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# SID 5 Research Project Final Report

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## Project identification

1. Defra Project code: FD1927
2. Project title: Understanding the Lowering of Beaches in front of Coastal Defence Structures, Stage 2
3. Contractor organisation(s): HR Wallingford Ltd., Howbery Park, Wallingford, Oxfordshire, OX10 8BA
4. Total Defra project costs (agreed fixed price): £ 164760
5. Project: start date ................ 14 February 2005
   end date ................ 13 August 2006

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so.................................................................................**YES** ☒ **NO** ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

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(b) If you have answered NO, please explain why the Final report should not be released into public domain

## Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.


**Objectives**

The objectives of this research project were to:

1. Screen existing scour prediction methods and produce an improved method resulting in less uncertainty.
2. Assess liquefaction potential of the sediment in front of coastal structures.
3. Provide information on the suitability of mitigation schemes.
4. Synthesise existing information and approaches to predicting general beach lowering and clearly summarise the implications for beach monitoring.

The findings of this research are summarised in the sections below, arranged in the order above.

**Improved predictor for wave-induced toe scour in sandy beaches**

Existing datasets of toe scour in sandy beaches were screened and the most appropriate toe-scour data was obtained. A new set of laboratory experiments was devised and conducted to complement the existing data. The combined laboratory dataset was then used to derive equations for toe scour depth and for the maximum scour depth in sandy beaches as functions of relative water depth. The maximum toe scour depth on a sandy beach was predicted not to exceed the deep water significant wave height. On shingle beaches the predictor of Powell and Lowe (1994) is recommended. The improved scour predictors will inform the future development of fault trees and fragility curves for coastal structures.

**Assess liquefaction potential of the sediment in front of coastal structures**

Wave induced liquefaction can reduce the bearing capacity of the seabed in front of a structure. One of the outputs from this project is a Mathcad script containing an analytical solution for the wave-induced pore pressure response in an isotropic infinite thickness seabed in front of a breakwater. This code was used to show that the likelihood of occurrence of momentary liquefaction of the seabed increases with a decrease in seabed permeability (grain size) and a decrease in the degree of saturation of the porewater within the seabed (i.e. the percentage of dissolved gas content). The wave height required to liquefy a fine sand seabed increases significantly when the degree of saturation increases above 0.995. Saturation levels of 0.95 have been measured in the intertidal zone.

**Suitability of mitigation schemes**

Once an existing defence has been identified as being subject to, or at risk of, beach lowering and / or toe scour, a decision must be made as to what course of action should be taken, if any. The management strategy for the management unit involved will have been set in the relevant Shoreline Management Plan (SMP) as either 'Hold the Line', 'Advance the Line', 'Managed Realignment' or 'No Active Intervention'. If

‘Hold the Line’ or possibly ‘Advance the Line’ has been chosen, the scour may be mitigated. The choice of mitigation method will depend not only on the technical feasibility and suitability of the methods, but also on a number of other factors, such as amenity, access needs, visual impact, impact on habitats, long-term sustainability, the severity of the problem, the length of frontage affected, cost and the benefits. However, only the first issue was discussed in FD1927 as the purpose was to inform the decision-making process by identifying technically suitable options for mitigating scour (which is part of the PAMS operational interface).

A description of the various mitigation measures has been given, which indicates which of the mitigation techniques described are technically suitable in which circumstances. Four categories of mitigation measure have been identified (arranged in approximate order of increasing cost):

- Monitoring and accommodating the effects of beach lowering, including flood warning, flood resilience, delimiting flood areas, improved drainage, strengthening surfaces and installing secondary defences;
- Ancillary works to minimise/control scour, including faggoting, wave breakers, scour mattresses, rock bankets, toe berms, rock fillets, detached breakwaters, shore-parallel sills and groynes;
- Adjustments to the structure itself; including underpinning, encasement, the addition of an apron or steps and reconstruction of the wall / revetment; and,
- Major beach improvement methods, i.e. a beach recharge scheme which generally consists of importing large quantities of sediment, performing ancillary works (e.g. adding groynes, breakwaters or other beach control structures), regular monitoring of the recharged area, analysing changes in beach volume and periodic recharge.

