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Beaches - the natural way to coastal defence

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BEACHES - THE NATURAL WAY TO COASTAL DEFENCE

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1 INTRODUCTION

Development of the coastal strip for industry, housing, and leisure has led to the construction of a wide variety of solid structures such as promenades, reclamation walls, and road/railway embankments. Many of these structures now also serve as defences against erosion or flooding. In most cases, a beach forms a vital part of the defences, but often by default rather than by specific design.

By continually adjusting its shape, a beach absorbs much of the incident wave energy, hence reducing the forces on the structures behind. Long term erosion will reduce the capacity of a beach to perform this function, and also allow the undermining of the defences themselves. The amenity value of the coastline is also reduced.

Recognising the key role of beaches in protecting the coast, and acknowledging the recreational opportunities and the need for environmental conservation, engineers are increasingly turning to 'soft' defence options. Active beach management techniques such as periodic nourishment, bypassing and re-cycling are now commonplace alternatives to strengthening or rebuilding seawalls. There are now a sufficient number of such schemes operating in the UK to demonstrate that they can be safe and economically worthwhile. However, designing a beach to provide a specified level of protection over a required lifespan is still a major problem. This paper concentrates on the role of beaches, whether natural or man-made, in defending the coast. In particular, attention is focussed on methods for predicting beach morphological changes, both well-established and novel.

2 NATURAL BEACHES AS ROLE MODELS

If existing, solid defences are to be protected by a 'managed' beach, the logical way to proceed is to base its design on existing local beaches. Indeed there is considerable pressure to choose just this strategy. There are clear advantages from both aesthetic and ecological viewpoints in adopting the equivalent to a vernacular style of architecture. It is also likely that there will be an economic advantage in using locally available materials.

It has to be recognized, however, that a healthy natural beach that has endured wave attack for centuries does not necessarily provide a satisfactory coastal defence. Massive barriers such as Chesil Beach have been overtopped - even breached - in the past, with subsequent serious flooding of the hinterland. With so much development close to the coast in modern times, similar failures in the future could be catastrophic. Artificially built or strengthened beaches will therefore have to be more substantial than their naturally created neighbours.

Showing that even a substantial beach will be an adequate defence is no easy matter. As in many other walks of life, there is an ever increasing requirement for certainty, especially when there is a threat to life or property. Solid coastal defences can fail suddenly, and without warning, leading to serious flooding or erosion. Despite this, the populace have grown accustomed to massive seawalls, and regard artificial beaches with suspicion, sometimes hostility. It is important to demonstrate the safety of a beach under severe conditions, and also to provide a well-justified estimate of its likely maintenance requirements and its expected life. This presents a challenging task when dealing with beaches and their responses in the complex and hostile coastal environment.

It is necessary, therefore, to use predictive techniques, principally numerical simulations or scale physical models, to examine the behaviour of beaches. In extreme conditions, for example storm waves occurring at the same time as an exceptional tidal level, it is the short-term response of a beach profile which is of prime concern. In the long-term, however, it is likely to be the movement of beach material along the coast which requires more attention. Understanding the morphological changes of natural beaches, and particularly the causes of erosion, is vital. Because of this, measurement of waves, tides, and especially beach changes is an essential component of the 'soft' defence strategy. The data obtained not only helps to demonstrate the performance of any scheme, but also provides both calibration of, and inspiration for, the methods used to predict beach behaviour.

3 NUMERICAL MODELLING OF ALONGSHORE SEDIMENT TRANSPORT

It is convenient to start a discussion of the various predictive methods used to study or design beaches by separating the movement of beach sediments into two components, namely along the coast (ie parallel to the beach contours), and cross-shore (ie perpendicular to the contours). As will be mentioned later, this is a simplification which can now be avoided, but will serve for the time being.

