Coastal Steepening - the UK view

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Report TR 91
July 1999

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Contract

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Summary

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This report outlines the British position on coastal steepening, defined as the phenomenon whereby the cross-shore profile does not retreat or progress as an equilibrium profile, but develops towards a steeper profile. It incorporates the views of HR staff and many other individuals, listed in Appendix 1. The evidence for coastal steepening in the UK is summarised. The effects of coastal steepening, determined from field observations, laboratory tests and numerical models are discussed. The postulated causes for coastal steepening are outlined and their likely importance commented on. A list of projects that are already in the planning stages and that could be used to study this phenomenon is given. The consequences for coastal management are discussed. Possible actions against the consequences and the outstanding problems in this field are listed. The UK view forms part of a larger picture of coastal steepening around the North Sea coast, described in a separate report prepared by a Working Group comprising representatives of five of the nations bordering the North Sea.

Contents

1. INTRODUCTION

At the meeting of the North Sea Coastal Management Group on May 28-30, 1997, some of the members suggested broadening the scope of the discussions by including more detailed work related to themes of common interest. The themes Profile Steepening and Probabilistic Design were selected for further studies in working groups under the leadership of Per Roed Jakobsen, Kystinspektoratet and Richard Jorissen, Rijkswaterstaat respectively.

At the first meeting in Billund, Denmark on 12 January 1999, led by Per Roed Jakobsen, Chr Laustrup was appointed chairman of the group and Holger Toxvig Madsen was appointed secretary. Besides the meeting in Billund, there has been a meeting in Brussels in March 1999 and a meeting in Amsterdam in April 1999.

The report "Profile Steepening, a report prepared for the North Sea Coastal Management Group" (Reference 1) was then prepared by a working group with these members:

Belgium:	Toon Verwaest, Ministerie van de Vlaamse Gemeenschap – Waterwegen Kust
Denmark:	Chr. Laustrup (chairman), Kystinspektoratet Holger Toxvig Madsen (secretary), Kystinspektoratet
Germany:	Hans Kunz, NLOE – Forschungsstelle Küste Peter Hüttemeyer, NLOE – Forschungsstelle Küste
The Netherlands:	Jean-Marie Stam, Ministry of Transport, Public Works and Water Management, RIKZ
United Kingdom:	Richard Soulsby, HR Wallingford Ltd.

Coastal steepening was defined as the phenomenon whereby the profile does not retreat or progress as an equilibrium profile, but develops towards a steeper profile. With such a steepening, assumptions of the future development cannot directly be extrapolated from the development up to now.

The UK position is given in greater detail in this report, TR91. Compared with the countries on the eastern side of the North Sea, the UK coastline is very varied. It has long lengths of both hard and soft cliffs, many estuaries and salt-marshes, beaches composed of all sediments from soft mud through sands to shingle, but relatively few deep, straight sandy beaches backed by dunes. Sediments are often of mixed material, and commonly consist of a thin veneer (less than 1m) of mobile material overlying substrates of hard clay, chalk, or compacted gravel. In addition, wave heights are generally smaller, and tidal currents larger, on the west than on the east coast of the North Sea.

To investigate the awareness about coastal steepening in the UK, and to seek evidence of it, enquiries have been made to representatives from regulatory authorities (MAFF, the Environment Agency and maritime Councils), coastal engineering consultancy firms, and government research laboratories. A list of those canvassed is given in Appendix 1. The results of these enquiries have been incorporated in this report. The consensus view of the people canvassed was that narrowing of the beach or inter-tidal zone is widely recognised as an issue, and has been observed along much of the south and east coastlines of England. However, there is little awareness of steepening of the sub-tidal shoreface, mainly because of lack of data.

"Coastal squeeze" as a generic term analogous to coastal steepening covering all the coastal zones is seen as a major issue (particularly on saltmarsh and mudflats), from both a flood defence and a habitat perspective. This perception is partly because the main evidence in the UK waters is from the inter-tidal zone (i.e. between the lines of Mean High and Mean Low Water Spring Tides). Although repeat hydrographic surveys are made in bathymetrically volatile areas, for navigation purposes, they do not appear to have been analysed to search for evidence of either deepening or steepening of coastal waters.

2. EVIDENCE FOR COASTAL STEEPENING IN THE UK

Examples of inter-tidal narrowing, and hence steepening, are well illustrated by Figure 1, taken from the English Channel coast (Reference 2). In the eastern half of the figure, the LW mark has retreated in 95 years by 50 to 100m, whereas the HW mark has retreated by only 10 to 30m. Thus here the inter-tidal zone has narrowed by up to 1m per year. In contrast, in the western half of the figure there has been little if any narrowing. Taking the whole coast of Hampshire (c. 60 km), most of the coastline exhibits inter-tidal narrowing. This occurs on flatter salt-marsh coasts as well as steeper beach-lined coasts. In places, the inter-tidal width is only one-fifth of that recorded 100 years ago.

Similar evidence is found on the South Wales coast (Reference 12), bordering the Bristol Channel (Figure 2). The greatest narrowing occurred between 1880 and 1915, possibly following coast protection works, although a change in definitions of LW and HW marks between the two surveys cannot be ruled out. Since 1915 the process seems to have slowed or stopped, except near Port Talbot and Aberthaw.

Anglian Water commissioned a study of the historic behaviour of the coastline from Flamborough Head to the Thames over the period from about 1850-1890 to the 1970's (References 3, 4). As part of the study, combinations of advance/retreat and steepening/flattening were categorised on scale indicated by –6 to +6 (Figure 3). Short lengths of the coast were individually assigned values on this scale. They found that 70% of the coastline was retreating, and 78% was steepening inter-tidally (Figure3). The inter-tidal narrowing in some places occurred at up to 2m per year. The rate is very variable along the coast, with inter-tidal widening occurring in a few short lengths, and some steepening with net advance also occurs. They observed that the behaviour correlates with the geological setting and coastal structures, such that:

- glacial till cliffs retreat and cause intertidal steepening
- a sand veneer over a clay or chalk bed can give steepening through abrasion
- deep non-cohesive sediment beds exhibit little steepening
- beach control structures of all kinds are associated with steepening.