**Beach level measurements, results and analysis methods**
Advances in measurement technology have made it easier than ever before to measure beach levels at a point in front of a coastal structure, although several of the available instruments have not yet been used for this purpose. There is a gap in the frequency of data collection between point measurements through a tide (typically sampling 4 to 6 times per hour) and beach profiles (typically sampling 2 to 4 times per year) so it is not possible to determine if beach variations at the different frequencies are related. Usually, beach levels can be de-trended using a simple linear least-squares method. Further research is needed to determine whether regional allowances could be set for beach lowering (for use in design) similar to the regional allowances for sea level rise. Advanced methods for analysing beach level data are becoming more common in academic circles. They require more data than the simpler methods, but could become more commonly used as regional coastal monitoring programmes begin to supply the high quality data in the quantity required.

**Results from the analyses of beach levels**
The average beach level and its standard deviation were shown to have seasonal trends. Beach surveys designed to predict long-term erosion rates should be conducted when the standard deviation in beach levels is low. Beach surveys designed to predict the minimum level a beach can fall to should be conducted when beach levels are low and standard deviations are high. In Lincolnshire, based upon analysis of existing data, these conditions are met around August and March, respectively. Residual (de-trended) beach levels have a Gaussian distribution about the mean beach level, provided that beach management has not altered during the time that the data was collected.

When a linear trend is extrapolated to predict future beach levels, it has a site-specific prediction horizon (the average length of time over which the prediction had a skill level above zero). A method to calculate this is presented. Extrapolation of a linear trend fitted to 10 years of Lincolnshire data gave prediction horizons between 0 and 14 years for different locations. The use of extrapolated beach levels is more suitable for a managed / adaptive beach management policy than a precautionary approach as the latter has a longer timeframe than the longest prediction horizon calculated so far.

**Prediction tools, shoreline retreat and coastal state indicators**
Different tools are needed to predict the response of the coastline at different scales. These tools come with different levels of reliability, accuracy, skill and required expertise and may be allocated to one of 4 basic types: statistical analysis (or historical trend analysis), process-based numerical modelling, geomorphologic analysis and parametric equilibrium models. The suitable time and space scales for different model types have been illustrated.

According to the Bruun rule, the rate of shoreline movement is proportional to the rate of sea level rise so the rate of erosion will increase with an increase in the rate of sea level rise. When this is applied to the UK coast, using current Defra allowances, the erosion rates increase by factors of up to 13 during the 21st century. The systems model SCAPE has predicted a rather more complex response to sea level rise in certain regions, with lower overall vulnerability to sea level rise than the Bruun rule. The Bruun rule’s predicted increases in the rate of erosion should be treated with some caution, therefore, as they may well be too high.

The uncertainty in shoreline positions derived from Ordnance Survey tidelines is a combination of source uncertainty, interpretation uncertainty and natural variability. Methods for calculating these uncertainties have been developed and example results presented. These errors can be incorporated into analysis of historic shoreline positions, which are often used in SMPs and strategy studies.

The best coastal state indicator for assessing the contribution of a beach to the overall risk of flooding or erosion is not yet known.

**Recommendations for future research and guidance**
Further improvements in the confidence of the existing predictive capability can be obtained with the following activities:

- Conduct large-scale flume tests of scour in front of coastal structures to confirm results from medium-scale tests;
- Conduct flume tests on the stability of rock protection in front of coastal structures;
- Research and model development to gain a better understanding of cross-shore sediment transport and to improve the skill of models to predict it. This will help in the development of morphologically-balanced models that can run for weeks or months with an acceptable level of skill.
- Conduct combined field measurements of intertidal beach profiles and beach levels through a tide over a duration of months, to provide test data for the predictive methods.
- Continued incorporation of the outputs from FD1927 into reliability analysis (e.g. RASP and/or PAMS Operational Framework).
- Determine the best coastal state indicator to represent the contribution of beaches to overall flood risk.