In most situations where beach erosion is rapid, and persists over a period of months or years, the cause is a change in the pattern of alongshore transport of sediment. One eminent coastal engineer (Galvin, 1990) recently stated that

"...all examples of shore erosion on nonsubsiding sandy coasts are traceable to manmade or natural interruptions of longshore sediment transport"

This is certainly an over-simplification but serves to emphasise the importance of alongshore drift in the evolution of beaches, both in the UK and overseas. When material has been lost from beaches that have been nourished, for example, it is usually this mechanism that has caused the damage.

Against this background it is not surprising that much of the effort exerted in predicting beach evolution has been spent in developing models of alongshore sediment transport and the changes in beach plan shape that it can cause. Simple computer methods that can, for example, simulate beach accretion and erosion on opposite sides of a harbour or long groyne have been in routine use for over 20 years, and are now available as off-the-shelf packages from a variety of specialist consultants around the world.

The most common type of model is the so-called "one-line" method in which the advance or retreat of the beach face is deduced from predictions of the changing position of a single, representative contour (usually the high-water mark or mean sea-level). By definition, such models do not predict changes in beach profile shape but if the objective is to simulate the long-term changes in a beach, over several years or more, then this is not a serious drawback. Nett changes in the beach profile over such a period are usually small compared to those brought about by alongshore sediment transport.

The formulation of the equations used to calculate the rate of transport are generally rather simple, and often partly empirical. As a result they may not be sufficient to accurately predict the movement of beach material over a few hours or days in a severe storm. Despite this, long-term modelling has proved to be a powerful technique, especially on relatively straight coasts when there is good historical information which can be used for calibration. The simplicity of the one-line model has also been an advantage in tackling more complex coastline problems. The original validation of this type of model was for the long, straight, sandy beaches of California (Komar and Inman, 1970), where tidal currents were low and waves were often near-monochromatic in character (ie of single wave height and period). Over the years, however, very similar models have been developed to study the changes in beaches along the coast of the UK, where tidal ranges are high and the beach material is often of shingle (Brampton and Motyka, 1985), or a mixture of sand and shingle.

Recent developments have included the ability to model the effects of groynes on shingle beaches, a necessary improvement given the large number of such structures around our coasts. Since such groynes are rarely long enough to prevent some transport of shingle past their tips, it has been necessary to calculate the variation in the alongshore drift rate across the beach profile. This involves using information on the level of the tide at any instant, expressed in probablistic terms, together with an expression for the distribution of wave-induced transport of beach material at different depths relative to the tidal level. At present the distribution function is derived from experimental data, but could equally well be calculated from numerical modelling of processes acting over the whole beach face. This extra element in the modelling of alongshore transport has identified an interesting feature affecting coastal development. At several sites around the coast of the UK, it has been found that the nett direction of alongshore sediment transport is different at different beach levels. Small but persistent wave action may produce a drift northward on the upper part of the beach profile, for example, while occasional large storm waves can cause a southward movement lower down the beach face.

This effect may also be caused by tidal currents, which modify the wave-induced drift of beach material, particularly on the seaward portion of the active beach profile. Again recent modelling of beaches in the UK has suggested that the situation where drift is in opposite directions at the beach crest and the toe of the beach profile is more than a theoretical oddity.

The modifying effect of tidal flows on beach sediment movement greatly complicates any modelling exercise. It is difficult enough to produce sufficient, accurate wave data (recorded or hindcast) to drive a model of beach evolution. The increase in effort to include the tidal currents and variation in water levels would be a serious additional burden. In view of this, considerable effort has been spent in "input filtering", that is to say in reducing the amount of data needed to successfully predict the changes which a beach will undergo. One simple example is ignoring all waves with height less than a certain threshold value, because they would not have sufficient energy to move the beach material. A more complicated idea is to adjust the formula for wave-induced sediment transport to reflect an 'averaged' effect of tidal currents. This involves the use of a subsidiary model, run prior to the main beach model, which calculates the total effect of both waves and tides on alongshore transport rates over a complete tidal cycle (or even over a Spring-Neap cycle) for a wide variety of wave conditions. This results in a more complex model, but one which can still be run relatively easily, for long periods, and with sufficient resolution to examine alternative groyne layouts, for example.

