CHAPTER 189

SHORE NOURISHMENT AND THE ACTIVE ZONE: A TIME SCALE DEPENDENT VIEW

Marcel J.F. Stive[1], Huib J. De Vriend[2], Robert J. Nicholls[3] and Michele Capobianco[4]

Abstract

First results towards the development of a predictive method of cross-shore spreading of beach and shore nourishments are described. Present interest in nourishment as an appropriate answer to long-term erosion motivates special attention for the time evolution of the cross-shore spreading. Hallermeier's (1981) annual shoreward boundary, D_l, of the shoal zone is probably the most applied quantitative boundary for the seaward extent of nourishments. The extension of this concept to include time-dependency is a logical and necessary step to improve our understanding of nourishment performance. Moreover, insight into the precise cross-shore variation of the spreading process is lacking.

By application of a detailed process-based, cross-shore morphodynamic model and some inductive assumptions the spreading process is studied as a function of time. The results give qualitative and quantitative indications of the spreading process, in particular concerning the evolution character of the spreading and the relation between the nourishment foot and closure depth.

Introduction

The seaward extent and the rate of morphodynamic activity across the active zone are of fundamental importance in designing shore nourishment (Davison et al., 1992). A valuable and useful approach to determine the seaward extent (closure depth) was developed by Hallermeier (1981), who defined it as the

---

[1] Laboratori d'Enginyeria Marítima, Universitat Politècnica de Catalunya, Spain (visiting from Delft Hydraulics, The Netherlands);

[2] Delft Hydraulics, The Netherlands;

[3] Laboratory for Coastal Research, University of Maryland, USA;

[4] Tecnomare S.P.A., Venezia, Italy

annual shoreward boundary of his shoal zone. Obviously, as qualitatively indicated by Hallermeier (1981), the rate of activity varies across the active zone profile. This rate will depend not only on the hydraulic impact, but also on the time scale considered. Similarly, a time scale dependence of the seaward extent of the active zone (the closure depth) can be expected. Taking 20 years of hindcast wave data at Ocean City, Maryland, and considering it on a year-to-year basis, Anders and Hansen (1990) found D_l had a mean value of about 5 m, but annual values varied from 3.7 to 7.3 m. Suggestions for the time scale dependence were made by Hands (1983) in his analysis of the Great Lakes profile responses to mean lake level variations. Insight into the time scale dependence of the closure depth and the relative activity across the active zone is of importance for more accurate prediction of nourishment behaviour and lifetime. This is particularly true in the light of the likelihood of accelerated global sea-level rise (e.g. Nicholls et al., 1992). Shore nourishment will be required to counteract the resulting shoreline recession in many parts of the world. In this context however, the coastal system is considered on longer time and space scales than has been common practice sofar.

Because of the very limited field information about the cross-shore spreading of nourishments, we have chosen to initially rely on a mathematical-physical approach, using the combination of physical inductive concepts and a detailed process-based model. This approach may be termed behaviour oriented modelling. In order to analyse our results and to obtain predictive methods, we also rely on system dynamics related approaches to describe the nourishment behaviour. An example of this is the application of a diffusion-type equations to simulate in the simplest way some aspects of the observed behaviour. The coefficients of such equations are at the moment derived by using a parameter identification method with "experimental" data produced under well defined boundary and initial conditions. We plan further work to generalize our results in order to be able to handle a variation of boundary and initial conditions, and we intend to confront and verify our findings with real world data.

Study approach and assumptions

In order to indicate our present scale of interest we distinguish the following scales of profile behaviour (see Table 1).