A view contrary to the last point was made in a later study of observed changes in salt-marshes, which did not find any clear correlation between coastal squeeze and the presence of sea defences (Reference 5).

Deductions about the behaviour of the "shoreface ramp" along the Holderness coast of the North Sea, extending north of the Humber estuary, are made in a recent paper (Reference 6). By assuming a constant profile retreating at 0.8 to 1.9 m per year (observed as cliff erosion), and assuming a seabed slope of 1:100 in the region from MSL-3m to MSL-14m, it was deduced that the seabed is deepening at 0.8 to 1.9 cm per year. This is attributed to abrasion of the hard-clay glacial-till seabed by an overlying veneer of sand. Note that this corresponds to deepening, but not to steepening. They showed that cliff erosion provides only 23%, and seabed erosion 77%, of sediment input on this coast, and they surmised that cliff retreat is governed by seabed erosion, and not vice versa.

Several of the local Councils canvassed by HR reported a tendency for the upper beach face to become steeper, especially for recharged beaches in front of seawalls. A few maritime local authorities have also been surveying the nearshore seabed, by continuing their conventional beach profile surveys below the low water mark. Of those canvassed, only Bournemouth CBC had noticed any evidence for changed levels below low water; at the seaward end of their surveys (about 5m below lowest tide), they have detected some increase in bed levels. They tentatively attribute this to isostatic re-adjustment following erosion of cliffs over the last millennium or so. The changes in the subtidal zone and the lower shoreface were seen as impacting on the upper beach. Cyclic changes in profile steepness from winter to summer were noted at some beaches. A summary of the opinions expressed by those surveyed can be found in Appendix 2.

3. EFFECTS OF COASTAL STEEPENING

3.1 Field evidence

Field evidence for the effects of coastal steepening comes from the damage done to almost identical rock groynes at Barton-on-Sea and Milford-on-Sea which are only 5 km apart on the south coast (Reference 7). The inshore wave climates are similar but the groynes at Milford-on-Sea, where the foreshore has a slope of 1:25, suffered much more damage than those at Barton-on-Sea where the foreshore slope is only 1:90.

3.2 Laboratory evidence

Allsop et al (Reference 7) performed tests in a wave flume that showed that damage to beach control structures is significantly increased by steep (local) beach slopes, even for simple slopes subject to normal wave attack.

Hawkes et al (Reference 8) performed a series of laboratory tests to measure the overtopping of, and damage to, coastal structures, which included the effect of varying the beach slope in front of the structure. Figure 4 shows the overtopping rate against beach slope for three wave conditions. In all cases the overtopping rate increases with beach slope up to a steepness of between 1:20 to 1:10, and is then approximately constant for greater slopes. Figure 4 also shows the percentage damage for eight wave conditions, each of which propagated over beach slopes of 1:20 and 1:50 before reaching the same structure. In all cases the steeper beach slope resulted in a substantially greater amount of damage.

3.3 Numerical model evidence

Numerical models have been used to investigate the effects of differences in the steepness of the beach slope in front of a seawall on the overtopping rate, damage and undermining potential. The layouts for these tests are shown in Figure 5. A combination of two numerical models was used: COSMOS-2D (Reference 9) to model wave propagation from a point 3km offshore up to the vicinity of the seawall, and the newly-developed shallow-water research model OTT (Reference 10) to model the run-up and overtopping behaviour within the last 120m.

The key results are shown in Figure 5 and Table 1. The upper part of figure 5 shows the variation in bathymetry, and the wave height distribution determined by COSMOS-2D, for six approach beach steepnesses between 1:200 and 1:20 with offshore significant wave height of 8m, a peak period of 13s and mean water level 3m above the toe. This represents 10-year return period conditions for a typical UK east-coast storm and a JONSWAP sea. The 6m high impermeable sea wall has a front slope of 1:2. Decreased dissipation on the steeper approaches causes the significant wave height at 120m, H_{s120} (at the start of the OTT run) to increase with increasing beach slope from 2.54m to 6.64m. The middle panel shows that the mean overtopping rate increases markedly as the beach slope in front of the structure steepens, from almost zero at 1:200 slope to 0.54 $m^3/m/s$ at 1:20 slope. The bottom panel shows that the maximum velocity at the mid-point of the structure (U_{max2}), and the r.m.s. velocity at the toe (U_{rms1}), both approximately double as the beach slope increases from 1:200 to 1:20. This is an indication that both structural damage and toe-scour will be greatly increased if the beach steepens in front of the wall.

Table 1 shows the input conditions for the OTT model (unshaded) and the output (shaded). OTT outputs the root-mean-squared (U_{rms1},U_{rms2}), and the maximum (U_{max1},U_{max2}), depth-averaged wave-orbital velocity at the toe of the structure (subscript 1) and at the midpoint of the structure (subscript 2). The mean overtopping rate is Q_{mean} ($m^3/m/s$), the maximum overtopping rate in any one timestep is Q_{max} ($m^3/m/s$), the number of overtopping waves is N_{OTT} and the maximum volume of water that overtops the structure in any one wave is V_{max} (m^3/m). These figures give respectively an indication of the likelihood of scour at the toe of the structure and damage to the structure. OTT was run for 500 peak periods.

Four additional runs were performed, all at 1:50 slope, that showed that increasing the offshore wave height (H_{so}) or mean water level (MWL_o) increased the overtopping rates and the velocities on the structure. It can be seen from the tabulated values that the increase in overtopping rates and wave orbital velocities resulting from a steepening of the beach from 1:50 to 1:30 (with H_{so} = 8m and MWL_o = 3m in both cases) is greater than that resulting from an increase of H_{so} to 11m (with a slope of 1:50). Similarly, the effect of steepening to 1:30 is greater than the effect resulting from an increase of MWL_o to 4m (with slope = 1:50 and H_{so} = 8m). Likewise, the amelioration that results from a reduction of the slope to 1:70 is comparable to a reduction of H_{so} to 5m, or a reduction of MWL_o to 2m. Thus, from the model results it can be concluded that the impact of coastal steepening on overtopping, damage and scour at sea defences is as severe as that due to increasing storminess or extreme water levels.

