การกัดเซาะชายฝั่งบริเวณเขื่อนกันทรายและคลื่น
COASTAL EROSION IN THE VICINITY OF A BREAKWATER

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บทคัดย่อ

บริเวณชายฝั่งรอบเขื่อนกั้นทรายและคลื่น เขื่อนแรกในประเทศไทยที่จังหวัดเพชรบุรี ได้เปลี่ยนแปลงไปในระยะเวลา 24 ปีหลังจากก่อสร้างเสร็จใน พ.ศ. 2511 จากข้อมูลภาพถ่ายทางอากาศ พ.ศ. 2523, 2534 และแผนที่ร่องน้ำจากกรมเจ้าท่าในปี พ.ศ. 2535 พบว่าบริเวณทิศใต้ของเขื่อนมีการทับถมยื่นไปในทะเลประมาณ 420 เมตร และด้านทิศเหนือมีการกัดเซาะเข้ามาในชายฝั่ง 88 เมตร ในการศึกษานี้ได้พัฒนาแบบจำลองคณิตศาสตร์แบบ “one line” คำนวณการเปลี่ยนแปลงชายฝั่งในอนาคต 50 ปี โดยปรับเทียบตัวแปรในการจำลองกับข้อมูลชายฝั่ง จากการสำรวจพบว่าด้านทิศเหนือจะมีการทับถมเป็นระยะทาง 580 เมตร และกัดเซาะ 116 เมตร ส่วนทิศใต้ต้องใช้เวลากว่า 100 ปี ทรายจะทับถมตลอดความยาว 1,200 เมตรของเขื่อน การกัดเซาะชายฝั่งมีค่าน้อยแต่ยังมีผลในระยะยาว เพราะในบริเวณที่กัดเซาะมีศักยภาพที่จะพัฒนาเป็นพื้นที่ท่องเที่ยวได้ ดังนั้นควรมีการป้องกันและบรรเทาปัญหาในอนาคตด้วยวิธีการที่เหมาะสมต่อไป

ABSTRACT

Coastal erosion was studied at the first breakwater in Thailand 24 years after completion. Sand deposited at upcoast area of breakwater while erosion was found at downcoast area. Aerial photographs in 1980, 1991 and available field survery map in 1992 were used to compute rate of shoreline deposition and recession. Maximum erosion distance was -88 m while deposited distance in upcoast area is 420 m. Mathematical model so called “one line” was developed to predict the shape of shoreline in next 50 years. It was found that maximum deposited distance is 580 m and erosional distance at downcoast area is 116 m. It would take more than 100 years to have sand deposition for the whole length of a breakwater which is 1,200 m. The erosion in the vicinity of breakwater is not severe but the lost area having good potential to develop for recreation beach. Coastal protection should be studied and carried out in more detail.

INTRODUCTION

The first breakwater in Thailand located at Cha-am Beach, Phetchaburi province. Thailand. were constructed by a Cement factory in 1968. There are two parallel breakwaters 1,200 m long functioning as training jetties at a mouth of dredged canal in order to prevent siltation. Canal is used as a waterway for vessel to transport cement product to Bangkok, capital of Thailand. At present the need for such transport is reduced due to improved highway. Fig. 1 illustrates location of study area. The recreational beaches in the vicinity of this breakwater are visually observed and found that sand deposit at the upcoast area or in south direction of breakwater occurs. Thia phenomena has advantage and make beach face wider. However, on the opposite side, there is erosion at the downcoast area or in north direction of breakwater. The recreational beach is lost to the sea. The existing of breakwater is the main cause of coastal phenomena. The amount and shape of shoreline suffered from coastal erosion will be studied quantitatively.

DATA ANALYSIS

After 24 years of completion of breakwater construction, surveys along coastal area in the vicinity of breakwaters are conducted by Royal Thai army survey department, the supreme command headquarters. Aerial photographs in 1980 and 1991 with scale 1:10,000 and 1:20,000 are available. The detail survey was conducted by harbor department in 1992 providing a map scale 1:5,000. Recent photographs cover both sides of breakwater with approximate distance 6,000 m. All shoreline data are used for two purposes. Firstly, shape of shorelines in different years are taken from field data and compared with a map before breakwater construction in order to assess shoreline change. Secondly these shoreline data are used for calibration and verification of mathematical model in order to predict shoreline change in the future. Fig. 2 shows comparisons of shoreline change in 1968, 1980, 1991 and 1992. Shoreline in 1968 is a straight line. For the first purpose, after analysis of shoreline field data, it is found that maximum deposition distance at upcoast area is 420 m while maximum retreated shoreline distance is -88 m at downcoast area covering alongshore distance 2,500 m. Location of maximum erosion is approximately 800 m from the breakwater. However it is noticed that there is some sand deposition close to the breakwater. Deposit distance is 250 m with along shore distance of 300 m. The deposition rate is approximately 17.5 m/year while erosion rate is approximately 3.7 m/year. The eroded area is sandy beach and is an attractive recreational area. There are resorts and small hotels with good potential to be developed for international tourism in the future.

MATHEMATICAL MODEL DEVELOPMENT

Numerical shoreline model is developed to compute shoreline change. The model concept is to compute variation of sediment transport along shoreline. When the amount of transport is not uniform with longshore distance then deposition or erosion will occur. Shoreline position can be represented by "one line" with coordinate y as shown in Fig. 3a. A continuity equation of sediment used to compute shoreline is expressed as

$$\frac{\partial y}{\partial t} + \frac{1}{D}\frac{\partial Q}{\partial x} = 0 \qquad (1)$$

where y is the shoreline position at each grid point, t is time, x is alongshore distance. D is closure depth, Q is the longshore sediment transport.

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Equation (1) can be written in different form as

$$\Delta y = - \frac{\Delta Q}{\Delta x} \frac{\Delta t}{D} \qquad (2)$$

$$\Delta y_i = - \frac{(Q_i - Q_{i+1})}{D\Delta x} \Delta t \qquad (3)$$

$$\Delta y_1 = \frac{(Q_1 - Q_2)}{D\Delta x} \Delta t \qquad (4)$$

Fig. 3 shows concept of shoreline computation in mathematical model. Shoreline is treated as a one line represented by a number of grid points, y. The offshore distance of deposition or erosion at each grid cell is Δy as shown in side view in Fig. 3b. The sand volume is $D\Delta y\Delta x$. Equation (3) expresses calculation of shoreline change at a grid point as a function of the amount of sediment coming in (Q_1) and going out (Q_2) in a short time (Δt). When $Q_1 = Q_2$, there is no deposition or erosion. When $Q_2 > Q_1$, shoreline will erode as shown in Fig. 4a and vice versa in Fig. 4b. For boundary condition, sand volume is assigned as zero at breakwater. There is no sediment transport come across breakwater as shown in Fig. 4c. At some distance, fix shoreline condition is assigned as boundary condition in model or $Q_1 = Q_2$.

Parameter D, closure depth which is the depth that sand starts moving and it provides the same corss sectional area in the field and model as shown in Fig. 3b represents for the same.