As can be observed from Table 1 the time and length scales of our topic are larger than years and longer than the surfzone. This implies that we are dealing with what we would define as long term modelling: modelling on a time scale longer than can be handled by existing validated process-based (mathematical-physical) models. This, in turn, implies that we have to fall back on inductive concepts, so that we enter the field of behaviour oriented modelling (Stive et al., 1990). In practice this means that we have to adopt some assumptions based on our physical intuition and our expectations of the process behaviour.

physical process	cross-shore length scale	approximate time scale
response to relative sea-level rise	total shoreface to inner shelf	decades to a century
spreading of structural shore nourishment	upper to middle shoreface	years to a decade
surfzone bar evolution	surfzone	storms to a year

Table 1 Time and length scales of cross-shore profile behaviour

In fact, we base some of our assumptions on the results due to an interesting application with respect to shore nourishment made by Van Alphen et al. (1990). Based on simulations with the process-based dynamic model of Roelvink and Stive (1989) the efficiency of nourishments, placed at different positions in the active zone, was systematically investigated. The simulations were run over many years with a synthesized, observed wave climate over one full year as hydraulic input. De Vriend and Roelvink (1989) were the first to conclude from the results that the spreading of the nourishments closely resembles the smoothing out of a "disturbance" on an otherwise equilibrium profile. This smoothing process shows a shoreward asymmetry: the smoothing is stronger at the shoreward side. Associated with this asymmetry, the part of these artificial disturbances tending to move onshore exceeds the part tending to move offshore. And finally, the time scale of adjustment after a disturbance increases rapidly with depth.

Stimulated by these conclusions we adopt the following approach to generate results on the spreading behaviour of nourishments. By using a synthesized or schematized wave climate as an input, pairs of profile evolutions are generated by the Roelvink and Stive model: one for an undisturbed, ideal profile (giving the "autonomous" development) and one for a disturbed, ideal profile, which is identical to the former except for the nourishment. Our basic assumption is that -until we know better- the spreading can be derived by comparing a nourished profile development with an autonomous profile development. The reasoning behind this is twofold:

(1) The autonomous profile development on the scale of years to a decade is most probably not well represented by the dynamic model, both because of

deficiencies in this model and because in reality there will be more than just cross-shore processes responsible for the profile development. So, for the time being we assume that in a practical situation, there exists in one form or other an "autonomous" profile development, which is not resolved nor affected by our approach;

(2) Because we may consider the nourishment as a profile disturbance lifting the profile away from "equilibrium" we assume that the dynamic development is more accurately computed by the dynamic model than the "equilibrium" development.

Our present, initial interest is into beach or upper shore nourishments rather than into subaquaous profile nourishments. Although we would promote the application of profile nourishment in general (Stive et al., 1991), common practice is still to feed the beach rather than the subaquaous profile.

The "ideal" profile applied as the initial profile for the calculations, which we term the Dean-Moore-Wiegel profile (DMW-profile), consists of the equilibrium profile with a grain diameter dependence in the proportionality constant (e.g. Dean, 1991). Near the waterline, however, we adopt a constant slope, related to the grain diameter and the exposure of the coast following Wiegel (1964), as follows:

$$D=Ax^{2/3} \quad \textit{for} \quad dD/dx \leq \tan\beta$$

$$D=D^{*}-\tan\beta(x^{*}-x) \quad \textit{for} \quad dD/dx > \tan\beta$$

where D is the mean still water depth, x the cross-shore distance from the virtual waterline belonging to the Dean-profile, tanβ the beach slope, A the proportionality constant and the parameters denoted with an asterisk are evaluated at the location where dD/dx = tanβ. D^* and x^* may be easily computed, but since these parameters are imposed by the Dean-profile, it is not possible to directly control the resulting DMW profile value at x = 0. In the cases presented we have chosen a grain diameter of 200 μm (so that A=0.1) and a corresponding beach slope for exposed beaches of 1:75.

On the resulting ideal profile we place a nourishment (i.e.; beach fill) of 100 m^3/m which with a triangular shape, maximum height near the waterline and reaching from minus 2.5 m to plus 1 m, bringing the coastline some 57 m seaward. This may be considered as intermediate between a pure dry beach nourishment and a pure subaquaous nourishment. Since, in general, beach fill is spread quickly across the upper part of the profile, the present results can be considered representative for most of the commonly applied beach nourishments.