The research can be delivered with the following activity:

- Consideration should be given to the development of a toe scour guidance manual that would place to scour in the context of coastal management policy, provide methods for predicting toe scour and give guidance on the development and selection of mitigation options.

## Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

# Understanding the Lowering of Beaches in front of Coastal Defence Structures, Stage 2: Project Report to Defra

## Background needs

A research scoping study (FD1916) on beach lowering in front of coastal structures identified the generic elements and processes involved. It also highlighted key shortcomings in the available knowledge for which substantive progress could be made in the short term. This project (FD1927) was the direct follow on to the scoping study and addressed a number of the identified shortcomings. This Technical Report for Users, FD1927/TR, does not update the research scoping study, which reviewed the whole area, but reports on the advances made during project FD1927 (2005-2006).

## Main Objectives

The objectives of this research project were to:

1. Synthesise existing information and approaches to predicting general beach lowering and clearly summarise the implications for beach monitoring. This objective is fulfilled in Section 3 of FD1927/TR.
2. Screen existing scour prediction methods and produce an improved method resulting in less uncertainty. The scour prediction method should be suitable for use both in design and in a risk-based methodology of asset management. This objective is fulfilled in Sections 4 and 6 of FD1927/TR.
3. Provide information on mitigation schemes. Information has been collected on a number of mitigation schemes to assess how well they performed. This objective is fulfilled in Section 5 of FD1927/TR.
4. Assess liquefaction potential of the sediment in front of coastal structures. This objective is fulfilled in Section 7 of FD1927/TR with the development of a new tool to assess the potential for momentary liquefaction.

## Summary

### Development of improved scour predictors

Toe scour can reduce the level of the beach in front of a structure and increase the risk of undermining.

1. An extensive literature review and assessment of existing datasets have been used to identify laboratory test datasets that include measurements of toe scour and maximum wave-induced scour in sand beaches in front of vertical or sloping seawalls with wave heights sufficiently high to generate suspended sediment transport. A set of new laboratory experiments was then undertaken to extend this dataset.
2. The combined laboratory dataset was then used to derive equations for toe scour depth and for the maximum scour depth in sand beaches as a function of water depth.
3. The maximum toe scour depth, $S_{t,max}$ on sandy beaches was predicted not to exceed the deep water value of significant wave height, $H_{s0}$, i.e. $S_{t,max} < H_{s0}$.
4. Statistical analysis gave a Root-Mean-Square error in the predicted values of relative scour depth of about 0.17. A single equation was derived to calculate toe scour depth as a function of relative water depth, $h_t/L_m$, where $h_t$ is the water depth at the toe of the structure and $L_m$ is the deep water linear theory wavelength based on the mean wave period. This equation has systematic and unsystematic errors. An equation was then derived as an alternative with zero systematic error and zero bias, but a slightly higher total root mean square error. The predictor takes beach slope as well as relative toe depth into account and provides significant additional predictive capability for seawall scour in sand beaches.
5. On shingle beaches the predictor of Powell and Lowe (Proc. Hornafjordur Int. Coastal Symposium, 1994) is recommended.
6. The medium-scale flume tests, from which the sand beach toe scour predictors were derived, have used a limited range of wave heights and bed sediments. A set of large scale flume tests is therefore recommended to discriminate the effect of wave height and sediment size on scour depth.

### Assessment of seabed liquefaction

Wave induced liquefaction can reduce the bearing capacity of the seabed in front of a structure.