The major requirement for such models is now good calibration data, from laboratory experiments but more importantly from suitable coastal sites. The morphological data from the coast will need to be accompanied by information on wave conditions as well. Numerical experiments, supported in part by historical data on coastline changes, have shown very large variability from year to year in the alongshore transport at many sites around the UK coast. This fluctuation in nett annual drift rates makes it very difficult to define an average value. Typically, it may take 10-20 years to produce a statistically reliable estimate of the mean value, by which time climate changes may well be a factor needing to be taken into account.

4 NUMERICAL MODELLING OF CROSS-SHORE SEDIMENT TRANSPORT

The variability of beach levels, particularly against the face of a seawall is a source of considerable excitement and concern around the coast of the UK, and the world outside. Local residents - and sometimes the local coastal managers - are often convinced that their own stretch of coast is unique in this respect, and talk in awed tones of the sudden fall in levels during a single tide, ie between successive low-water periods. It is worth making the point, in passing, that levels against a defence may fall even lower at the time of high water than revealed by a survey a few hours later when the beach dries. A method of recording beach levels continuously during a storm would provide valuable, new information either for natural beaches or those with defences at their rear.

On an open, unobstructed beach (ie without groynes), short-term morphological changes will be dominated by cross-shore transport mechanisms. Despite this, modelling the movement of sediment up and down the beach face has been neglected in comparison with alongshore drift studies. In the UK particularly, the large tidal range usually prevents the formation of significant nearshore 'bars' which intrigue coastal research workers in many other countries.

Models currently available to predict beach profile changes fall into two categories. On one hand there are empirical techniques, usually based on relationships between the beach profile shape and the incident wave parameters. These models are based upon analysis of laboratory experiments, and make no attempt to represent the transport mechanisms. They are, however, easy to apply and cheap to use. Limited field measurements also show that the laboratory experiments give realistic representations of beach profile response to wave action, particularly when dealing with shingle.

The alternative approach, being developed in many countries around the world, is to model first the hydrodynamics affecting the beach, and then calculate the resulting transport of sediment. This is clearly a more satisfying approach from a scientific viewpoint, but some degree of approximation is still required to obtain reasonable results. The models of this type also allow the time development of a profile to be studied, rather than presenting just the final 'equilibrium' profile for any wave condition. Understandably, such techniques require much greater computational effort and have been slow to develop. The most recent versions are beginning to show encouraging signs of reproducing beach profile changes measured in large laboratory experiments.

Even so, a recent paper on beach response to storm waves (Huntley, 1991) states that the predictive skills of such models are very low. This is hardly an encouraging assessment for those needing to demonstrate the safety of artificial beaches in extreme conditions! Little convincing work has yet been done on the effects of man-made structures on the development of beach profiles using such models, nor on the interchange of sand between dunes and the beach face.

It is also becoming clear that wind waves alone do not necessarily determine the changes in beach profiles, or the associated cross-shore transport of sediment. On oceanic shorelines especially, the primary (ie wind-generated) waves produce underlying 'long-waves' which have periods of a few minutes. These long-waves are much more important than the primary waves when considering certain aspects of coastal engineering, particularly the movement of large vessels within harbours. A number of research studies point to the possibility of such long-waves being important in moving sediment on the face of a beach, and thus being a factor in shaping the beach profile. If this is indeed the case, there will need to be considerable further work on wave prediction in shallow water to produce appropriate input conditions for beach profile models.

Before leaving the subject of beach profile models, a further difficulty needs to be highlighted. The models of beach profile development are usually only used for a short time period, typically long enough to consider the effects of a single storm event. It seems likely that 'upscaling' these models to predict profile evolution over weeks, or months would be very difficult, and perhaps impossible, at least in the foreseeable future. There is no equivalent, apparently, to the long term one-line models used for beach plan shape predictions, which can be 'downscaled' to predict short-term changes without exciting great concern.