In compliance with Hallermeier (1981), we have adopted the nearshore wave climate synthesis of Thompson and Harris (1972). They provide a relatively straightforward year distribution for nearshore wave heights as a function of the yearly mean H_{sig}. Here we have assumed that this distribution may be extrapolated to reach a 10-year climate. We are aware of the fact that this assumption may not be correct. Further efforts into this are foreseen.

Results

In our analysis of the results, we have sofar concentrated on the following three questions:

(1) How does the nourishment spread (diffusively, advectively) as a function of the process variables?

(2) Is there a relation between the depth of closure and the "foot" of the nourishment?

(3) How does the nourishment foot (and the depth-of-closure) evolve in time?

In the present paper we discuss results of the following calculations:

■ Run 50 vs run 51, being an undisturbed DMW-profile evolution vs a nourished DMW-profile evolution subject to the same wave climate characterized by a steepness of 3% (see Figure 1);

■ Run 60 vs run 61, being an undisturbed DMW-profile evolution vs a nourished DMW-profile evolution subject to the same wave climate characterized by a steepness of 1% (see Figure 2).

The principal variation between these cases is the wave steepness (all cases have a year-mean H_{sig} of 75 cm). From trial calculations it was concluded that the principal process variable is the wave steepness.

Figures 1 and 2 confirm our earlier thoughts that the beach fill spreads over the profile both diffusively and advectively. To a first approximation, the beach fill spreads like a thinning wedge with its foot going to deeper water, and with the rate of seaward propagation clearly larger for the less steep wave climate. It is interesting to note that the propagation of the nourishment foot more or less follows Hallermeier's closure depth which we have extended for the larger timescale (see Table 2). The extension of Hallermeier is simply realized by assuming that we may replace the important variable H_{sx}, the significant wave height exceeded 12 hours per year, by $H_{sx,y}$, the significant wave height exceeded 12 hours per y year. These results suggest that -to a first order of approximation- we may predict the spreading evolution of a nourishment by applying the suggested extension of Hallermeier for the position of the foot of the nourishment and by assuming that the nourishment volume simply decreases as a thinning wedge.

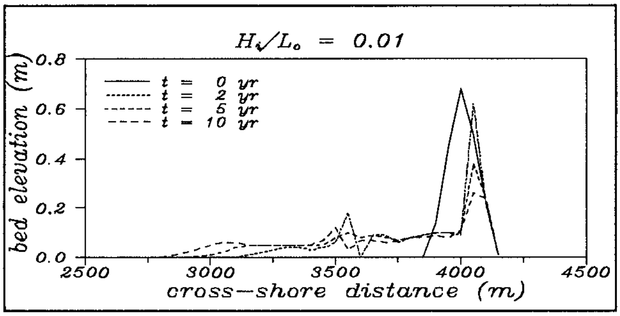

Figure 1 Cross-shore spreading of a triangular beach fill for a low steepness wave climate (SWL at 4000 m)

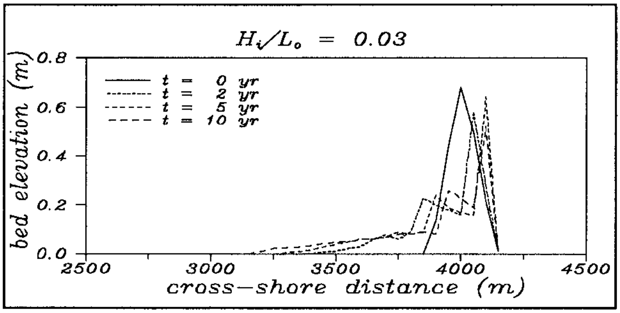

Figure 2 Cross-shore spreading of a triangular beach fill for a high steepness wave climate (SWL at 4000 m)

wave steepness	1/y year storm	$D_{l,\mathrm{Hallermeier\ ext}}$ (m)	$D_{\mathrm{nourishment\ foot}}$ (m)
$H_i/L_0 = 0.01$	1	7.3	8.1
	2	8.0	8.9
	5	8.9	9.9
	10	9.6	10.9
$H_i/L_0 = 0.03$	1	6.5	5.6
	2	7.2	6.1
	5	8.0	7.4
	10	8.7	8.6

Table 2 Comparison of the time evolution of the nourishment foot versus an extension of Hallermeier's D_l.