1. An analytical solution for the wave-induced pore pressure response in an isotropic infinite thickness seabed in front of a breakwater was used to study the liquefaction potential of the seabed in front of coastal defence structures subjected to various wave loadings. The liquefaction potential was determined by calculating the minimum total wave height to depth ratio that will cause the momentary liquefaction of the top 0.05m of a sandy seabed in front of a vertical seawall. The liquefaction potential depends on the degree of saturation of the pore water in the sediment which affects its compressibility.
2. Calculations were made for fine, medium fine and coarse sand with the degree of saturation between 0.90 and 1.0, for a range of water depths and a typical storm wave period of 8s. The results can be used

to indicate whether liquefaction of the seabed in front of a coastal structure is likely to occur. If so, a more detailed study should be carried out.

3. The likelihood of the occurrence of momentary liquefaction of the seabed increases with a decrease in seabed permeability, which is associated with a decrease in grain size. A seabed of fine sand is therefore more likely to experience momentary liquefaction than a seabed of coarse sand;
4. The likelihood of the occurrence of momentary liquefaction increases with a decrease in the degree of saturation of the seabed;
5. The wave height required to liquefy a fine sand seabed increases significantly when the degree of saturation of the seabed increases higher than 0.995;
6. A degree of saturation of 0.95 is recommended for the estimation of the minimum wave height required to liquefy the seabed, in the absence of a site-specific study;
7. Graphs have been developed that can be used to provide a quick check on the potential for momentary liquefaction of the top 0.05m of the seabed. If the potential for momentary liquefaction exists, a more detailed, site-specific study can be carried out by adapting the Mathcad code developed in FD1927, or using another liquefaction model.

## Integration into reliability analysis

The results of the research need to be implemented in the existing analysis methodologies used to determine the performance of coastal structures.

1. The derivation of the improved scour predictor will inform the future development of fault trees and fragility curves for coastal structures which are known to be sensitive to scour;
2. The identification of the Gaussian distribution of beach levels about a long term trend will reduce the uncertainty in the calculation of the fragility curves of coastal defences at a particular time;
3. The forecasting of changes in the mean beach level in front of a coastal defence, whether through extrapolation of historical data or numerical modelling, will allow the change in the fragility curve with time to be calculated. This contributes to calculations of the deterioration in asset condition with time and could be used to trigger a more detailed form of condition assessment, rather than waiting for scour to be observed or failure to occur;
4. In regions where beaches are regularly monitored the use of a visual condition index for a beach should, in time, be replaced by a quantitative measure of beach performance derived from the measurements. This may require the development of suitable coastal state indicators and of methods to determine suitable threshold levels for them;
5. The method for calculating prediction horizons developed in FD1927 can be used to calculate the duration of the forecasts of future beach behaviour (if sufficient data is available) that can usefully be used in coastal management;
6. The *frame of reference approach* (van Koningsveld and Mulder, *J. Coastal Res*., 2004, 20[2] pp 375-395) has been identified as a useful way of linking management objectives to the technical solutions that are used to meet those objectives and evaluating their success.

## Prediction tools, shoreline retreat, uncertainty and coastal state indicators

1. Different tools are needed to predict the response of the coastline at different scales. These tools come with different levels of reliability, accuracy, skill and required expertise. These tools may be allocated to one of four basic types: statistical analysis (or historical trend analysis) process-based numerical modelling, geomorphological analysis and parametric equilibrium models. The numerical models attempt to describe fewer and fewer processes in detail as the spatial and temporal scale they are deployed over increases. The suitable time and space scales have been illustrated for the different model types;
2. In the coastal regions where the Bruun rule can be said to apply, the rate of shoreline retreat is directly proportional to the rate of sea level rise. It follows that the ratio of future shoreline retreat rate to present day shoreline retreat rate (the shoreline retreat rate multiplier) will be the same as the ratio of future sea level rise rate to present day sea level rise rate. The shoreline retreat rate multiplier has been calculated using present day rates of sea level rise and regional sea level allowances (Defra, *FCDPAG3 Economic Appraisal: Supplementary note to Operating Authorities: Climate Change Impacts,* 2006). These calculations show that shoreline retreat rates in regions where the Bruun rule applies could increase significantly – in some cases by a factor of 13 - during the 21$^{st}$ century;
3. The shoreline retreat rate multipliers are highest for the Northwest and Northeast of England and Scotland as this region has the lowest present day rate of sea level rise, due to isostatic rebound following the last ice age, which may also imply lower rates of present day shoreline retreat. The systems model SCAPE predicted a rather more complex response, with lower overall vulnerability to sea level rise, than the Bruun rule. Therefore the magnitudes of the shoreline retreat rate multipliers should be treated with some caution as they may well be too high. It seems probable that the shoreline recession rate will increase in many places if the rate of sea level rise increases;
4. The uncertainty in shoreline position from OS tidelines is a combination of source uncertainty, interpretation uncertainty and natural variability. Methods for calculating each of these uncertainties have been developed and example values calculated. These errors can be incorporated into analyses of

