CHAPTER 124

VALIDATION OF CROSS-SHORE TRANSPORT FORMULATIONS

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ABSTRACT

Seymour and King (1982) evaluated eight models for predicting cross-shore transport using beach profile data from the Torrey Pines experiment of the Nearshore Sediment Transport Study (NSTS). None of the models showed useful skill in predicting the sense, or direction, of transport. Three more data sets were acquired under NSTS and have been used in the present work to re-evaluate the original four models as well as another six not previously tested. The three new data sets include two nominally plane West Coast beaches and a barred beach on the Atlantic coast, each under a variety of wave conditions. Six of the models evaluated claimed a capability to predict the sense of the cross-shore transport, two predicted the beach slope as a result of cross-shore movement, and two gave detail predictions of changes to the beach profile position and shape.

The performance of the six models predicting direction of transport ranged from a skill factor of 0.49 (less than chance) to only 0.68. Five of the models required large changes to their calibration factor (usually based upon laboratory data) in order to have approximately the same skill in predicting erosion or accretion. One of the slope models was validated and the other gave no useful results. One of the two generalized models gave interesting results in predicting the time history of profile changes on the plane beaches for which it was developed. The other general model was not evaluated because it exhibited the lowest skill in predicting direction of transport.

INTRODUCTION

Following the first field experiment in the Nearshore Sediment Transport Study at Torrey Pines Beach, CA (see Seymour, 1983 for a review of the NSTS program) Seymour and King (1982) attempted to use the observed beach changes to evaluate the predictive capability of a number of formulations related to cross-shore transport. Of the twelve models reviewed, eight were found capable of making predictions of the transport knowing incident wave height and period - and in some cases the sand size and beach slope as well. The model performance was evaluated by determining the squared correlation coefficient between the beach face volume response and the forcing function prescribed by the model. The best of these, Dean (1973), based upon a dimensionless ratio that has come to be known as the Dean Number, and a modification by Hattori and Kawamata (1980) in which beach slope is added to the Dean Number, explained only about a third of the variance in the volume of the beach face. The other models ranged down to about 2% of the variance explained. This disappointing performance may have been due in part to the characteristics of the data set employed to test the models. A thorough analysis of this is given in Seymour (1988a), which concludes that the Torrey Pines data set was noisy, lacked significant erosionary events, and was unlikely to provide general insights into cross-shore transport mechanisms.

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NSTS produced three other beach profile data sets which did not suffer from the problems seen with Torrey Pines. These sets, which included data on waves and tides as well as characteristic sand sizes, were published in Seymour (1986). The three locations were Leadbetter Beach at Santa Barbara, CA (29 day series), Scripps Beach at La Jolla, CA (25 day series) and Virginia Beach, VA (23 days with a one day gap in the profiles). Santa Barbara and Scripps are typically without bars except for breaker bars which form immediately following major erosive events. Virginia Beach typically has a within-surf-zone bar that moves rapidly in response to changing wave conditions. These three data sets provided an attractive opportunity to reevaluate the cross-shore models and to include some others that had not been treated in the earlier work.

SELECTION OF MODELS

Of the eight models evaluated in Seymour and King (1982), four were in a form which would allow the prediction of a threshold point - that is, the incident wave condition above which erosion would be predicted and below which accretion would be expected, for a given beach condition. These four were Dean (1973), Hattori and Kawamata (1980) and two models contained in Short (1978). Two other threshold-type models were added for this study, Quick and Har (1985) and Sunamura and Horikawa (1974). With the exception of Quick and Har, these models were formulated to give only the direction of cross-shore transport. The formulations for the six threshold models are shown in Table I.

Two other models were added that attempted to describe the beach slope. Dalrymple and Thompson (1976), using laboratory data, established a linear relationship between the slope at mean sea level and the Dean Number. Dean (1977) established empirically an exponential shape for beach profiles, independent of wave or sediment characteristics, which takes the form

$Y = AX^m$

where Y = water depth and X = offshore distance

Both of these models lent themselves to testing with the present data.

Finally, two models were added that claimed to predict the time history of changes to the beach profile caused by cross-shore transport. These were Quick and Har, mentioned above, and Swart (1976). The Quick and Har model establishes an equilibrium profile based upon the Dean Number in which the major readjustment is a rotation of the profile. The model of Swart is an empirically-based, numerical formulation which allows for both rotation and translation of the beach face. A description of these models is contained in Seymour (1988b).