The problem of long-term beach profile prediction is further complicated by gradual effects not included in the normal models. These include sea level change relative to the land, erosion of the often soft rock substrate on which the beach material rests, and losses of material both seaward and landward. These losses may include wind-blown sand moving landward of the active dune system, or the dispersal offshore of fine-grained material, as well as direct human intervention (eg sand-mining).

The only method of predicting long-term beach profile changes at present therefore appears to be to statistically analyse historical data, for example regularly surveyed beach cross-sections, and to extrapolate into the future using the trends identified. This further strengthens the case for monitoring beaches by coastal authorities charged with their management.

5 NUMERICAL COASTAL AREA MODELLING

The previous two sections of this paper have discussed the modelling of beach morphology by separating the sediment transport into perpendicular components, along the contours and parallel to them. Interactions between the transports in the two directions are either ignored or only taken into account in a simplified way. Recent developments in the modelling of coastal changes have allowed this simplification to be overcome.

First, for straight or nearly straight beaches, it is possible to combine the methods already developed for the alongshore and cross-shore sediment transport, and so produce a model which can calculate, at least in the short-term, the changes in morphology in a single operation. One such model was developed, and subsequently employed as part of the NRA (Anglian Region) study of the management of sea defences between the Humber and the Thames Estuary. It can be anticipated that such models will become a standard tool in the coastal manager's tool-kit in the future.

In situations where the sea bed contours, or the solid geomorphology of the coast is complex, however, the basic assumption that waves and tidal current are shore-parallel and vary only slowly along the beach is untenable. In this situation it is necessary to change the basis of the beach morphological model completely. A grid system has to be established over both the beach and the nearshore sea bed, and the hydraulic forces, ie the waves and tidal currents, evaluated at each mesh point. This is then followed by calculation of the sediment transport vectors over the whole grid, leading to deductions on the resulting morphological changes. The whole cycle of operations is then repeated. Since such models have been developed to deal with beaches which are not of a simple shape, it can be appreciated that the computational effort involved can be enormous, even to consider changes over a few hours or a single tidal cycle. The development of these complex models has therefore required a great deal of thought to decide on both the range of processes that should be included, and the degree of detail required to represent each (process filtering), and also the number of different input conditions (eg tidal range, wave height) that are needed to provide useful predictions (input schematisation). The development of both these powerful coastal area models, and the methods used to apply them in practical situations, will be the subject of many further years of research worldwide.

6 PHYSICAL MODELLING OF BEACH MORPHOLOGY

Given the difficulties, and cost, of using numerical models of complex beach areas, for example in the lee of a system of offshore breakwaters, scale physical models remain a major force in predicting coastal changes.

The introduction of sediment into scale models always requires careful planning, and validation from prototype beaches whenever possible. In addition, it is normally necessary to use a numerical model alongside a physical model, in order to evaluate the sediment transport rate scaling (which is generally different to that for the water velocity scale). A discussion of this interactive use of physical and numerical model techniques has recently been presented, (Brampton et al, 1991) which provides further details.

Given this initial effort, which is certainly required for numerical models as well, the use of scale physical models can certainly provide useful predictions of short-term beach changes. It is worth making the point that such models have also provided much of the calibration data for many of the numerical modelling methods now in everyday use.

At the same time, there are clear limitations on such models. It is difficult to model more than 1-2 km of coastline in a normal laboratory basin. Time and cost constraints also prevent the use of physical models for longer than a few weeks (prototype), so that beach evolution over longer periods has to be extrapolated using numerical techniques.

7 BEACH MONITORING

If we are to use beaches as a method of defending our coasts, the best results will be achieved by a combination of careful design with subsequent monitoring and analysis.