Table 1 Overtopping rates and orbital velocities predicted by COSMOS-2D plus OTT

Beach slope	H_{so} (m)	MWL_o (m)	H_{s120} (m)	U_{rms1} (m/s)	U_{max1} (m/s)	U_{rms2} (m/s)	U_{max2} (m/s)	Q_{mean} (m^2/s)	Q_{max} (m^2/s)	N_{OTT}	V_{max} (m^2)
1:200	8	3	2.524	0.67	2.5	1.2	5.8	0.010	1.8	240	2.8
1:100	8	3	3.192	0.79	3.2	1.4	6.7	0.036	3.3	328	6.3
1:70	8	3	3.733	0.89	3.6	1.5	7.2	0.071	4.7	335	10
1:50	8	3	4.416	1.0	4.1	1.6	8.6	0.15	7.2	385	18
1:30	8	3	5.743	1.3	5.8	1.8	9.6	0.32	13	415	38
1:20	8	3	6.637	1.5	7.7	2.0	11.7	0.54	19	448	59
1:50	5	3	3.859	0.94	3.8	1.5	7.7	0.058	4.6	322	9.7
1:50	11	3	4.752	1.1	4.3	1.6	9.0	0.22	9.1	415	24
1:50	8	2	3.855	0.86	4.0	1.3	7.4	0.015	3.2	106	6.0
1:50	8	4	4.946	1.1	4.5	1.6	8.2	0.51	13	532	38

3.4 Effect on coastal flood defence after 20 and 50 years

As an illustration of the effects of coastal steepening on coastal flood defence, consider the results of the above modelling study applied to a part of the North Sea coast with a spring tidal range of 4m, and an initial inshore slope of 1:100 (typical values). Thus the present intertidal width is 400m. If the intertidal zone narrows at 2m per year, which Figure 3 shows is representative of parts of this coast, then after 20 years the intertidal width is 360m and the slope is 1:90 (0.0111 rad). After 50 years the slope is 1:75 (0.0133 rad).

Taking the wave-height of 8m, period of 13s, and MWL of 3m, which corresponded to the 10 year return period conditions, future values of overtopping and velocities can be found by interpolating in Table 1. We find that after 20 years of coastal steepening the mean overtopping rate is 25% larger, the maximum midpoint velocity is 1.9% larger, and the toe r.m.s. velocity is 3.3% larger. The corresponding increases after 50 years are 75%, 5.7% and 9.7%. Thus, bearing in mind that damage and scour increase as a high power of velocity, there could be severe consequences for flood defence as a result of coastal steepening if the defences are not improved.

It should be emphasised that OTT is still a research model, and the reliability of its predictions is not yet established. Once this is done, a wide range of alternative scenarios could be explored relatively easily by making further runs of COSMOS-2D and OTT.

4. PHYSICAL CAUSES OF COASTAL STEEPENING

This section gives an overview of the possible physical causes for coastal steepening. It is difficult to attribute coastal steepening to one single factor (e.g. sea-level rise). Several factors that may influence coastal steepening have been listed, both natural and man-induced. Most of them are hypotheses in different stages of verification. Some of these items are fairly consistent hypotheses while some are reinforcing effects and still others are factors with a very local effect.

The evidence in the inter-tidal zone and the near shoreface seem to point incontrovertibly to sediment erosion as the underlying mechanism for coastal steepening. But in deeper water where the evidence comes solely from repeat echo-sounding surveys showing long-term deepening we should examine other possible explanations, if only to eliminate them. These include:

1. Uncertainties over whether the datum has changed between surveys
2. Vertical movements of the seabed due to isostatic re-adjustment
3. Sea-level rise
4. Subsidence of the North Sea basin due to hydrocarbon extraction
5. Subsidence of the seabed due to tectonic movements

The best up-to-date estimates of relative sea-level (RSL) rise, accounting for items 2 and 3 above, show marked disagreements about the distribution of contours of RSL rise rates over the North Sea, but agree that the absolute figures are generally less than +/- 2 mm per year. These are much less than the figures of 10 to 20 mm per year observed by several countries as evidence of coastal steepening, and hence explanations 2 and 3 can be eliminated. Oil and gas extraction will cause subsidence, the rate of which will depend on many factors. Subsidence levels of 0.2m to 0.3m in 20 to 40 years have been estimated for a large Dutch field (Reference 1). The subsidence may affect an area up to 35km from the field. So it is unlikely to have any large-scale impact on the coast, eliminating explanation 4. Evidence of explanation 5 is hard to come by, but is probably included in data for explanation 2, and hence can be eliminated.

4.1 Causes of steepening due to sediment transport

The most common explanation given by those questioned was that fixing the coastline by hard or soft engineering (which slows the retreat of the HW mark), but allowing continued erosion of the deeper water (and hence continued retreat of the LW mark), may be the dominant mechanism causing inter-tidal narrowing/steepening. However, research by HR into the observed changes in saltmarshes, particularly those on the North Sea coast, did not show any clear correlation between coastal squeeze and the presence of defences (Reference 5) although earlier research (References 3, 4) had suggested some correlation.

Reference 2 concluded that inter-tidal narrowing was "difficult to ascribe to a single cause such as rise in sea level", but may be exacerbated by dredging, construction of sea defences, and growth and decline of salt-marsh plants. The first two of these possible explanations are discussed below.

The dredging of sand and shingle for commercial purposes generally occurs at depths greater than 15m below LAT. No evidence for its effects on profile steepness has been obtained in the UK.