Longshore sediment is transported by waves breaking and has expression as follows:

$$Q = (H^2C_g)_b \left\{a_1 \sin 2\theta_b - a_2 \cos\theta_b \frac{\partial H_b}{\partial x}\right\} \qquad (5)$$

where H is wave height, C_{gb} is celerity of wave group at breaking location, θ_b is angle of breaking waves to shoreline, b is a subscript denoting wave breaking.

The nondimensional parameters a_1 and a_2 are given by

$$a_1 = \frac{K_1}{16\ (\rho_s/\rho-1)\ (1-p)\ (1.416)^{5/2}} \qquad (6)$$

and

$$a_1 = \frac{K_2}{8\ (\rho_s/\rho-1)\ (1-p)\ \tan\beta(1.416)^{7/2}} \qquad (7)$$

where K_1, K_2 are empirical coefficients, treated as calibration parameters, ρ_s = density of sand ($2.65 \times 10^3 kg/m^3$ for quartz sand), ρ = density of water ($1.03 \times 10^3 kg/m^3$ for seawater), p = porosity of sand on the bed (taken to be 0.4), $\tan\beta$ = average bottom slope from the shoreline to the depth of active longshore sand transport. The factor involving 1.416 are used to convert from significant wave height, to root-meansquare (rms) wave height.

The first term with coefficient K_1 is a amount of sand transport due to breaking wave. In general, coefficient K_1 is 0.77. The second term with coefficient K_2 is sediment transported by longshore current behind a breakwater. This term shows effect of circulation of longshore current at downcoast area of breakwater. The direction of generated longshore current is opposite to transport direction of breaking wave. Longshore current flows and carries sediment to breakwater while wave breaking tries to move sediment away and erode shoreline. In the present study, K_2 has strong influence since there are sand deposited at downcoast area of breakwater as shows in Fig. 2. In general, coefficient K_2 is less than K_1.

Wave characteristics at a breaking point is needed in order to compute longshore sediment transport in Eq. (5). Those quantities are H_b, h_b and C_{gb}. However C_{gb} can be written in term of h_b, so only H_b and h_b are needed to be solved. Equation of wave breaking's criteria is

$$H_b = \gamma\ h_b \qquad (8)$$

where γ = 0.78. For equation of wave transformation, it is written as

$$H = K_s K_r K_D H_{ref} \qquad (9)$$

where K_s is shoaling coefficient, K_r is refraction coefficient, K_D is diffracted coefficient and H_{ref} is reference wave height. K_s and K_r are function of water depth and wave angle. K_s is computed using linear wave theory while K_r is determined from Snell's law. K_D is calculated pragmatically using Kraus (1982, 1984) with expression of

$$K_D = \sqrt{\frac{50[\tanh\ 2.084\theta_D]+1}{100}} \qquad (10)$$

where θ_D is a defined angle as shown in Fig. 5. For area close to breakwater, θ_D is small and negative, K_D value is also small. When θ_D increases, K_D will increases but it will not exceed 1. H_{ref} is a reference wave height which may be deep water wave or wave height at tip of breakwater.

Equating Eqs. (8) and (9), h_b can be solved. Then H_b is calculated accordingly.

Field wave data used in simulation are obtained from recent installed experimental buoy of National Research Council of Thailand (NCRT) for period of two years between 1993 and 1994. Wave height, wave period, wind velocity and wind direction were recorded at hourly basis. Fig. 6 shows wave roses for all year and seasons. Period of calm or no wave (wind blow from land to sea) is 72 percent of time in a year. Time period having wave is 28%. Mostly waves come from south, south-southeast and southeast directions having 15.4 percent of all year wave. Computer model is developed to compute shoreline change using the above procedure and detailed suggested by Kraus et al (1983). Input wave data has 5789 records for 2 years. Grid spacing (Δx) is 200 m. Time step for computation (Δt) is 1 hour. Open boundary condition with fixed shoreline is set at distance 3-4 km from a breakwater. This location where there is almost no shoreline change is taken from aerial photograhp. Computer model is then developed using the above concept by Weesakul (1994).

MODEL RESULT AND DISCUSSION

Calibrated parameters in model are closure depth D, coefficients in longshore sediment transport formula, K_1 and K_2. Closure depth which is the depth that sand started to move was computed from mean wave height by Paksee (1996) and found that it equals 1.0 m. Since most of waves coming from southeast quadrant or upcoast area and to simplify calibration procedure, it is assumed that only coefficient K_1 is calibrated with deposited shoreline shape at upcoast area. Then coefficient K_2 is calibrated later using shoreline recession data at downcoast area. Available shoreline data in 1968 is used as initial condition and shoreline in 1980 is used for calibration purpose. In upcoast area, computed shoreline for coefficient K_1, varies between 0.3 and 0.9 is shown in Fig. 7. Shoreline calibration is conducted and shown in Fig. 8. Calibrated coefficient K_1 is found to be 0.44. Computed shoreline has more carvature than the measured one so more deposit distance is shown at a breakwater. However it provides satisfactory result. Verification of upcoast deposit area are made with data of 1991 and 1992 as shown in Figs. 9 and 10. Good agreement between measured and computed values are obtained and it shows better result than the calibration case.

For calibration of coefficient K_2, the eroded shoreline at downcoast area of breakwater is used. Fig. 11 shows plots of computed shoreline with variation of coefficient K_2 between 0 and 3.5 while K_1 is kept constant as 0.44. When K_2 equals 0, shoreline adjacent to breakwater is immediately eroded and it starts to recover when K_2 increases. Using shoreline data in 1980 for calibration, the appropriate K_2 for calibration is found to be 1.6 as illustrated in Fig. 12. Computed downcoast shoreline shows more deposit distance at breakwater while it has the same magnitude of eroded distance. These shorelines have similar shapes.

Figs. 13 and 14 show verification of computed shoreline in 1991 and 1992. It has the same discussion as the result of calibration but computed maximum eroded distance at shoreline is slightly small and its location is moved away from the measured one approximately 200 to 400 m. For computational of downcoast erosion, the appropriate coefficient K_1 is equal to 0.44 and coefficient K_2 is equal to 1.6.

Plot of net longshore sediment transport is shown in Fig. 15. The average transport rate is 5,000 m^3/yr. Net direction of transport is from south to north. Table 1 summaries value of coefficients K_1 and K_2 from other studies obtained by comparing calculated and measured shoreline. it is noticed that most of K_1 is less than the standard value (K_1 = 0.77) except the study of shoreline change at Chonburi. Coefficient K_1 is greater than standard value two times. Coefficient K_2 is quite high compared with K_1. However coefficients K_1 and K_2 depend on other factors. Source of wave data is one of the factors. When field wave data is measured by either wave gage of buoy, values of K_1 and K_2 tend to be low. Another important factor is closure depth, D. From Eqs. (2) or (3), when D increases, Q should increase to provide the same value of shoreline change (Δy). In this study, K_1 will almost equal 0.77 when D increases two times. However the result of model computation will not change.