One consequence of the growing use of beach nourishment has been an increase in the surveying of the coast. In this situation, simple analysis of the volume of beach material provides an easily understood way of checking on the success of the defence scheme. Changes in volume can be converted into monetary terms, and the cost-effectiveness of the works can be assessed. This is much less simple to do when assessing the cost-effectiveness of other types of defences, for example groyne systems.

Monitoring beaches can achieve much more than this, however, and it is worth setting out the main advantages that could be gained from regular surveying. First, it is clear that money available for defending the coast should be allocated on the basis of demonstrable need. Surveying and analysing the coast provides evidence to support assertions that beaches are likely to fall to dangerously low levels in the future. Using the observed trends, and information on severe wave and tidal conditions, it is then possible to evaluate the likely future performance of defences, and arrange a programme of improvements well in advance. Strategic planning of this sort is not common around the coast of the UK at present, and awaiting the failure or near-failure of defences rarely allows an optimal solution to be installed.

Monitoring should also provide useful information on the relative performance of different types of defence works. As an example, it is still rare to see beach profiles compared with the cross-section of a groyne. It is difficult to see how groyne profiles can be improved without this basic information. Similarly, many authorities have a variety of sea walls along a single frontage. Measuring beach levels close to the face of defences should indicate whether different slopes, roughness, or permeability could produce a healthier, less volatile upper beach.

Finally, from a scientific viewpoint, the data obtained will be invaluable in the development of predictive models of beach behaviour. Better understanding of natural or artificial beaches can only help in the adoption of 'soft' defences which are safe, economical and environmentally sensitive.

8 REFERENCES

1. Brampton A H, and Motyka J M,(1985). 'Modelling the plan shape of shingle beaches', Lecture Notes on Coastal and Estuarine Studies, 12 , Springer Verlag, Berlin.

2. Brampton A H, Powell K A, Goldberg D G and Lowe J P,(1991). 'Application of numerical and physical modelling to beach management problems', Proc 3rd International Conference on Coastal & Port Engineering in Developing Countries, Mombasa, Kenya, pp180-194.

3. Galvin C,(1990). 'Importance of longshore transport', Shore and Beach, 58, no 1.

4. Huntley D A, (1991). 'Beach response to waves and currents detailed field measurements', Developments in Coastal Engineering, University of Bristol.

5. Komar P D, and Inman D L, (1970). 'Longshore sand transport on beaches'. Journal of Geophysical Research, 75, no 30.

SCRIPT

Thank you Mr Chairman

(1) Good afternoon, Ladies & Gentlemen. The title of my presentation is "Beaches - the natural way to coastal defence"

(no question mark - no exclamation mark)

(2) In the next 20 minutes, I would like to review some of the current thinking on this subject.

(no mention of PPG v DOE committees
not even a slide of the house perched on the cliffing)

(3) As an introduction it is worth reflecting on progress achieved. Over the last 10 years in particular there has been a shift away from steep, impermeable, solid structures towards shallow sloped, permeable and flexible coastal defences. Rock mounds, concrete armour and deformable revetments have all appeared and been successful. It is beaches however, that are the ultimate example of this trend - whether natural beaches controlled re-inforced or "new" beaches created.

(4) You will recall, I am sure, the list of significant milestones in Coastal Engineering presented by Dr Fleming yesterday. He pointed out the early 1970s as a time of rapid advances in measuring and modelling the coastal zone.

(5) I would add to that period the first major beach nourishment schemes in the UK, for example Portabello & Bournemouth - the runner of so many soft defence schemes.

(6) Perhaps the coastal engineers and managers are to modest about these successful innovative/schemes methods. Without them soft defences options would be an academic concept (still) not the popular "bandwagon" so widely advertised [These people have engendered the change]

(7) As the first main topic area, I would like to review the advantages and disadvantages of beaches as defences. Please note, I have <u>limited</u> my presentation to beaches of sand and shingle (<u>non-cohesive</u>) material), however. Management of muddy foreshores is an important future area - but one with, as yet, insufficient UK practice for me to form opinions.