Constructions protruding into the sea, such as harbour moles have two effects on the shoreface profile:
1. Accretion of the near shoreface due to blocking of longshore sand transport
2. Erosion of the deep shoreface due to converging of tidal flow at the upstream side of the construction. As a rule of thumb, the influence of harbour moles on the local currents extends for a distance along the coast of approximately seven times the length of the mole. The effect is, therefore, expected to be very localised.

Two sources independently suggested that beach steepening might be reinforced by the following sequence of events:

increased wave penetration
↓
increased winnowing of fine sediments
↓
coarsening of beach sediment
↓
steepening of beach

It was also observed (Reference 3) that retreat rates correlated better with tidal currents than with wave energy – though it is not clear whether this is also true for steepening. If so, another reinforcing mechanism might be that with steepening the deeper water penetrates further inshore, and tidal currents are greater in deeper water because of reduced friction.

In considering natural causes for profile steepening, sea-level rise is often forwarded as a possible agent. For this to happen it is important that a combination of two factors should occur: a decreasing rate of sea-level rise and a coastline that naturally (e.g. fixed by vegetation) or artificially (e.g. groynes) remains in place instead of receding. When these two factors happen, the so-called active part of the profile becomes relatively narrower, while the deep shoreface zone becomes relatively larger. A decreasing rate of sea-level rise allows sediment on the deeper part of the shoreface to be transported to the near shoreface by cross-shore transport (second-order Stokes wave-asymmetry but also salt water upwelling). The erosion of the deep shoreface and accretion on the near shoreface result in a steepening of the whole profile. However, it is not clear how this explanation can cover both the long-term decrease in the rate of sea-level rise since the last ice age, and the recent (50 to 100 year) increase in the rate.

Several possible causes of shoreface steepening have been examined, but none are conclusive. The most probable effects are keeping the coastline at a fixed position, an increased cross shore transport induced by decreasing sea-level rise and dams and harbour moles. Other reasons such as decrease of sand supply, oil and gas extraction and sand extraction were considered less probable.

5. PAST, PRESENT AND FUTURE RESEARCH

To the authors' knowledge, there have been no generic research projects specifically on coastal steepening in the UK to date, although some regional studies have considered it, as described in section 1.

Nor do there appear to be any research projects specifically on coastal steepening approved for imminent funding from UK sources at present. MAFF and the Environment Agency recently commissioned a report (Reference 11) into research needs for flood and coastal defence. Coastal steepening was not specifically identified as one of these needs, but it could be part of a wider theme of Long-term Macro-scale Sediment and Morphological Processes.

There are also some other broad-scope proposals (either suggested or submitted) and recently approved projects that could include coastal steepening as an element of study:

- Environment Agency (Anglian Region) are making offshore bathymetric surveys to a depth of -10m at 5-year intervals (Environment Agency, 1997), which they will analyse when there is sufficient data.
- Coastal sediment super-budgets (MAFF). A proposed new study, by HR and BGS, into the "lifetime" of beach sediment, including its "birth" (sources), transport along the coast and eventual "death", e.g. losses into estuaries, or to the offshore seabed.
- Southern North Sea Sediment Transport Study – Phase 2. A possible extension to an earlier study funded by MAFF via Waveney DC to determine seabed sediment transport pathways from a variety of types of evidence. Partners include Environment Agency, coastal authorities, Crown Estates.
- FORCE and OC4Z. Projects within the Core Strategic Programme (1999-2004) of NERC, designed to improve the present ability to predict the evolution of coastal morphology and biology over a range of scales, in response to climate change, coastal erosion, flooding and policies of flood defence.
- INDUS. A NERC/DTI LINK project to develop a new technique for measuring beach profiles by using SAR images to determine the boundary between land and sea as the tide rises and falls.

6. CONSEQUENCES FOR COASTAL MANAGEMENT

The UK regulatory authorities for coastal flood defence and erosion (MAFF and Environment Agency) are conscious of the potential impact of coastal steepening/inter-tidal narrowing on flood defence and habitats. They perceive that coastal steepening makes defence more difficult, possibly unsustainable, and affects operational management decisions. This occurs because increased wave penetration leads to greater wave overtopping, beach erosion, and damage to, and undermining of, coastal defence structures such as sea-walls, breakwaters and rock groynes.

Narrowing of the inter-tidal zone also leads to squeeze of habitats, which is a major concern in view of the Habitats Directive. In many cases there is a conflict of socio-economic pressures with technical pressures (e.g. the best technical solution to a problem may not be acceptable to the populace environmentally, or may be in breach of law relating to Habitat Directives).

Coastal steepening is not commonly tackled as a management problem *per se*, but rather as a localised part of an erosional problem. Coastal erosion (where it has implications for coast defence) is tackled more strategically.

There is strong evidence that coastal steepening is occurring within the inter-tidal zone (at least) along many parts of the east, south and west coasts of the UK. Beach erosion is both a symptom and a consequence of coastal steepening. The findings from field data, laboratory data and numerical modelling all indicate that over time this will lead to greater overtopping, damage, and undermining of sea defences. Although this only becomes significant on time-scales of 20 to 50 years, other factors such as sea-level rise, increased storminess, increased storm surge and tidal levels, may combine with steepening to increase the vulnerability of beaches and defences.

The consequences of steepening on overtopping and undermining have been demonstrated by model calculations. The calculations are based on extreme wave conditions and on a 2 m per year narrowing of the intertidal zone. After 20 years the overtopping rate is 25% larger and the wave orbital velocity at the toe, which influences the scour, is 3% larger. After 50 years the overtopping rate is 75% larger and the toe velocity is 10% larger.

Possible actions against the consequences of coastal steepening are (Reference 1):

- To increase the dimensions and the strength of the structures.
- To increase nourishment volumes at the upper part of the shoreface.
- To change the nourishment strategy so the erosion is compensated not only in the near shoreface but also in the deep shoreface. In this way the steepening process is stopped, although we are not eradicating the cause(s).

In all countries the coastal managers are aware of the problems related to coastal steepening. However, the general attitude seems to be that a change in strategy should be based on more evidence.