Prediction of upcoast and downcoast shoreline is conducted using calibrated coefficients. In upcoast area, it will take 46 and 170 years for sediment to be accumulated at half and full breakwater length 1,200 m as shown in Fig. 16. The plot of deposited distance with time is shown in Fig. 17. Deposition rate increase at beginning then it reduces. Deposition rate is 16.7 m/year for the first 30 years and the average value is 6.5 m/year. In downcoast area, eroded shoreline is predicted for the next 50 years. Fig. 18 illustrated predicted shoreline change at different time period. Maximum erosion distance locates at 1,200 m from the breakwater is 116 m. An amount of sand deposition at the breakwater is 580 m. Plot of maximum eroded distance with time is shown in Fig. 19. The long term erosion rate is 2.2 m/year.

CONCLUSION

Mathematical model was developed to compute coastal erosion in the vicinity of a breakwater. Computational results were calibrated and verified with measured shoreline and appropriate coefficients K_1 and K_2 were proposed. Values of K_1 and K_2 at Cha-Um beach are 0.44 and 1.6 respectively. Shoreline change prediction was made and shown that it would take more than 100 years to accumulate sediment up to breakwater's length in upcoast area and eroded distance was approximately 116 m for the next 50 years in downcoast area. More study concerning with coastal protection in the study area should be made.

ACKNOWLEDGEMENT

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Table 1 Summary of Computed Coefficient K_1 and K_2 Using Calibration Method of Comparing Calculated and Measured Shoreline

Researchers	Location	Coefficient K_1	Coefficient K_2	Source of Wave Data	Closure Depth D (m)
Kraus (1983)	Oarai Beach, Japan	0.3	0.4	Measurement Using Wave Gage	6
Charulukhana (1991)	Songkhla, Thailand	0.25	-	Wave Hindcasting	up to 6 m
AIT (1995)	Chonburi, Thailand	1.7	1.0	Wave Hindcasting	6
Present Study (1996)	Cha-am, Thailand	0.44	1.6	Measurement Using Buoy	1

