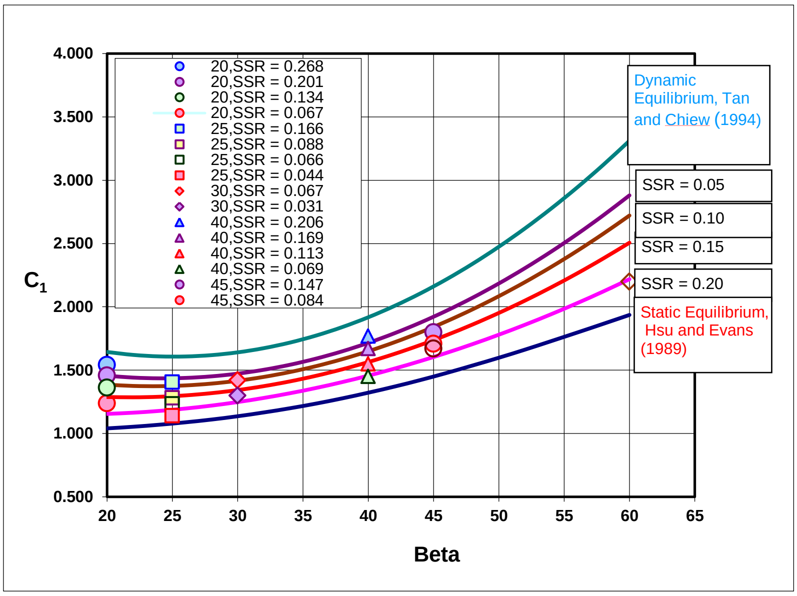


Figure 11. Proposed C_1 coefficient for dynamic equilibrium bay shape

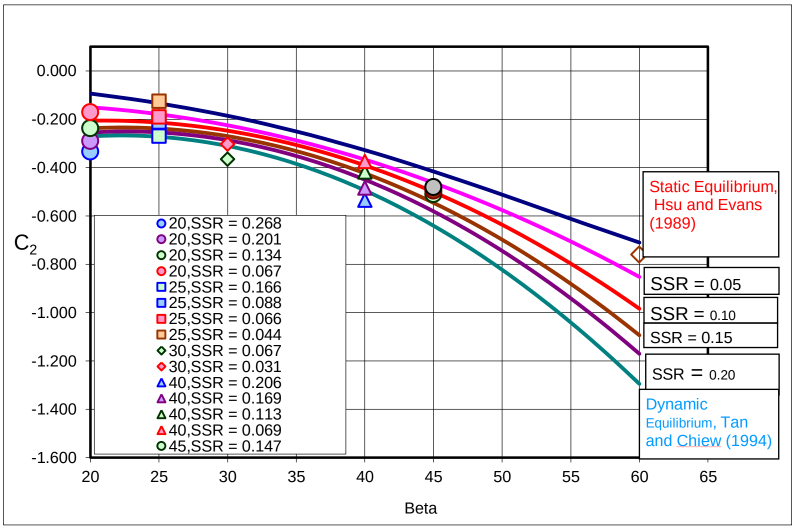
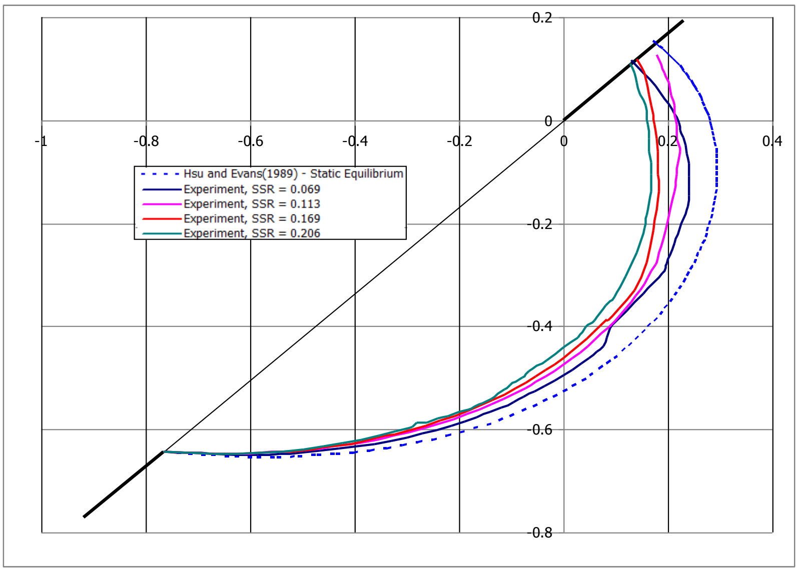
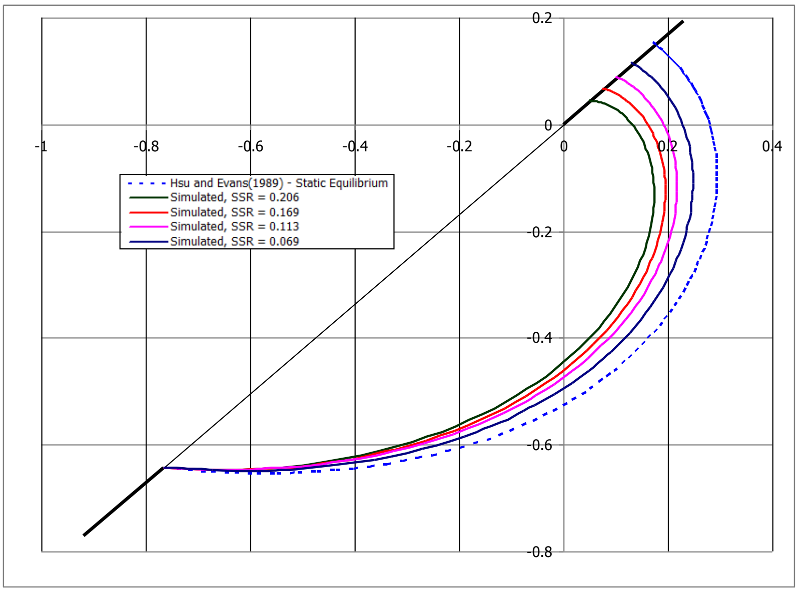


Figure 12. Proposed C_2 coefficient for dynamic equilibrium bay shape



a) Non-dimensional experiment results



b) Simulated of non-dimensional dynamic equilibrium

Figure 13. Non-dimensional dynamic equilibrium of 40 degree wave angle for various sediment supply ratio

CONCLUSIONS

The experiment of DEB with variation of sediment supply at upcoast headland is successfully conducted in the laboratory. The result shows that bays develop uniformly and systematically when sediment supplies increase. The data of final bay planform is obtained and used to derive the generalized parabolic equation of DEB. The coefficients in equation are newly proposed in an exponential function which can be applied for both SEB and DEB cases.

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