historical shoreline movement, which are often used in Shoreline Management Plans and strategy studies;
5. The best coastal state indicator for assessing the contribution of a beach to the overall risk of flooding or erosion is not yet known. Possible coastal state indicators include the beach level at the toe of a structure, the beach level plus beach slope and the beach cross-sectional area above a set contour.

## Beach levels – measurement, results and analysis methods

1. Advances in measurement technology have made it easier than ever before to measure beach levels at a point on a daily basis, or even more frequently;
2. Many of the possible techniques for measuring time series beach levels at a point have not yet been evaluated for the cases of beach level at the toe of a structure;
3. When beach levels have been measured at a point at a rate of at least once a day the time series have generally been short or, in the case of the Blackpool in situ “Tell-Tail” data, there has been no tie-in to other data gathering programmes. The Blackpool data would have been more useful if it had been collected within an integrated beach monitoring programme;
4. There is a gap in frequency of data collection between the point measurements of beach levels through a tide (sampling about 4 to 6 times per hour) and beach profiles (collected typically 2 to 4 times per year). It is therefore impossible to determine from the data if the beach variations at the two frequencies are related, although changes in the beach level at the toe of a structure between tides are the residual of the changes within each tide. An implicit assumption that the processes are unrelated has been made in incorporating these results into the development of fragility curves;
5. A clear seasonal trend was observed in the Linconshire dataset of beach levels at the toe of the local seawalls. The trend was lower than the standard deviation about the trend;
6. Beach levels at a point in front of a structure can generally be de-trended using a simple linear least squares method, providing that neither the coastal defences nor beach management policy changed during the data collection period;
7. Further data analysis should be undertaken to ascertain if a regional approach could be taken to providing guidance on possible changes in beach levels, for use in the design of new structures, in a similar way to the regional net sea level rise allowances (Defra, *FCDPAG3 Economic Appraisal: Supplementary note to Operating Authorities: Climate Change Impacts,* 2006);
8. There is a need to establish the relationship between the behaviour of a single contour and that of the beach volume at a local level before a contour can be used as a surrogate for beach volume;
9. Beaches around Donna Nook in north Lincolnshire often showed an increase in beach volume (area under a beach profile) combined with a retreat (landwards movement) in Mean Sea Level. Further south in Lincolnshire (between Mablethorpe and Skegness) beach volumes were found to decrease as the Mean High Water retreated (moved landwards);
10. Advanced linear analyses of beach level data (such as the use of wavelets and Empirical Orthogonal Functions) and nonlinear analyses of beach level data (such as Singular Spectrum Analysis and fractal analysis) are becoming more common in academic circles. These sophisticated methods require more data of good quality than the simple linear methods require. They may also impose more constraints on the data, such as the need to be equally spaced in time and position. It will be possible to apply these methods to more areas of the English and Welsh coastlines as coordinated regional data gathering and data management programmes extend their geographical range and temporal duration, as these programmes provide high quality data at regular intervals over periods of years and even decades.