(8) <u>ADVANTAGES</u> (most of the time)

- "easy" to install and maintain (in concept)
  not so much a building site as giant sandcastle
  (grace of dredging industry)

- do not transfer <u>erosion</u> effects alongshore
- easy to demonstrate performance measure

- aesthetically better
- added value for leisure pursuits
- require strategic planning (thought)

(9) Onto each a little rain must fall, however, even the just godly.

DISADVANTAGES

(a) New Beaches are unlikely to provide a permanent solution to problems of beach erosion - lifetime may be less than solid structures.

(b) Not practical over short frontages (eg to compensate for a localised seawall failure)

(c) Not seen as secure/reliable by the populace (used to seawalls) - although in the UK such defences are usually additional rather than on their can.

(d) To obtain the best - beaches require management ie monitoring and maintenance - and hence stuff resources to do this:-

(e) Siltation effects elsewhere

A successful soft defence policy/scheme this needs a local, longterm commitment to active shoreline management - staff and resources - a change in approval for many coastal authorities [8 mins]

(10) Scheme viability depends on local conditions two factors are site dependent.

(11)

(a) Ecological impact

- a beach scheme may have much better ecological attributes than a higher, deeper seawall - but you require eggs to make an omelette. The use of material which would other wise be lost to beach systems is recommended for research. Bournemouth Borough have recently re-nourished their beach using material from the entrance channel to Poole Harbour - great.

(12) Mother Nature tends to be untidy/as well as spiteful) - recovery of beach material being lost offshore naturally is also research - worthy.

Beware, of course, outwashing of spines, especially where marine biology can be adversely affected (rare in UK waters)

(13) (b) Cost Effectiveness

- Size of beach affects capital cost - but has to be sufficient to withstand severe events.

- maintenance requirements and lifetime clearly also vital factors/in equation.

(14) Retrospectively major beach schemes have worked better than hoped for - predictions were perhaps over cautious.

(15) There is a need for good predictive techniques, therefore to judge future beach performance -

In the long-term (several years)
the short-term (severe storm)
(including any cyclic behaviour in between)
(John Pethick)

(16) Over caution may produce missed opportunities. Under design may cause damage/perhaps loss of life/and set-back the whole movement to more environmentally acceptable defences.

(17) Predictive techniques can be physical models, computer simulation of teach processes numerical analysis of observed behaviour and the like. A brief review is presented in the written paper.

(18) I would highlight the following:

Modelling alongshore drift is complicated even on straight coastlines by natural drift variability from year to year. Global warming may affect this already volatile behaviour with much more substantial changes to our shoreline than sea level rise.

(19) Linking hydrodynamics, sediment transport and beach morphological changes on curved shorelines has proved very difficult - eg timescale of response to changing wave climate.

(20) Cross-shore transport and beach profile changes are poorly understood - although they dominate upon shorelines in the short term (UL lags??)

(a) More work is needed on the effects of structures

(b) Are long-waves important - and if so how do we prove/measure this

(c) How important are long term profile changes- certainly seem to be on cohesive foreshores. Where there is a soft rock substrate. Is sea-level rise important? - difficult so to prove on past evidence.

(21) Data gathering - much mentioned already in this gathering
- to anticipate and prioritise defence works.
- to monitor success of schemes (or not!)

but also (!)to provide inspiration for a validation of predictive models of beach changes.

(22) Conclusions

(1) All defence schemes have to be <u>designed</u> - with no exemption for beach schemes
(2) It is difficult to predict beach behaviour
- in the short term
- in the long term (and in between).
(3) Further modelling developments and data gathering will improve the predictions of beach change and hence, I expect, increase their use.

(23) <u>Recommendations:</u> (Specific)

(1) Need for proper modelling of the evolution of strongly curved shorelines.
(2) To consider, measure and evaluate the effects of long-waves on beach (profile) changes
(3) Optimise measurements of beach changes and what causes them (feedback loop)

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