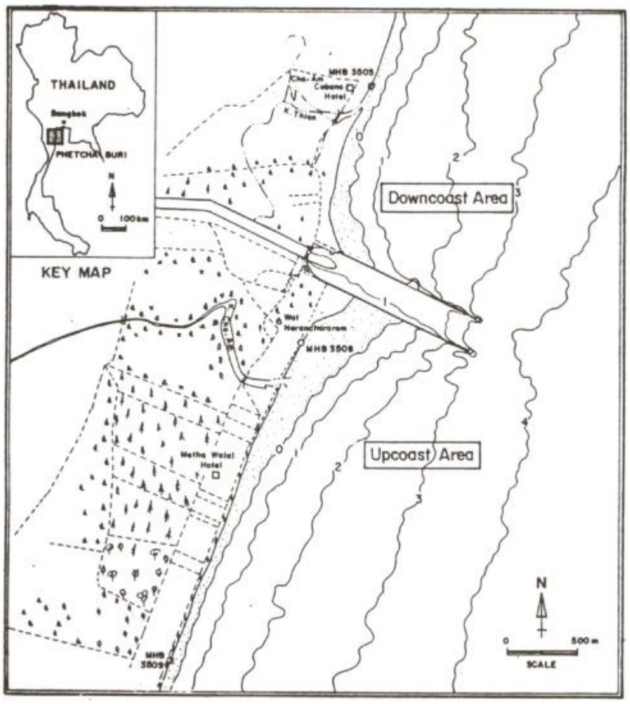

Fig. 1 Location of Study Area

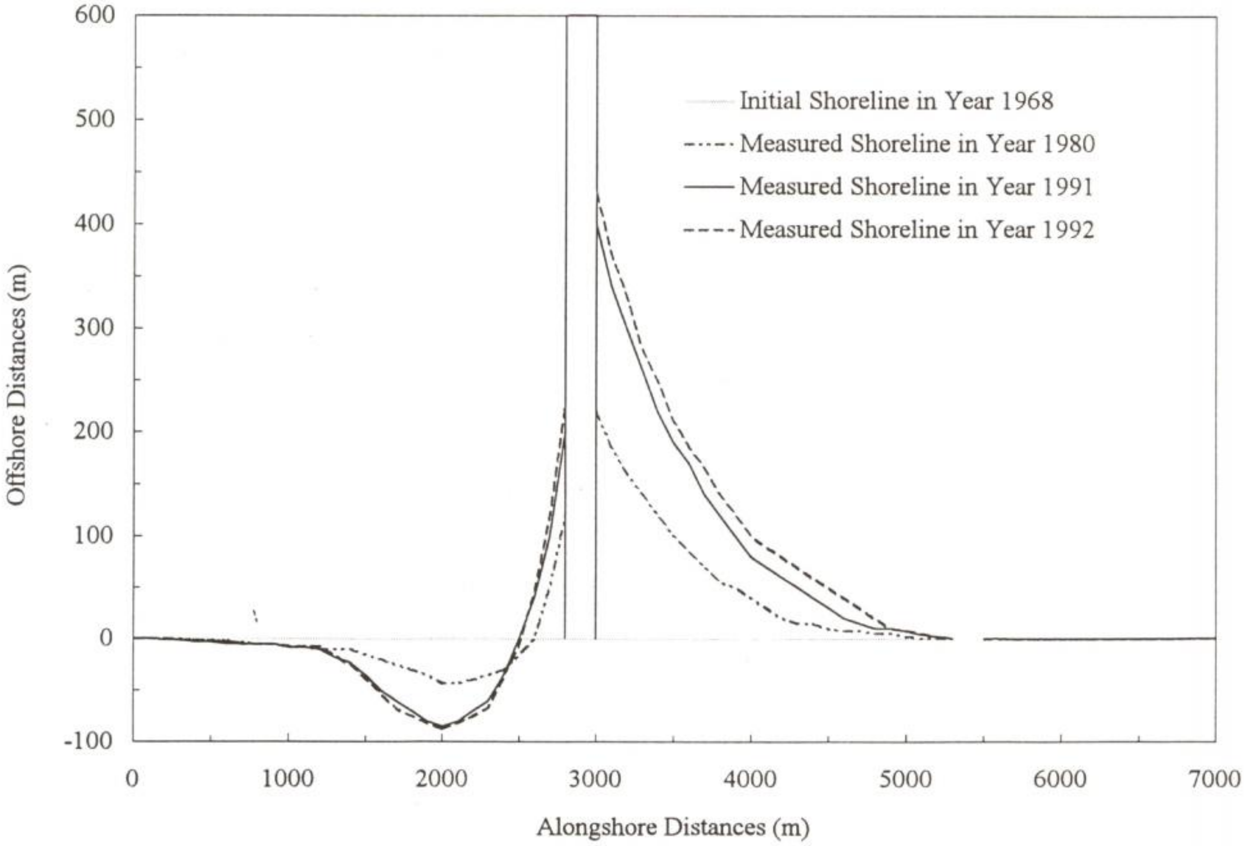

Fig. 2 Measured Shoreline at Breakwater in Year 1968, 1980, 1991 and 1992

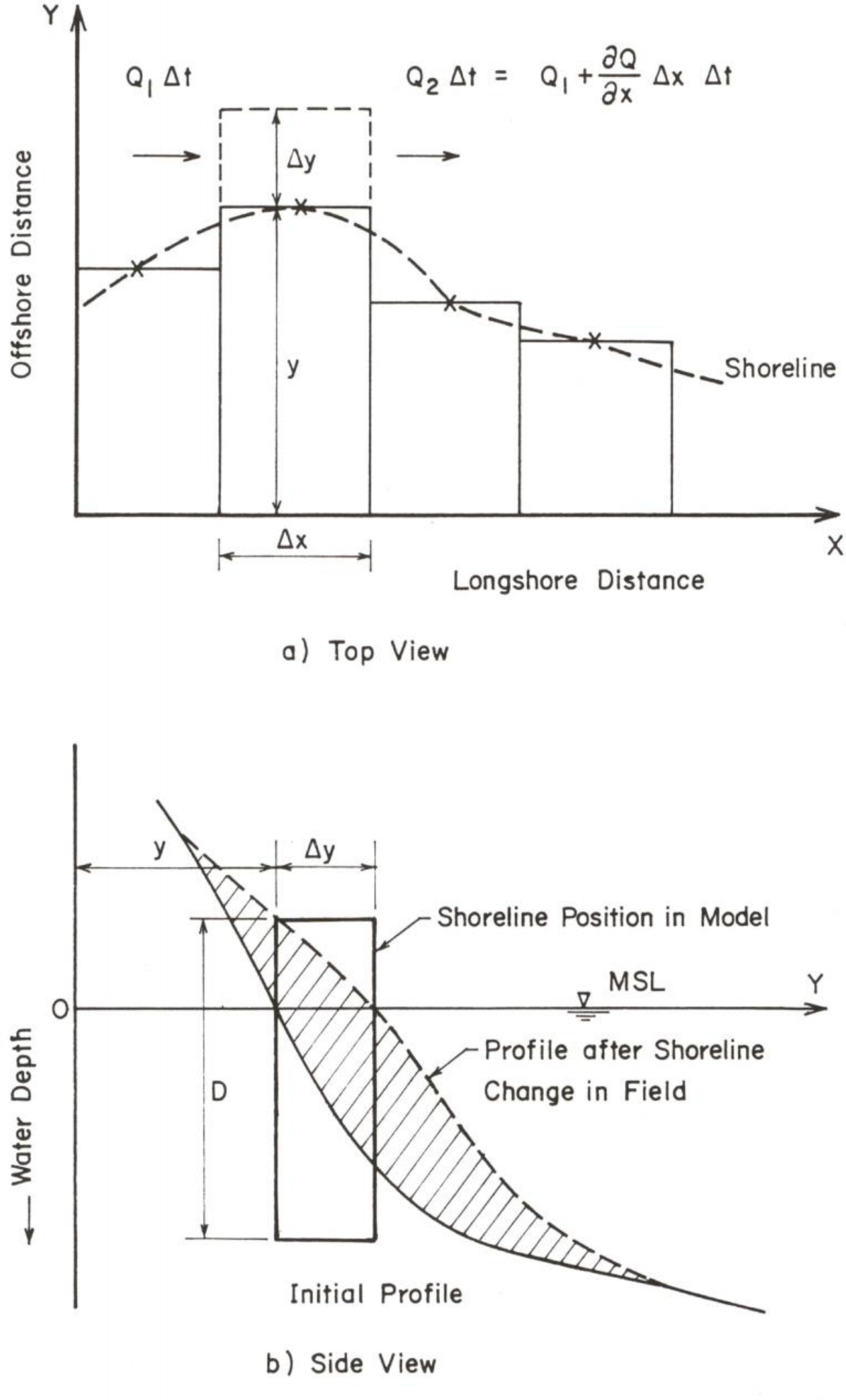

Fig. 3 Concept of One Line Model