## Results obtained from analysis of beach levels

1. Beach surveys that are intended to predict the long-term trends in shoreline position should be made when the standard deviation in the beach level is low. This occurred in August for the Lincolnshire data (but in June/July for Duck, N.C., U.S.A.) and also coincided with relatively high beach levels.
2. Beach surveys that are intended to indicate how low beach levels can fall should be undertaken when the average beach level is low and the standard deviation in beach level is high. In Lincolnshire this occurred around March.
3. When a linear trend is extrapolated to provide a future prediction of beach level it has a site-specific prediction horizon. This is the average length of time over which an extrapolated trend produced a useful level of prediction compared to a baseline prediction (taken to be that future beach levels will be the same as the average of the measured beach levels). A useful level of prediction is defined here as having a positive Brier Skill Score;
4. Extrapolation of a linear trend fitted to 10 years of data gave prediction horizons between 0 years and 14 years;
5. Extrapolation of a linear trend fitted to 5 years of data always gave a negative skill score (i.e. a worse prediction than the baseline) so should not be used;
6. The use of extrapolated beach levels is more suitable for managed / adaptive beach management policies, rather than the precautionary approach as the latter has a longer timeframe than the longest prediction horizon;

7. The standard deviation in beach level from using 2 surveys per year was 6% different from using 10 surveys per year. The difference was approximately halved by increasing the number of surveys from 2 to 3 times per year;
8. Residual (de-trended) beach levels have a Gaussian distribution about the mean beach level, again providing that neither the coastal defences nor beach management policy changed during the data collection period.

## Review of mitigation measures

The likelihood of beach lowering should have been included in the design of any structure. In many cases the details of how a structure was constructed have been lost so, for example, the level of the structure toe is not known and the allowance made for beach lowering is not known. In some cases it will be possible to accommodate beach lowering by installing storm warning systems, delimiting areas to prevent development, increasing flood resilience, improving drainage, strengthening surfaces behind the structure to withstand higher flows or installing secondary flood defences to limit the extent of flooding.

Various approaches to reinforcing the beach or bed in front of a seawall have been tried over the years. Other techniques and structures have been applied to reduce the rate of shoreline retreat or to maintain a beach in front of a structure:

1. **Fagotting and wave breakers** have been used to reinforce shingle ridges protecting low lying areas from flooding. Most such installations are now redundant, with beach nourishment being widely used instead. The anticipated structural life of faggoting is generally low, possibly as little as 5 to 10 years, while timber wave breakers can be expected to achieve at least twice this lifespan, although they are vulnerable to being damaged by wave impact, and are prone to abrasion by beach sediments;
2. Fagotting and wave breakers may well be of some benefit as emergency works, or as short-term low-cost schemes in instances where more costly methods of protection are difficult to justify. Fagotting, in particular, is a technique that might be suitable in sheltered environments where abrasion is not a serious issue, where low cost is an overriding factor, where manual labour is available at low rates, and where the possible need for maintenance is not a major concern;
3. **Scour mattresses** are typically deployed to prevent the undermining of structures, as bed levels near them are lowered by scour caused by the presence of the structures themselves. These mattresses, which are normally prefabricated, provide an interface between the normally solid and impermeable structures and the mobile, permeable sediments surrounding them. However, there are few instances of this type of protection being used within the intertidal beach zone anywhere in the UK. Their usage on the open coastline is generally restricted to backshore protection although there are a few examples of these being used as lightweight revetments at or above high water;
4. The availability of suitable **rock,** and greater awareness of the consequences of scour, has led to its increasing use in mitigating problems caused by beach lowering through the construction of rock blankets, toe berms and fillets. A good starting point for the design of rock (or concrete armour unit) structures in coastal engineering is the “Rock Manual” (CIRIA special publication 83 / CUR report 154 [1991], CIRIA / CUR / CETMEF: CIRIA report C683 [2007]).
5. The infilling of scour trenches, and the construction of a scour blanket or a sloping rock toe are designed to prevent the undermining of the structure. They are likely to suffer further beach lowering if the processes of beach erosion continue and this should be considered in their design. They are often installed at or below the beach level so may be covered for much of the time;
6. The construction of a more substantial rock fillet that extends partially up the height of the coastal defence structure may also serve to reduce one or more of wave run-up, overtopping, impact pressures, wave reflections and scour. Care must be taken in the design of rock fillets to ensure it does not increase run-up, overtopping and/or impact pressures by changing the way the wave break onto the structure;
7. The more substantial rock structures commonly have bedding layers or geotextiles to form an interface between the rock and the beach sediment;
8. **Detached breakwaters** are best suited for situations where the existing defences require higher levels of protection at sensitive points, i.e. over short frontages of coastline where beach lowering / scour are causing localised problems of overtopping or undermining. They may be well also suited to frontages where the wider beach formed can be justified for recreation/amenity purposes. In areas where there are large tidal ranges and/ or strong tidal currents, detached breakwaters may have more detrimental impacts than in micro-tidal or sheltered regions. (The shore protection performance of detached breakwaters under these circumstances is being studies in the ongoing LEACOAST project.)
9. There are no low crested breakwaters or submerged reefs in the UK, but their applicability for mitigating problems of beach lowering or scour in front of coastal structures remains uncertain, based on the observations made elsewhere;
10. **Shore parallel sills** have been used with some degree of success in Mediterranean countries, but only in micro-tidal/moderate wave energy conditions. Their usefulness in high energy/macro-tidal conditions is yet to be proven. However, they have been successful as backshore protection, i.e. in conditions where the tidal range is not a critical factor;