The North Sea Coastal Management Group working group has concluded (Reference 1) that a number of problems have to be dealt with in relation to coastal steepening:

- How serious is the problem?
- How reliable are the explanations?
- Is the 'wait and see' attitude dangerous?
- If the nourishment option has been chosen, what are the benefits and costs of nourishing only the upper part of the profile compared with nourishing the entire profile?

- Under what conditions is the better option to enlarge the dimensions of the structures compared with the nourishment option?
- Can we calculate a new equilibrium steepness as a result of human interference and a change in the natural impact?
- What is the combined effect of coastal steepening and other long term phenomena (sea level rise, increased storm frequency etc.)

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Figures

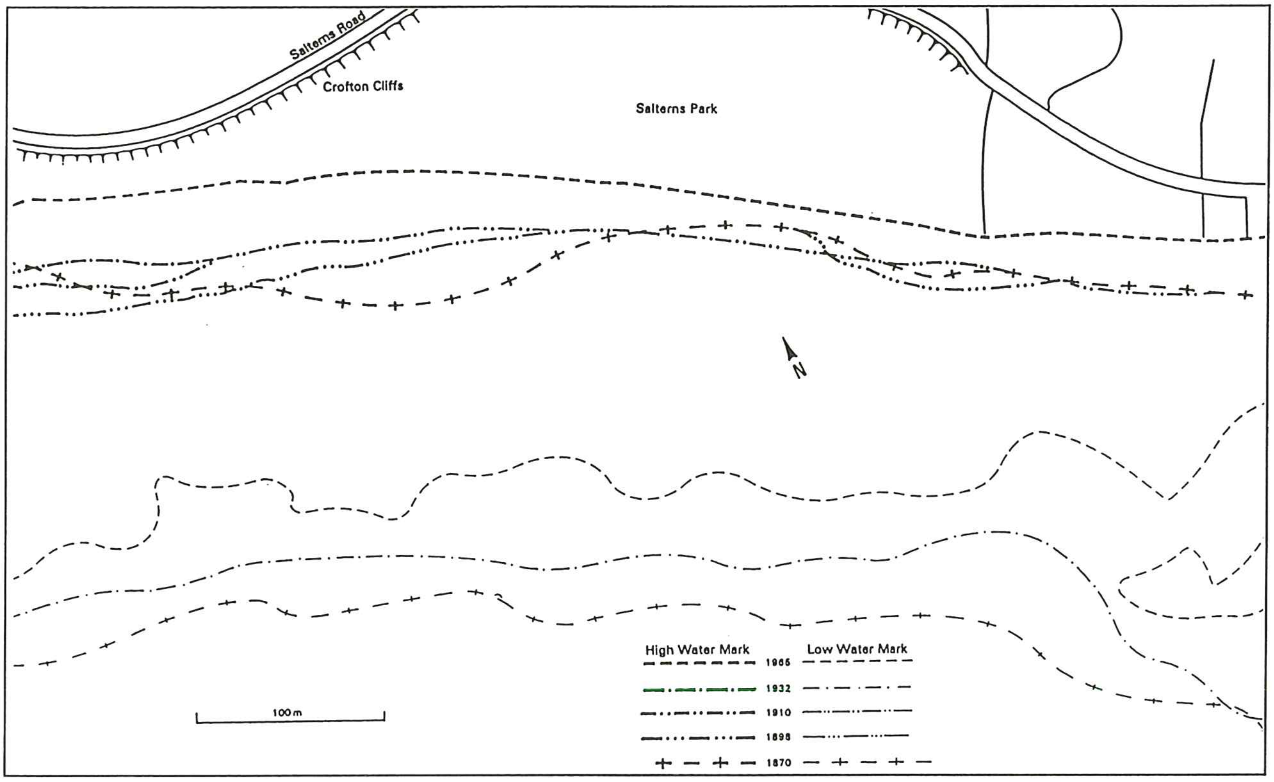

Figure 1 Changes of High and Low Water Marks, Hampshire coast, 1870 – 1965 (Reference 2)