EVALUATING THRESHOLD MODELS

To evaluate these models, time histories were prepared of the daily sediment loss or gain for each site based upon changes in the profiles. In each case, the changes were interpreted as being caused entirely by cross-shore transport. The rationale for this interpretation and an assessment of its validity for each site is provided in Seymour (1988a). The variability is shown in Figure 1. This quantitative record could then be converted to a binary form of time series in which only the sign of the change is preserved. The six models provide just such a binary (erode/accrete) prediction and this was compared to the measured result. The skill of the predictor is represented by two numbers: the percentages of correct predictions for accretion and for erosion. It was interesting to note that the original four models used in the Torrey Pines study all exhibited an almost complete one-sidedness with these data - that is, they tended to predict either all erosion or all accretion. They had nearly perfect skill in one direction and almost zero skill in the other. This characteristic is illustrated in Figure 2, which shows the as-formulated predictions of Dean's model. The two models added for this study had approximately equal skill (as formulated) in predicting erosion or accretion but these skill factors were less than 0.5 and therefore not as effective as random chance predictions. The thresholds for all of the models were adjusted until they had a nearly equal skill in predicting either erosion or accretion. The results are shown in Table II.

Table I RESULTS OF THRESHOLD PREDICTION STUDIES					
Dean (1973)	$(2R)\frac{H}{wT}$	< >	1 ONSHORE 1 OFFSHORE		
Short (1979)	Н	<	120 cm ONSHORE		
Height model		>	120 cm OFFSHORE		
Short (1979)	$\left[\frac{\rho g^2}{16\pi}\right] H^2 T$	<	30 Kw/m ONSHORE		
Power model		>	30 Kw/m OFFSHORE		
Hattori and Kawamata	$2\frac{H\beta}{wT}$	<	0.5 ONSHORE		
(1980)		>	0.5 OFFSHORE		
Quick and Har	$\left[\frac{H}{wT}\right]_{INITIAL}$	>	$\left[\frac{H}{wT}\right]_{FINAL}$ ONSHORE		
(1985)		<	$\left[\frac{H}{wT}\right]_{FINAL}$ OFFSHORE		
Sunamura	$\frac{1.845}{g^{0.33}} H \frac{\beta^{0.27}}{(Td)^{0.67}}$	<	4 ONSHORE		
and Horikawa (1974)		>	8 OFFSHORE		

where:

 $\mathbf{R} = arbitrary \ constant$

H = deep water significant wave height w = sediment fall speed T = period of spectral peak

g = gravitational constant $\beta = beach slope$

- ρ = fluid density
- d = diameter of sand grains



Time histories of the observed daily volume changes in the three data sets. (------) Scripps Beach, (------) Santa Barbara, (......) Virginia Beach.



Comparisons of predictions of erosion or accretion using the model of Dean (1973) with observations. All three data sets are included.

TABLE II RESULTS OF THRESHOLD PREDICTION STUDIES						
Model	formulated threshold	adjusted threshold	skill factor			
Dean	1.0	2.62	0.62			
Short (height)	120	66	0.65			
Short (power)	300	43	0.63			
Hattori & Kawamata	0.5	0.064	0.68			
Quick & Har	1.0	1.01	0.49			
Sunamura & Horikawa	9-18	13.2	0.60			

Inspection of Table II shows that the predictive capability of the best of these models is quite limited, with wrong estimates expected about one-third of the time. The worst of the models succeeds less often than chance alone. Therefore, they should be used with caution. Although the differences in predictive capability between models are barely significant, it is of interest to note two things. First, Short's model considering only wave height does as well as the more complex model of Dean that includes period and sediment size (indirectly, through fall speed). Second, the alteration to the Dean Number by Hattori and Kawamata in adding the beach slope causes some increase in predictive capability, adding credence to the generally-accepted idea that this parameter is a first order factor in cross-shore transport.

EVALUATING SLOPE PREDICTION MODELS

Two models that attempt to describe the general slope or shape of the beach were evaluated against this data base. The first, by Dalrymple and Thompson (1976), gives a graphical relationship between the beach slope at mean sea level and the Dean Number. The validity of this relationship was tested by calculating slopes for each profile and plotting them against the corresponding Dean Number. The results are shown in Figure 3. Inspection of this plot shows that the proportionality found under monochromatic laboratory waves is not seen in the field. There appears to be no discernible effect of Dean Number on beach slope for these data.