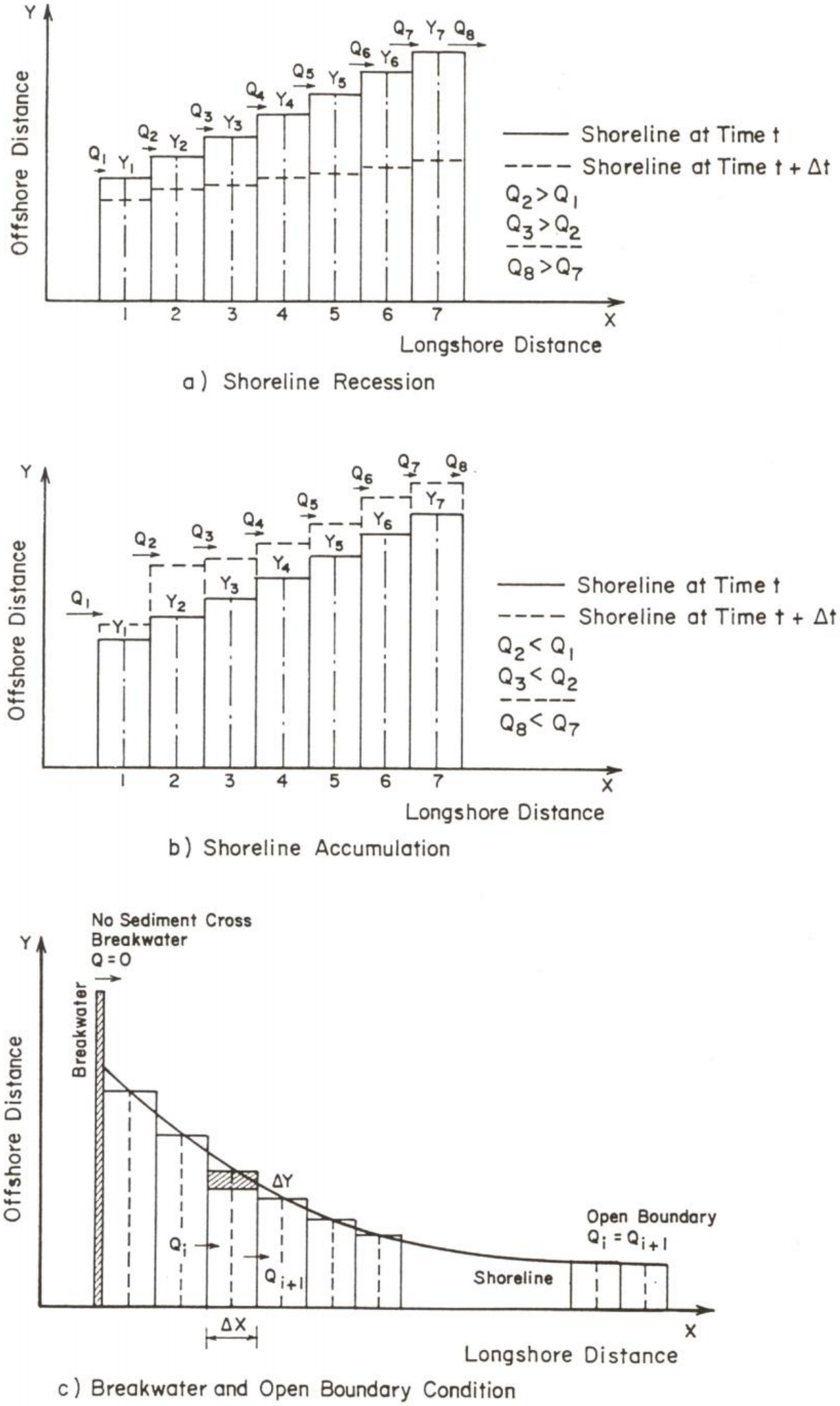

Fig. 4 Representation of Shoreline with Boundary Condition

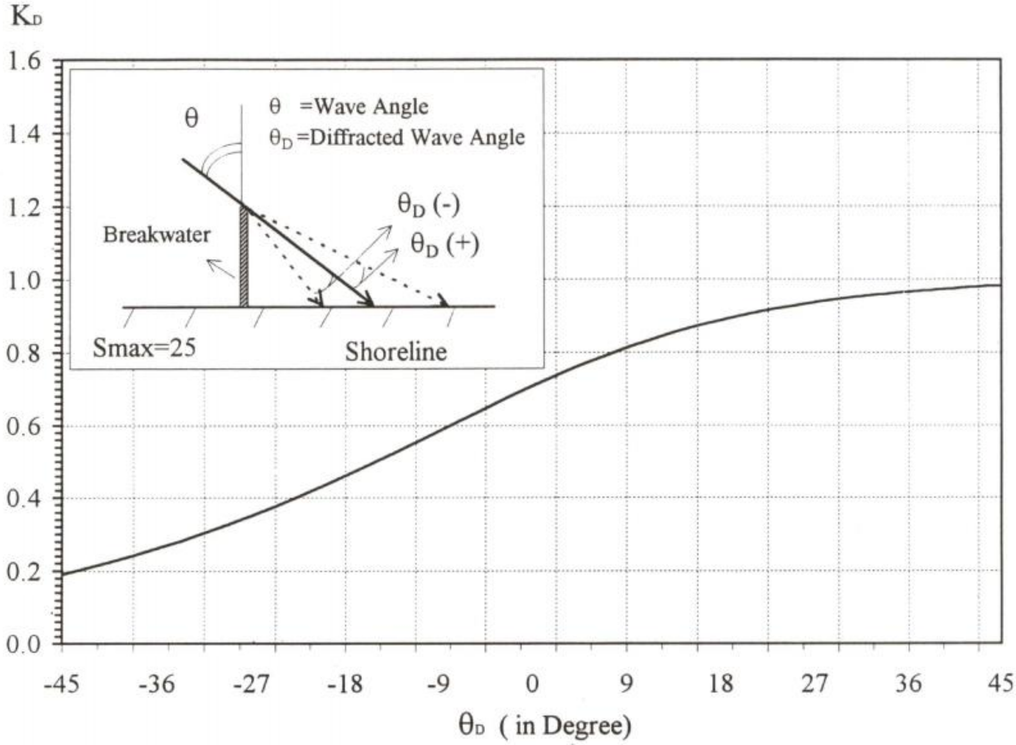

Fig. 5 Variation of K_D with θ_D

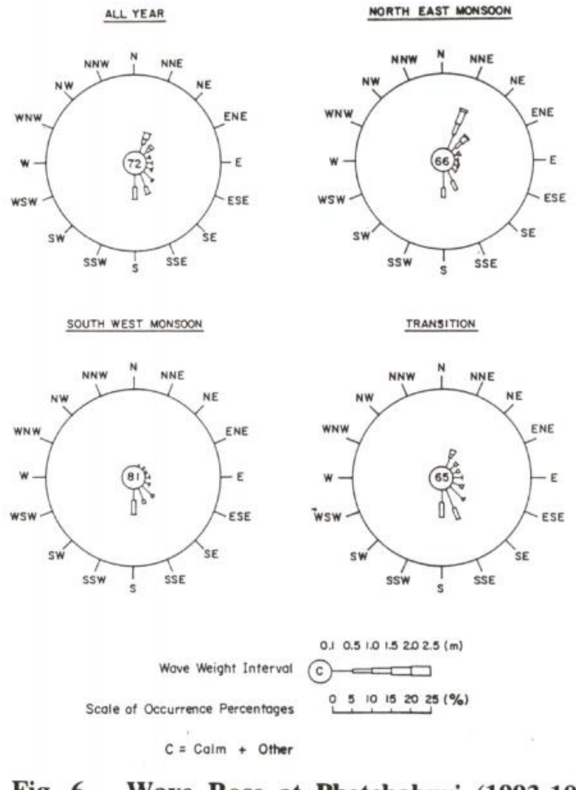

Fig. 6 Wave Rose at Phetchaburi (1993-1994)