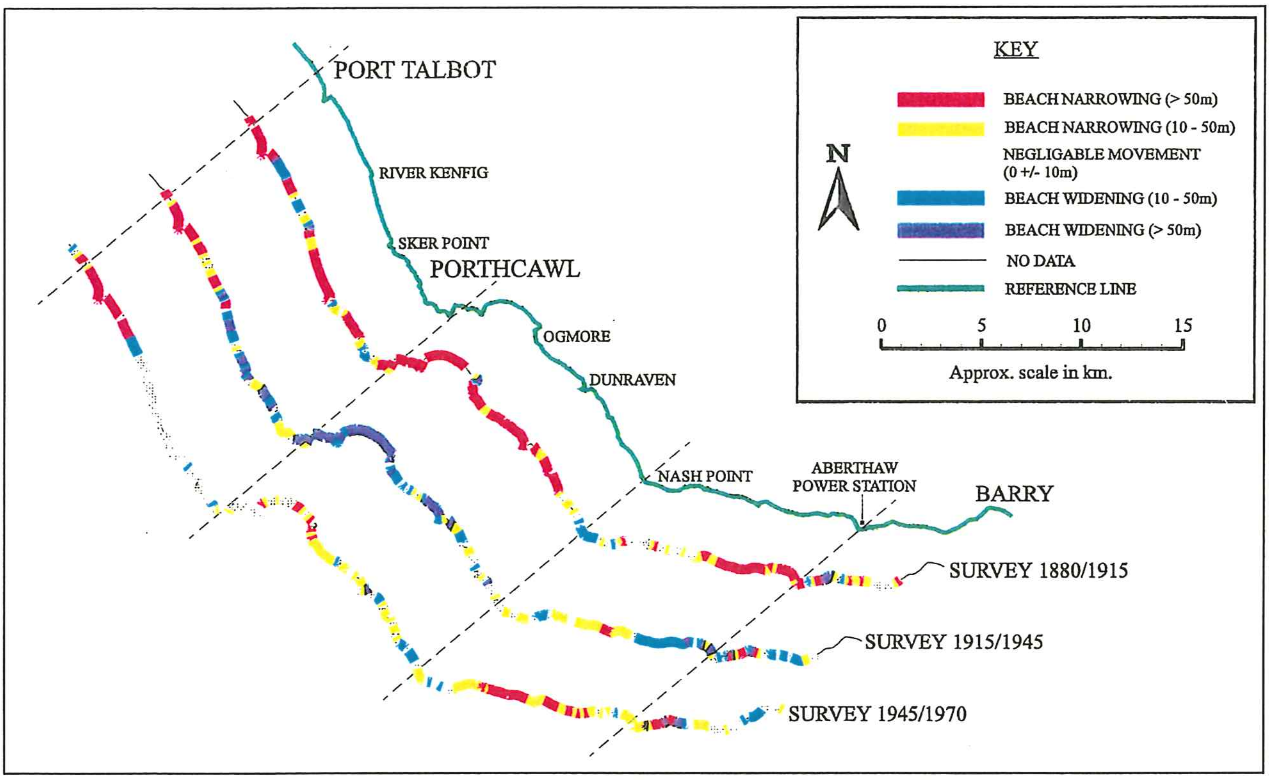

Figure 2 Changes of intertidal width, South Wales coast, 1880 – 1970 (Reference 12)

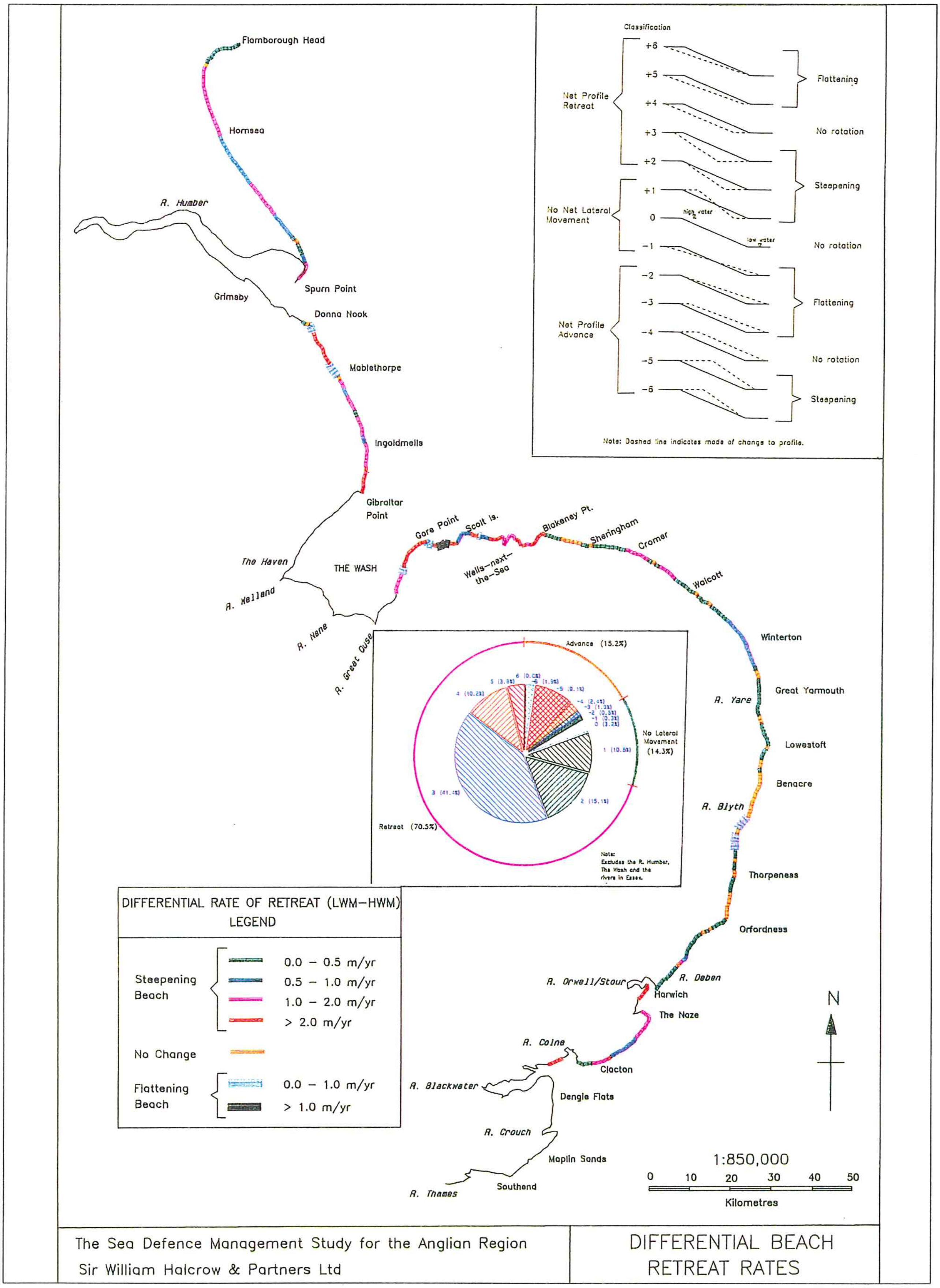

Figure 3 Changes of intertidal width, Anglian coast, approx. 1870 – 1970 (References 3, 4)