The second relationship tested was the exponential profile contained in Dean (1977) and described above. Best fit values for the coefficient A and the exponent m were plotted for each profile. A smoothed histogram of the distributions of these parameters are shown in Figure 4. Dean gave a typical value of 0.67 for the exponent, m, based upon Atlantic and Gulf Coast data. Figure 4 shows good agreement for these data as well. The value of the coefficient, A, is site-specific, varying from 0.065 to 0.13 and increasing with increasing sediment size, as predicted by Dean (1977). All three sites in this data set are well characterized by the $X^{0.67}$ model.



Beach slope compared to Dean Number (Wave Sediment Parameter) as described in Dalrymple and Thompson (1976). Scripps Beach, O Santa Barbara, and * Virginia Beach.



Smoothed histograms of the occurrences of the coefficients and exponents in the power law for beach contours from Dean (1977) in the form $Y = AX^m$. [Data from Santa Barbara has the shortest dash length, Scripps Beach has intermediate dash length and Virginia Beach has the largest dashes.]

EVALUATING PROFILE CHANGE MODELS

The model of Quick and Har (1985) was used in the threshold evaluations, where it showed the least skill of any of those tested. This formulation, based as most others on monochromatic laboratory moveable bed experiments, assumes that the beach slope will rapidly adjust to a new slope (based upon the model of Dalrymple and Thompson) as Dean Number changes, and that this slope will then follow the Dean exponential form into deeper water. Therefore, according to this model, beach response to cross-shore forcing is dominated by slope adjustment. It is interesting to compare this with the results of the analysis by empirical orthogonal eigenfunctions of the change in profiles in this data set contained in Seymour (1988a). This study shows that 97% of the variance about the mean profile at Santa Barbara was caused by horizontal motion of the profile without change of slope or shape. Only in the Scripps Beach set was there any substantial effect of slope change (coupled with a change in concavity) but the hinge point was well above mean sea level, rather than below as predicted by Quick and Har. Given the poor performance in predicting direction and its dependence on the Dalrymple and Thompson model, the decision was made not to undertake the substantial task of programming this model for varying tidal elevations and no further evaluations of it were performed.

Swain and Houston (1983, 1984) and Swain (1984) had shown that the model of Swart (1976) exhibited some skill in modeling the major erosionary event at Santa Barbara. The Swart model has a number of relatively complex geometric constraints on the profile and its rate of change that depend, in general, on how far it differs from some equilibrium profile (which is never achieved, in practice.) Seymour (1988b) contains a description of the major attributes of this model, which allows for changing sea level through tides.

The Swart model was evaluated by setting the initial profile, inputting wave height, period and tide height changes, and allowing it to proceed without further correction through the entire data set for each site. The results for each case are shown in Figures 5 through 7. The model shows interesting skill in predicting the Scripps Beach and Santa Barbara sets, which are of the unbarred type for which the model was formulated. The Virginia Beach set, which is dominated by bar movement rather than beach face excursion, is not modeled satisfactorily by the Swart model. The model was used without adjustment of any of the parameters. It is clear from Figure 6, the Santa Barbara simulation, that the model moves much faster than nature and that significant improvement in predictive skill could have been achieved by some alterations to the time constants.

DISCUSSION AND CONCLUSIONS

This study has resulted in an objective analysis of a number of cross-shore transport models which, collectively, probably represent close to the present state of the art. The list of models evaluated was not exhaustive, but served to illustrate that the understanding of, and the corresponding ability to make useful predictions of, cross-shore transport lags well behind that of longshore transport.

The poor performance, or outright failure, of models based upon laboratory moveable bed experiments with monochromatic waves in predicting cross-shore transport in the field has been emphatically demonstrated by these findings. Taken in its entirety, this evidence suggests that there are very substantial differences in the response of sandy beaches to monochromatic and natural waves and that empirical relationships established in the laboratory with monochromatic waves are unlikely to produce useful predictive tools for real beach profile changes.