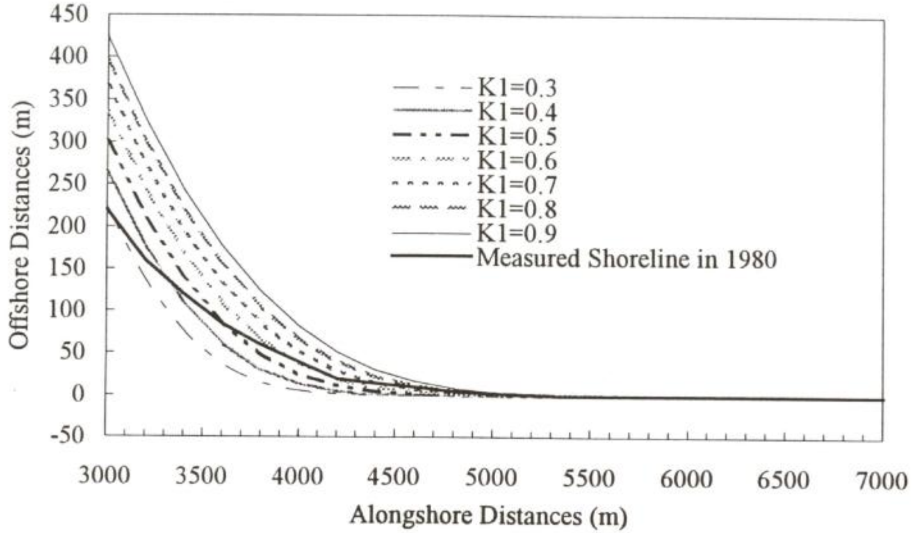

Fig. 7 Variation of Upcoast Shoreline with Coefficient K_1

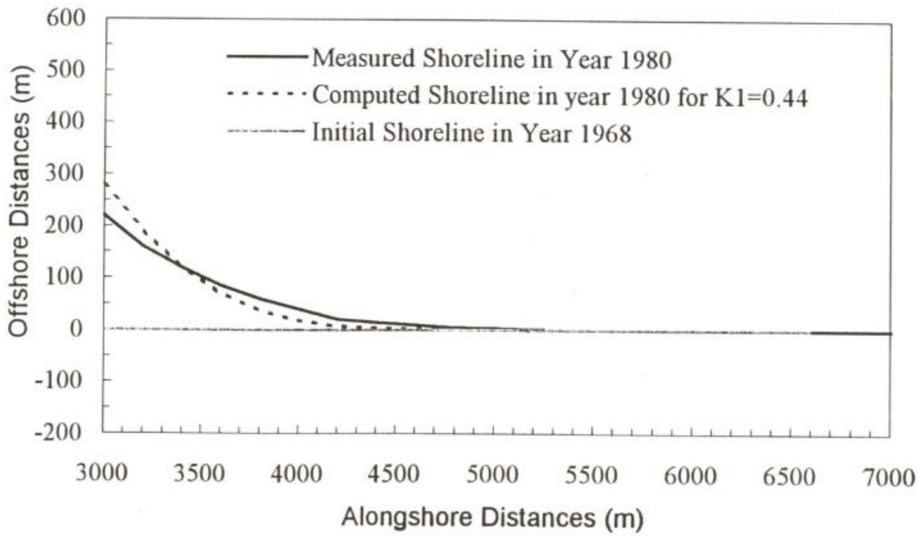

Fig. 8 Calibration Plot between Measured and Computed Shoreline, K1=0.44 for Calibration