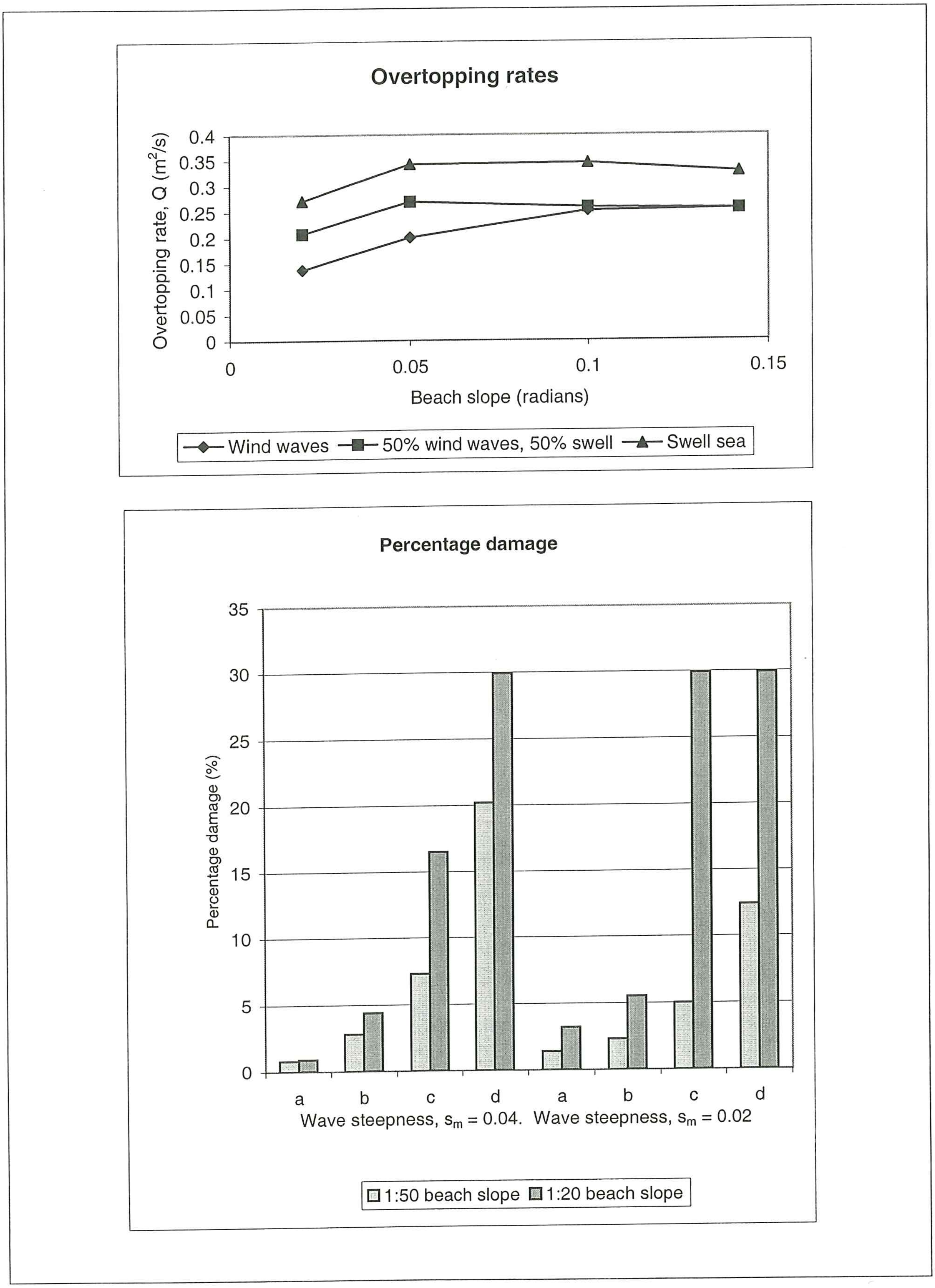

Figure 4 **Overtopping rates and armour damage as a function of beach slope (Reference 8)**