Simulation of the observed behaviour

It is one of our objectives to generalize and parameterize the spreading process, both for the purpose of practical applications and scientific understanding. In the context of practical applications it is important to note that the presented computational results require relative high computation times, e.g a 10 year simulation with a time step of one day on a 33 MHz 386 with coprocessor at 5 MIPS takes 12 hours. Our parameterization method follows the idea to identify space varying parameters in a diffusion-type equation.

In fact, we consider a class of behaviour models, basically proposed by De Vriend and Roelvink (1988) which shows a close similarity to the n-line concept (Perlin and Dean, 1983; De Vroeg et al., 1988). In general terms (e.g. Capobianco, 1992) we consider the following type of diffusion equation for the profile elevation z(x,t):

$$\partial z/\partial t=\partial/\partial x[F(x)\partial z/\partial x]+\partial/\partial x[V(x)z]+S(t,x,z)$$

where F(x) represents partly the diffusion character and partly an advective character, V(x) the advective character and S(t,x,z) is a source function. With appropriate initial and boundary conditions the *profile elevation* z(x) can be described as a function of *cross-shore position.*

The same basic equation may be applied to describe the evolution of the

The same basic equation may be applied to describe the evolution of the *cross-shore position* x(z) as a function of the *profile elevation*, or the actual cross-shore position $x(z)-x_e(z)$ referred to an "equilibrium profile position", or the actual cross-shore position $x(z)-x_a(z)$ referred to an "autonomous profile position".

The vertical variation of the diffusion coefficient allows us to represent a variation of the morphological timescale with the vertical position, and an asymmetry in the longterm residual sand displacement across the profile. The calibration of this parameter is the key element of the model definition: all information, on hydraulic and sediment characteristics as well as on shorter-term dynamics is stored in it. One objective of our study is to assess -in the context of shore nourishment behaviour- whether and to what extent the diffusion model concept stands in practice, and to find simple and manageable parameterized expressions for the diffusion coefficient F as a function of boundary conditions, geometrical features and environmental parameters.

Conclusions

The longer term objective of our study is to arrive at a predictive method to establish the cross-shore spreading of beach and shore nourishments. The present interest of coastal authorities in nourishment as an appropriate answer to long-term erosion, particularly in the light of an acceleration of sea-level rise, is our motivation to approach the problem with special interest in the time evolution of the cross-shore spreading. The currently most applied quantitative boundary for the seaward extension of nourishments is probably the annual shoreward boundary, D_l, of the shoal zone as developed by Hallermeier (1981). The extension of this concept to include time-dependency is a logical and necessary step in improving beach nourishment techniques. Moreover, insight into the more precise cross-shore variation of the spreading process is of great practical importance.

By application of a detailed process-based, cross-shore morphodynamic model and some inductive assumptions the spreading process is studied as a function of time. The results give qualitative and quantitative indications of the spreading process, in particular concerning the evolution character of the spreading and the relation between the nourishment foot and closure depth. We have extended Hallermeier's concept to longer time scales. This extension is simply realized by assuming that we may replace the important variable H_{sx}, the significant wave height exceeded 12 hours per year, by $H_{sx,y}$, the significant wave height exceeded 12 hours per y year. The propagation of the nourishment foot follows the time-dependent $D_{l,ext}$ quite closely in both examples. Thus, our results suggest that -to a first order of approximation- we may predict the spreading evolution of a nourishment by applying the suggested extension of Hallermeier for the position of the foot of the nourishment and by assuming that the nourishment volume simply decreases as a thinning wedge.