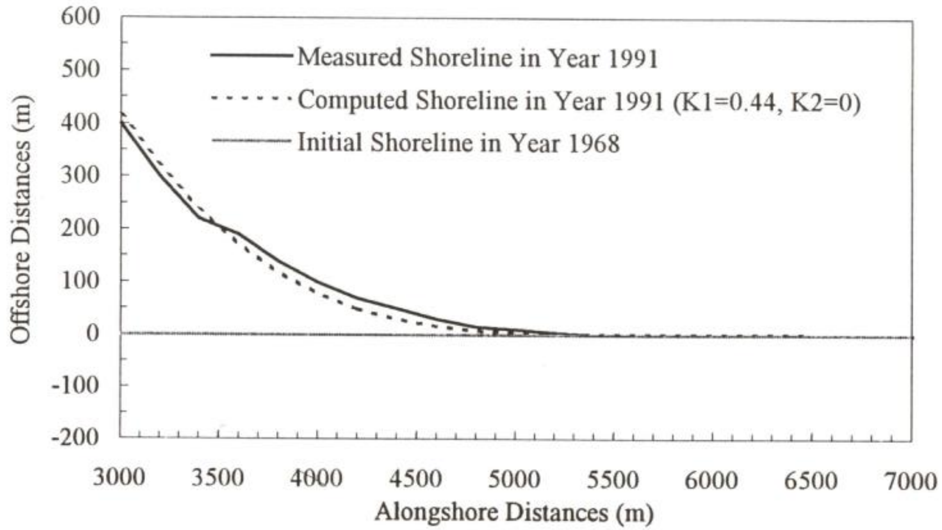

Fig. 9 Verification of Upcoast Shoreline in Year 1991

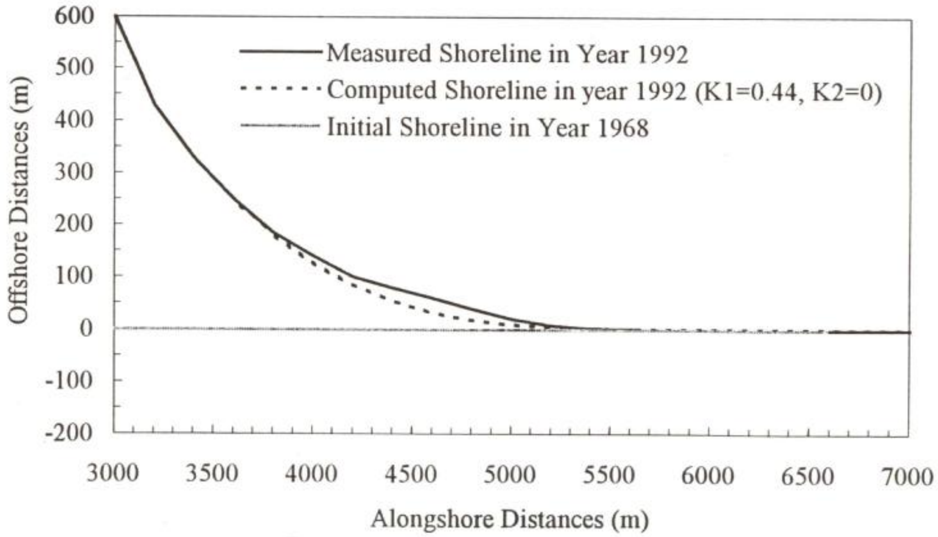

Fig. 10 Verification of Upcoast Shoreline in Year 1992

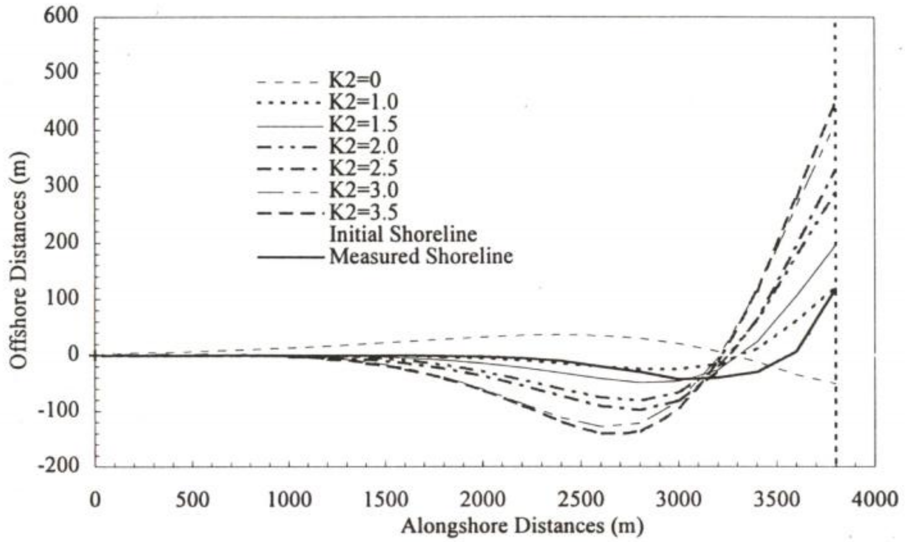

Fig. 11 Comparison of Measured and Computed Shoreline at Downcoast

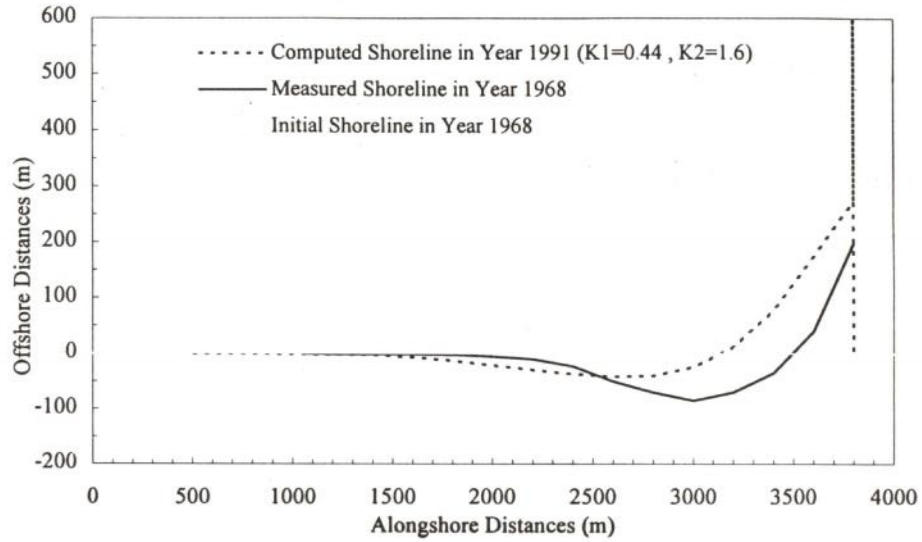

Fig. 13 Verification of Downcoast Shoreline in Year 1991

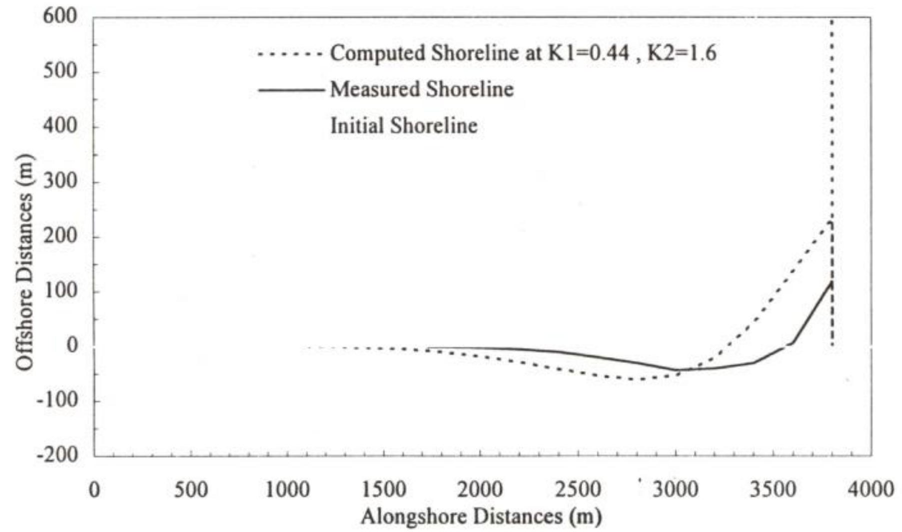

Fig. 12 Plot of Measured and Computed Shoreline for K1=0.44, K2=1.6 for Calibration