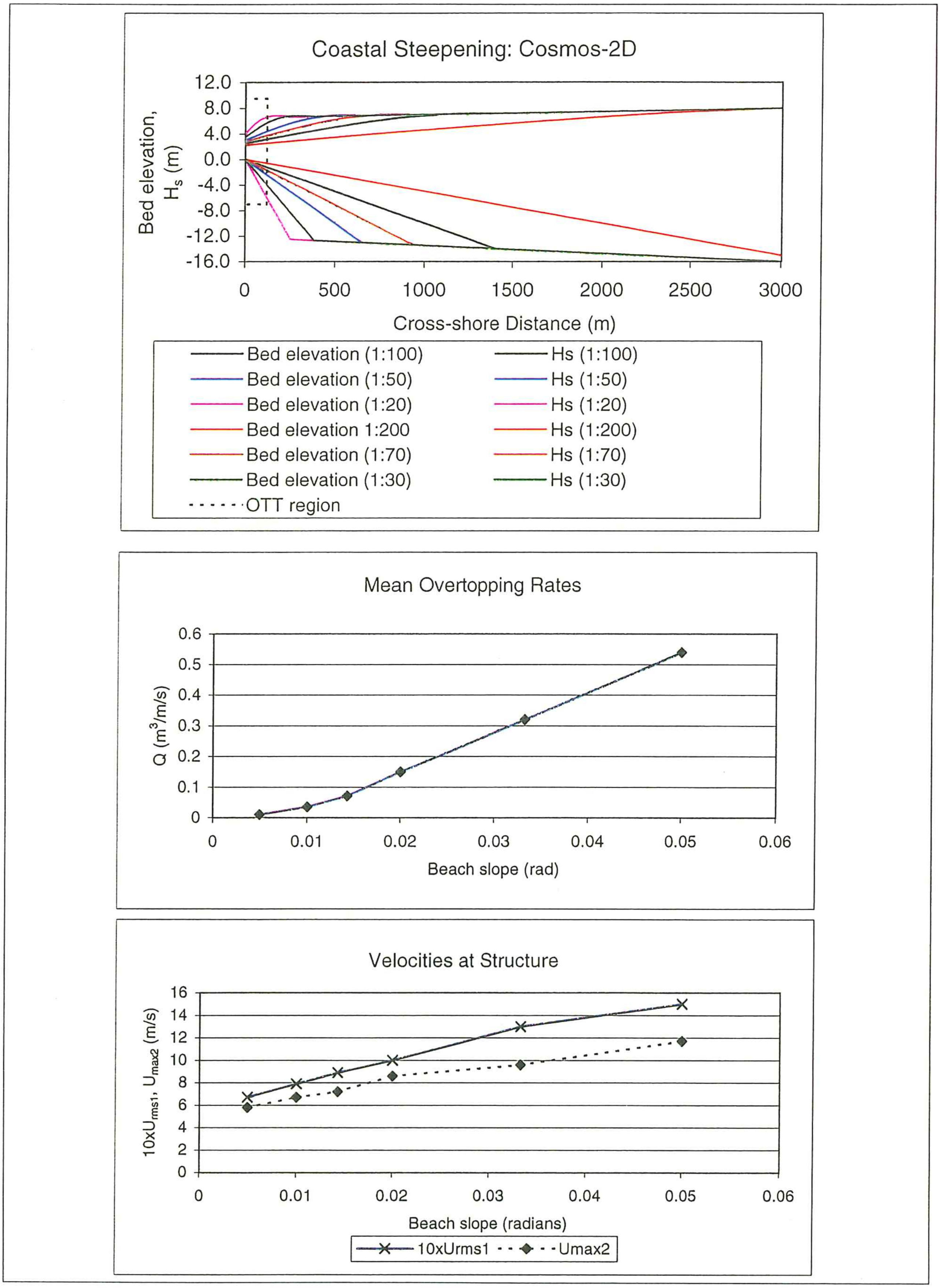

Figure 5 Bathymetries, wave-heights, overtopping rates, and orbital velocities from runs of the COSMOS-2D and OTT models

Appendices

Appendix 1

List of those who contributed information

Appendix 1 List of those who contributed information

The following were canvassed for their opinion on coastal steepening by telephone:

R Purnell	-	MAFF
J Goudie	-	MAFF
R Runcie	-	Environment Agency
J Rawson	-	Environment Agency
D Ayers	-	MAFF Regional Engineer, Taunton
H Payne	-	Environment Agency, Welsh Office
N Beech	-	Posford Duvivier
I Townend	-	ABP R & C
G Alcock	-	Proudman Oceanographic Laboratory
R Flather	-	Proudman Oceanographic Laboratory
P L Woodworth	-	Proudman Oceanographic Laboratory
K A Powell	-	HR Wallingford
C D R Evans	-	British Geological Survey
D Kelf	-	UK Hydrographic Office

The following responded to the questionnaire on coastal steepening (Appendix 2):

M Alexander	-	Metropolitan Borough of Wirrall
P Patterson	-	Waveney District Council
A Wrigley	-	Lancaster City Council
D Green	-	Arun District Council
P Brooks	-	Canterbury City Council
D A Harlow	-	Bournemouth Council
A Bradbury	-	New Forest District Council

Appendix 2

Coastal Steepening questionnaire

Appendix 2 Coastal Steepening questionnaire

A questionnaire was sent to representatives of a number of councils to ask for evidence of coastal steepening. A summary of their responses is included below. A copy of the questionnaire is included overleaf. The individuals and councils are listed in Appendix 1 and their help is gratefully acknowledged.

Overall the narrowing of the beach or inter-tidal zone was recognised as an issue although there is mixed evidence for it from the measured profiles analysed by the councils questioned, summarised in the table below. There was, however, more steepening than flattening of the upper beach and inter-tidal zone. The interaction of the profiles with defence structures was regarded as significant. For example, in the New Forest area, recharged beaches in front of structures steepened more than natural beaches. Moreover the changes in the subtidal zone and the lower shoreface were seen as impacting the upper beach. Cyclic changes in profile steepness from winter to summer were noted at some beaches. There are many fewer measurements of the sub-tidal zone and lower shoreface so it is not possible to reach firm conclusions.

Council	*Upper Beach (1)*	*Inter-tidal zone*	*Sub-tidal zone*	*Lower shoreface*
Arun DC	Steeper	Steeper (2)		
Bournemouth BC	Steeper	Steeper	Steeper	No change
Waveney DC	No change or flatter	No change or flatter		
MB Wirral	No change	No change		
New Forest DC	Steeper or no change (3)	No change	No change	No change
Canterbury DC	No Change	No change		

Notes:

1. Definitions of Upper beach etc are given overleaf.
2. Summary of analysis of 350 profiles
3. Recharged beaches in front of structures have become steeper. Elsewhere there is no change. The lower shoreface is generally bedrock
4. Blanks in table imply that no measurements were made (or none were suitable analysed)

COASTAL/ SHOREFACE PROFILE CHANGE

We are investigating possible long-term changes in the profile of the "shoreface" around the UK coastline. This can be typically divided into four zones, proceeding from shallow water to deeper. These are:

- The upper beach (UB) usually of sand and/or gravel
- The inter-tidal zone (IT) which may be of a different sediment type, often flatter than the upper beach
- The sub-tidal zone (ST), below the normal low-tide mark, and including and rocky shore-platform
- The lower shoreface (LS), typically lying between –5m and –20m below lowest tides

Note: These zones are not always distinct, for example a shingle beach may occupy all the inter-tidal zone.

Now to the questions!

1. Have you any perceptions/ general observations on any long-term change in slope of these zones? (We are not too worried here about a simple landward (or seaward) shift in the whole profile.)

	Y/N	Steeper?	No change	Flatter?
UB				
IT				
ST				
LS				

2. Have you any analyses of long-term beach/ seabed level changes, repeated surveys or other information (e.g. previous reports, map analyses) that could be used in possible future stages of this research?

	Long-term analyses	Repeated surveys	Other data
UB			
IT			
ST			
LS			

3. Finally, have you any views, ideas or other comments that you think might be helpful in understanding and/ or quantifying any changes in shoreface profiles?

Name:

Organisation:

Thank you for your help! Please feel free to ring me on 01491 822245 to discuss, or to fax this form back to 014912 825539, or post it back to me at: Dr Alan Brampton, HR Wallingford Ltd., Howbery Park, WALLINGFORD, Oxon, OX10 8BA