Acknowledgement

This work is partly carried out as part of the European Community MaST G6 Coastal Morphodynamics Project (Directorate General for Science, Research and Development, MaST Contract no. 0035-C) and the Coastal Genesis Research Programme of The Netherlands (Rijkswaterstaat, Tidal Waters Division). MJFS acknowledges the support of the Researchers of Excellence Programme for Catalan Universities of the Generalitat de Catalunya.

References

ANDERS, F.J. and HANSEN, M. (1990)
Beach and borrow site sediment investigation for a beach nourishment at Ocean City, Maryland. U.S. Army Corps of Engineers, Waterways Experiment Station, Coastal Engineering Center, Technical report CERC-90-5, 77 pp

CAPOBIANCO, M. (1992)
A class of partial differential equations for modelling and control of medium term evolution of coastal profiles. American Control Conference, Chigaco, Illinois, 24-26 June

DAVISON, A.T., NICHOLLS, R.J. and LEATHERMAN, S.P. (1992)
Beach nourishment as a coastal management tool: An annotated bibliography on developments associated with the artificial nourishment of beaches. J Coastal Research, 8, 984-1022

DEAN, R.G. (1991)
Equilibrium beach profiles: Characteristics and applications. J Coastal Research, 7, 1, 53-84

DE VRIEND, H.J. and ROELVINK, J.A. (1989)
Innovation of coastal defence: interaction with the coastal system. Rijkswaterstaat/Delft Hydraulics, Memorandum "Coastal Defence after 1990", Technical Report no. 19, 39 pp.

DE VROEG, J.H. SMIT, E.S.P. and BAKKER, W.T. (1988)
Coastal Genesis. Proceedings 21st Int Conf Coastal Eng, Malaga, Spain, pp 2825-2839

HALLERMEIER, R.J. (1981)
A profile zonation for seasonal sand beaches from wave climate. Coastal Eng., 4: 253-277

HANDS, E.B. (1983)
Erosion of the Great Lakes due to changes in the waterlevel. In: P.D.Komar (Editor), Handbook of Coastal Processes and Erosion. CRC Press, Boca Raton, Fl, pp 167-189

NICHOLLS, R.J., DENNIS, K.C., VOLONTE, C.R. and LEATHERMAN, S.P. (1992)
Methods and problems in assessing the impacts of accelerated sea-level rise. Proc. "The World at Risk: Natural Hazards and Climate Change", In press

PERLIN, M. and DEAN, R.G. (1983)
A numerical model to simulate sediment transport in the vicinity of coastal structures. CERC, Vicksburg, Misc. Rept. no. 83-10, 119 pp.

ROELVINK, J.A. and STIVE, M.J.F. (1989)
Bar-generating cross-shore flow mechanisms on a beach. J. Geophysical Research, Vol 94, No.C4, pp 4785-4800

STIVE, M.J.F., ROELVINK, J.A. and DE VRIEND, H.J. (1990)
Large-scale coastal evolution concept. Proceedings 22nd Int Conf on Coastal Eng, Delft, The Netherlands, pp 1962-1974

STIVE, M.J.F. , NICHOLLS, R.J. and DE VRIEND, H.J. (1991)
Sea-level rise and shore nourishment: A discussion. Coastal Eng., 16: 147-163

THOMPSON E.F. and HARRIS, D.L. (1972)
A wave climotalogy for U.S. coastal waters. Proc. Offshore Tech Conf, 4th, Houston, Vol II, pp 675-688

VAN ALPHEN, J.S.L.J., HALLIE, F.P., RIBBERINK, J.S., ROELVINK, J.A. and LOUISSE, C.J. (1990)
Offshore sand extraction and nearshore profile nourishment. Proceedings 22nd Int Conf Coastal Eng, Delft, The Netherlands, pp 1998-2009

WIEGEL, R.L. (1964)
Oceanographical Engineering. Prentice-Hall, London