11. The problems of beach lowering will be sufficiently severe and widespread in some situations, as to be worth considering a **major scheme to improve those beaches.** The direct remedy to such problems is to import large quantities of extra beach sediment, i.e. sand or gravel, to replace that gradually lost previously, i.e. a beach recharge scheme. This approach will immediately cover over the toe of coastal structures and decrease water depths in front of them, and in many cases will improve the amenity value and aesthetic appearance of the frontage. Further details on the design and execution of major beach improvement schemes is provided in the Beach Management Manual (CIRIA report 153, 1996);
12. There will often be a need for ancillary works to accompany an initial "recharge" of a beache, such as the building of groynes, monitoring and analysis of the changes in beach levels and for periodic addition of extra material in later years. These various elements are now generally identified as components of a beach improvement scheme;
13. **Groynes** are the most widely used method of controlling beach levels in the United Kingdom, where they have been used in a wide variety of situations. On shingle beaches, groynes can be used in any tidal range and under most wave conditions. On sand beaches, however, groynes are most effective in low to medium tidal ranges, because their cost can be prohibitive in areas with large tidal ranges. The spacing of groynes is related to their length. Shorter, higher and closer spaced groynes are used on shingle beaches reflecting the steeper gradients that occur on such beaches, both perpendicular and parallel to the shoreline. In contrast, groynes on sandy beaches are longer, lower and more widely spaced, typically at twice their length or more;
14. Details of the design of groyne systems, with or without beach recharge, can be found in the Beach Management Manual (CIRIA report 153, 1996). It is worth noting, however, that the design of a groyne system should not be based purely on such guidelines alone; their design always needs to be matched to local conditions;
15. Installing groynes without recharge will normally lead to problems of erosion further along the coast in the direction to which the sediment is moving, (i.e. "downdrift") potentially extending over many kilometres. The greatest problems of erosion, however, tend to occur just downdrift of the last groyne, and may lead to the "outflanking" of a coastal structure if care is not taken to avoid this possibility. Groynes are often used in combination with beach recharge, and under such conditions model testing becomes almost mandatory;
16. Probably the most common adjustments to a coastal structure are **remedial works** such as underpinning, encasement, or addition of an apron to the wall, although there are few guidelines for design. Such works are rarely a permanent solution to the problem and hence they often have to be repeated later, either extending the protection downwards or further along the coastline. However, they do make maximum use of the existing structure which is often still sound, or can be repaired without great expense. Underpinning typically requires excavation beneath, and often behind, the face of the structure, the construction of a new and deeper "toe" and backfill of the area behind. Encasement also involves the covering of the front face of the structure, and sometimes building above its existing crest and even over an existing back-slope, i.e. covering some or all of the original structure with a new, normally concrete, layer;
17. The construction of an apron, or of steps, at the base of an existing structure can prolong the life and improve the performance of that defence, at reasonable cost. However, such an intervention will not remedy the underlying causes of beach lowering. Such additions to a structure will extend it seaward, often occupying an area of the beach that previously provided an amenity area, and affecting the natural sediment transport processes in that area. There is a danger that such seaward extensions of a structure will interfere with longshore sediment transport, and hence reduce sediment supply to downdrift beaches;
18. In some situations the situation may have become so critical, that it may become more cost effective to reconstruct/replace an old wall, rather than mitigate scour in front of it. Reconstruction will also not remedy the underlying causes of beach lowering and may interfere with longshore sediment transport.