Further, the significant differences between the Virginia Beach response (which has been verified through the findings at Duck, NC - see, for example, Mason et al., 1984) and the West Coast beaches illustrates that a simple characterization of the sediment on the beach by a single grain diameter will not be enough to allow effective predictions. It is clear that the dominant sediment transport mechanisms are quite dissimilar for the two beach types. A realistic model for cross-shore transport, involving the necessary physics, appears to be well beyond the present state of the art.



Scripps Beach 10/08/80 - 11/04/80

FIGURE 5

Comparison of observed beach profiles at Scripps Beach with the predictions using the model of Swart (1976). (-----) indicates predictions. Sequence starts at upper left and proceeds downward in each column. Horizontal lines are mean sea level.



Santa Barbara 2/1/80 - 2/25/80

FIGURE 6

Comparisons of observed beach profiles at Santa Barbara with predictions from the model of Swart (1976).



Comparisons of observed beach profiles at Virginia Beach with predictions from the model of Swart (1976).

REFERENCES

Dalrymple, R. A. and W. W. Thompson, 1976. Study of equilibrium beach profiles, *Proceedings*, Fifteenth Coastal Engineering Conference, July 11-18, Honolulu, HI, ASCE, New York: 1277-1296.

Dean, R. G., 1973. Heuristic models of sand transport in the surf zone, *Proceedings*, Conference on Engineering Dynamics in the Surf Zone, Sydney, Australia, 7 pp.

, 1977. Equilibrium beach profiles: U. S. Atlantic and Gulf Coasts, Ocean Engineering Report No. 12, Department of Civil Engineering, University of Delaware, Newark, Delaware.

Hattori, M. and R. Kawamata, 1980. Onshore-offshore transport and beach profile change, *Proceedings*, Seventeenth Coastal Engineering Conference, March 23-28, Sydney, Australia, ASCE, New York: 1175-1194.

Mason, C., A.H. Sallenger, R.A. Holman and W.A. Birkemeier, 1984. DUCK82 - a coastal storm processes experiment. Proceedings, Nineteenth Coastal Engineering Conference, Houston, TX, September 3-7, ASCE, New York: 1913-1928.

Quick, M. C. and B. C. Har, 1985. Criteria for onshore-offshore sediment movement on beaches, *Proceedings*, Canadian Coastal Conference, St. Jobus, Newfoundland: 257-269.

Seymour, R. J., 1983. The nearshore sediment transport study. J. Waterway, Port, Coastal and Ocean Div., Proc. ASCE, 109 (1): 79-85.

, 1986. Results of cross-shore transport experiments, J. Waterway, Port, Coastal, and Ocean Engineering, ASCE, 112 (1): 168-173.

, 1988a. Cross-shore transport. In: Nearshore Sediment Transport, R. J. Seymour, ed. Plenum Press, New York, in press.

, 1988b. Modeling cross-shore transport. In: Nearshore Sediment Transport, R. J. Seymour, ed. Plenum Press, New York, in press.

Seymour, R. J. and D. B. King Jr., 1982. Field comparisons of cross-shore transport models, J. Waterway, Port, Coastal and Ocean Division, *Proceedings*, ASCE, 108 (WW2): 163-179.

Short, A. D., 1978. Wave power and beach stages: a global model, *Proceedings*, Sixteenth Coastal Engineering Conference, August 27-September 3, Hamburg, Germany, ASCE, New York, 2: 1145-1163.

Sunamura, T. and K. Horikawa, 1974. Two-dimensional beach transformation due to waves, *Proceedings*, Fourteenth Coastal Engineering Conference, June 24-28, Copenhagen, Denmark, ASCE, N.Y.: 920-938.

Swain, A., 1984. Additional results of a numerical model for beach profile development. *Proceedings* of the Annual Conference, CSCE, Halifax, Nova Scotia, Canada, May.

Swain, A. and R. J. Houston, 1983. A numerical model for beach profile development. Sixth Canadian Hydrotechnical Conference, CSCE, Ottawa, Canada, June, 2: 77.

, 1984. Discussion to the Proceeding Paper 17749 by Richard J. Seymour, The Nearshore Sediment Transport Study, J. Waterway, Port, Coastal and Ocean Engineering, ASCE, February, 110 (1): 130-133.

Swart, D. H., 1976. Predictive equations regarding coastal transports, *Proceedings*, Fifteenth Coastal Engineering Conference, July 11-17, Honolulu, HI, ASCE, N.Y.: 1113-1132.