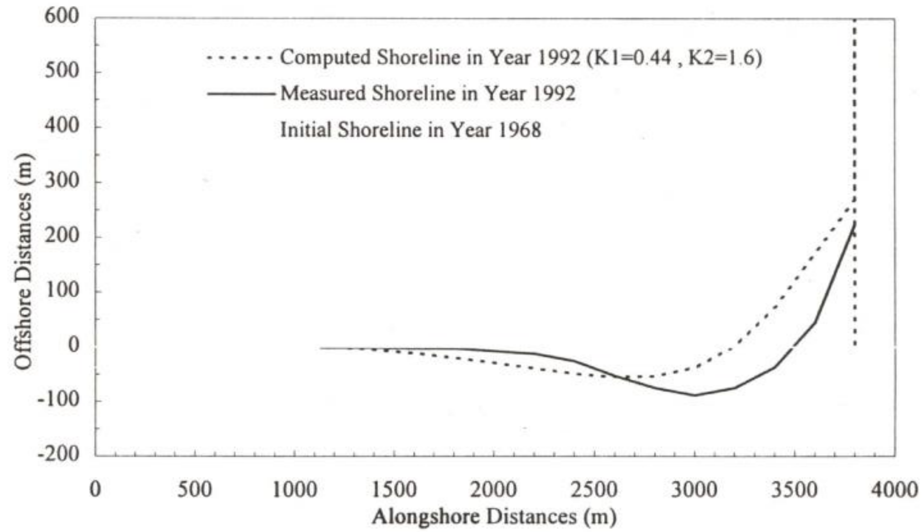

Fig. 14 Verification of Downcoast Shoreline in Year 1992

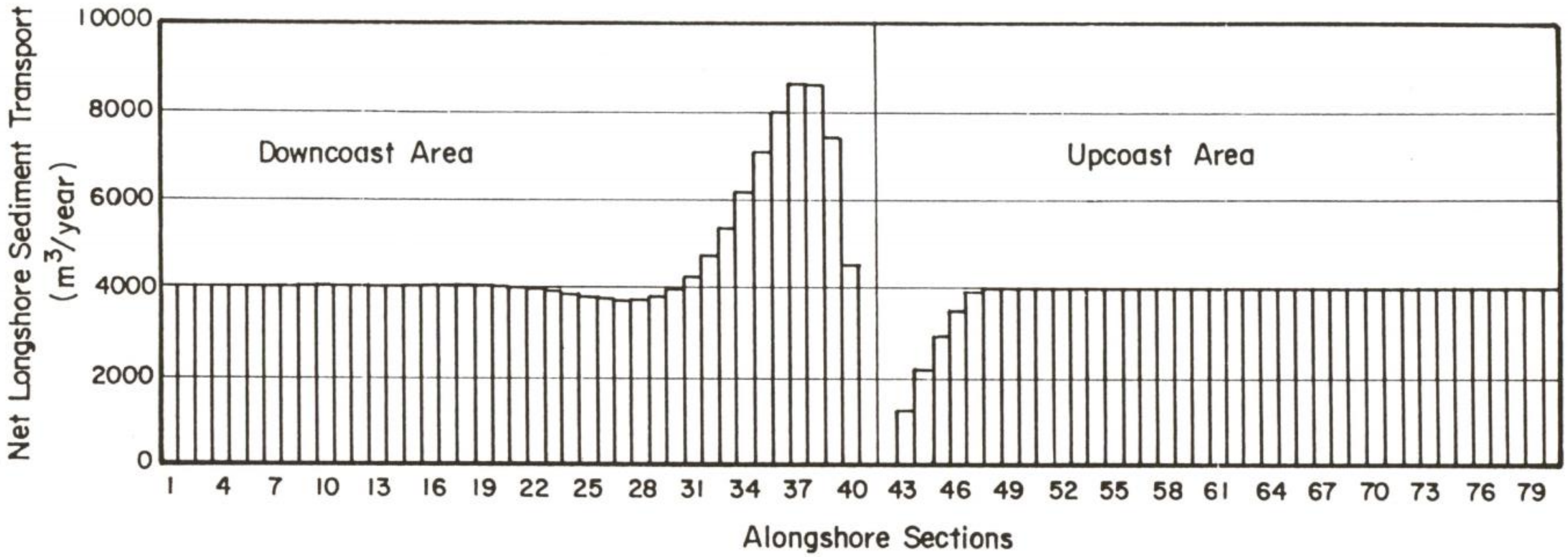

Fig. 15 Plot of Net Longshore Sediment Transport

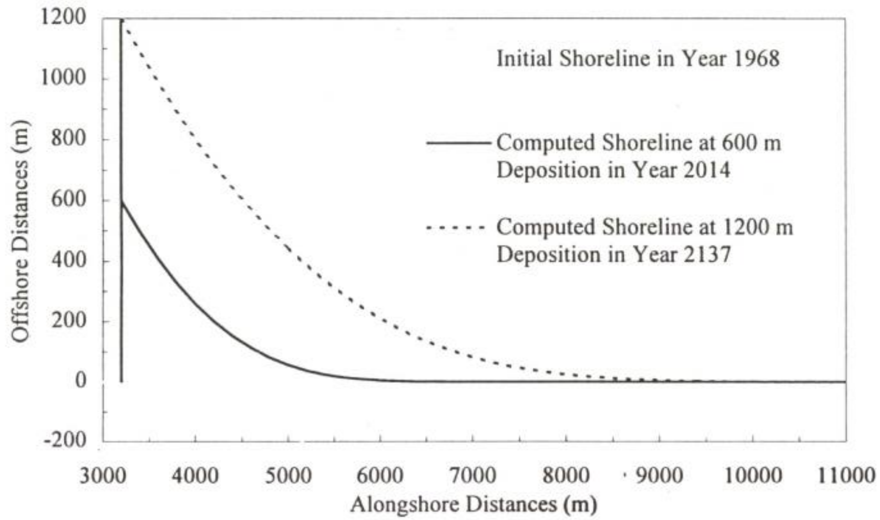

Fig. 16 **Upcoast Shoreline Prediction for 600 m and 1,200 m Deposited Distance at Breakwater**

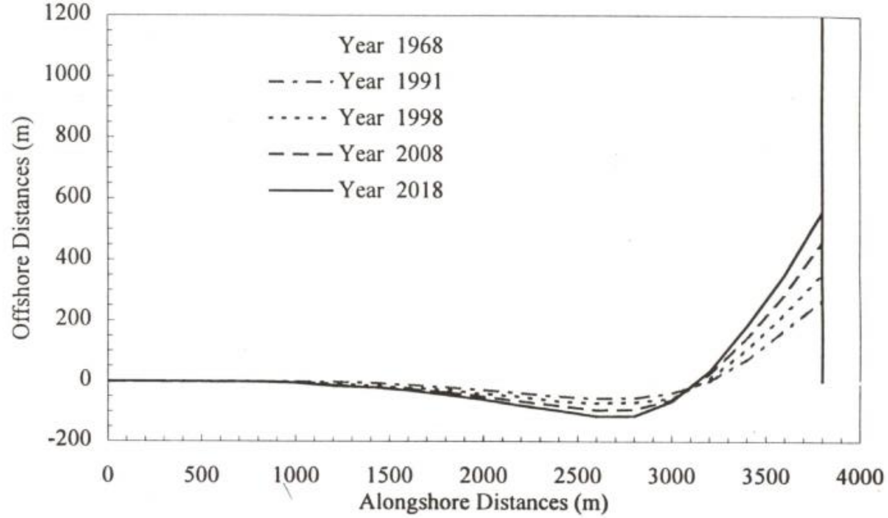

Fig. 18 **Computed Downcoast Shoreline After 50 Years**

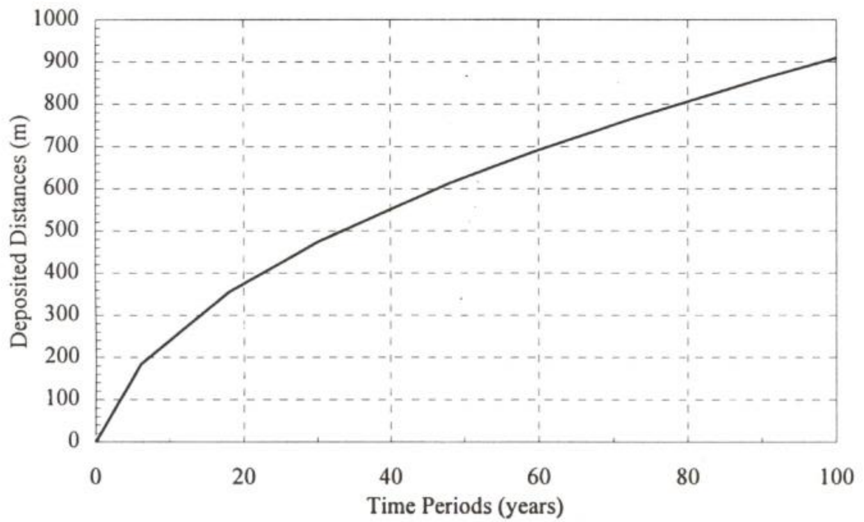

Fig. 17 **Relationship between Deposited Distances at Breakwater and Time Periods**

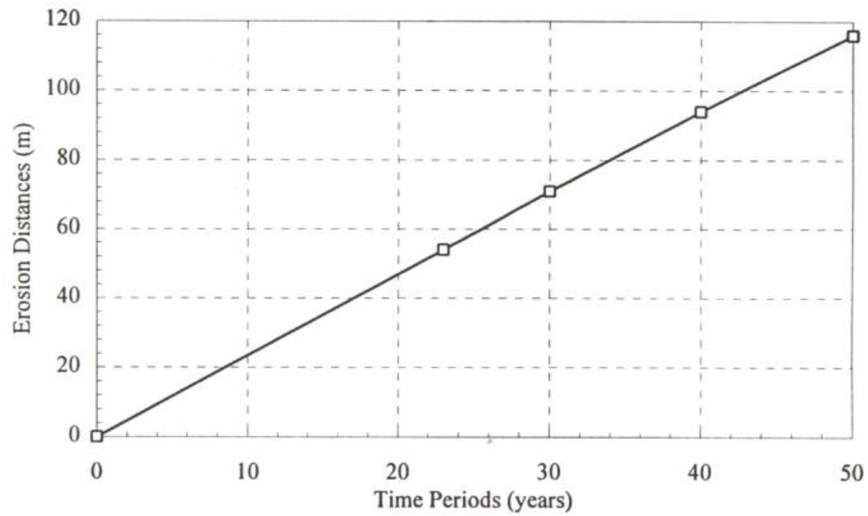

Fig. 19 **Plot of Maximum Eroded Distance with Time**