## Recommendations for future research and guidance

The work in FD1927 has identified the following research and guidance needs, some of which may be best suited to funding through a research council. Further improvements in the confidence of the existing capability can be obtained with the following activities:

1. Large scale flume tests of scour in front of coastal structures to confirm the scour relationships performed at a single (medium) scale;
2. Tests on the stability of rock toe protection in front of coastal structures, to improve design guidance;
3. Detailed processes research and numerical model development to gain a better understanding of cross-shore sediment transport. Without this it will not be possible to produce a morphologically balanced model that can run for months to years without significantly and erroneously eroding or accreting a beach. This could include the following item;
4. Combined field measurements of intertidal beach profiles and beach levels through the tide at a seawall at a timescale of months. This will relate the scour within a tide to the variations in beach level between tides to produce a better understanding of beach level variation in front of coastal defence structures over periods of weeks to months;

5. Continuing work to incorporate the results of this research into reliability analysis. This work is being undertaken within Floodsite and FRMRC and care should be taken to ensure that the outputs from these projects are taken up for general use within reliability analyses using, for example, RASP and/or the PAMS Operational Framework;
6. Work should be undertaken to attempt to quantify which coastal state indicator will best represent the contribution of beaches to overall flood risk.

The research can be delivered with the following activity:

7. Consideration should be given to the development of a toe scour guidance manual that would place toe scour in the context of coastal management policy, provide methods for predicting toe scour and provide guidance on the development and selection of mitigation options.

## References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

**Technical Report**

Sutherland, J., Brampton, A.H., Obhrai, C., Dunn, S. and Whitehouse, R.J.S., 2008. Understanding the Lowering of Beaches in front of Coastal Defence Structures, Stage 2. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, R&D Technical Report FD1927/TR.

**Technical Notes**

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**Conference Papers**

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Sutherland, J., Obhrai, C., Whitehouse, R.J.S. and A.M.C. Pearce, 'Laboratory tests of scour at a seawall'. Proceedings of the Third International Conference on Scour and Erosion, Amsterdam, 2006. CURNET, Gouda, The Netherlands [CD-ROM].

**Publicity**

Project web site at http://www.hrwallingford.co.uk/projects/lowering_beaches/index.html with information and downloads.

Publicity sheet on Southbourne tests distributed as page 2 of Channel Coast News Issue 23 – July 2005. www.channelcoast.org.

Article on laboratory and field work appeared in Streamline (2006), HR Wallingford's annual newsletter to approximately 7,000 clients and contacts.

'Beach Lowering at Seawalls', an article on field and laboratory work appeared in Innovation and Research Focus, Issue 64, February 2006. Innovation and Research Focus is an insert on recent research periodically distributed with New Civil Engineer.

Article in special issue of "Edge" (HR Wallingford's periodic publicity brochure) prepared for the Defra FCERM conference (2006).

Article in October 2006 issue of "Edge" (HR Wallingford's periodic publicity brochure).