

Research and Development

Final Project Report

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Project title

Understanding the lowering of beaches in front of coastal defence structures, stage 1

DEFRA project code

FD1916

Contractor organisation and location

HR Wallingford Ltd.,
Howbery Park,
Wallingford, OX10 8BA

Total DEFRA project costs

£ 30,000

Project start date

01/01/03

Project end date

30/06/03

Executive summary (maximum 2 sides A4)

Background to R&D project

Toe scour is blamed for the failure of many coastal structures but toe scour holes are infrequently observed in the field. This leads some to believe that a beach will go through the same cycle of erosion and accretion, whether it has beach control structures or not. Many studies of toe scour have been carried out, but the results have been highly varied. Therefore, this scoping study was commissioned to improve understanding of beach lowering in front of coastal defence structures. The objectives of the report were:

- To identify the generic elements and processes involved and the research and development needs
- To provide preliminary guidance on the mitigation of scour.

Results of R&D project

This scoping study has reviewed the present state of knowledge on the lowering of non-cohesive sediment beaches in front of coastal defence structures. It has concentrated mainly on toe scour, which is the short term lowering of beach level close in front of a coastal defence structure. (A parallel project, FD1915, led by Posford Haskoning has looked at the lowering of cohesive foreshores). Most beach lowering studies have considered toe scour only and have treated it as a purely cross-shore transport phenomenon.

Toe scour has been reproduced in several small-scale laboratory experiments as a short-term wave-driven phenomenon caused by cross-shore transport of sand (or shingle). Case studies in the UK have often indicated that longshore transport plays an important and sometimes even dominant role in beach lowering in front of coastal structures. There have been few laboratory toe scour tests that have generated suspended sediment transport despite the fact that bedload and suspended load scour occur by different mechanisms and occur in different places. It is therefore questionable whether

small-scale bedload transport experiments always provide reliable design guidance on toe scour depths at full scale.

Design relationships have mainly been derived for scour depths in sand beaches at vertical seawalls, subject to normal incidence waves. Even if the empirical equations derived from generally small-scale laboratory tests are taken as reliable, there is still no design equation for many cases. When there is no design guidance, toe scour can often be estimated from normal-incidence vertical wall cases, either by taking this as the likely worst case or by adjusting it according to rules-of-thumb. In other cases, the only design guidance comes in the form of rules-of-thumb. There is little evidence of the empirical formulae being used in the design of coastal structures or in the design of mitigation measures, indicating a lack of belief in these methods amongst designers.

Many of the mitigation schemes implemented around the UK have involved protective aprons at the toe of a pre-existing structure. Consequently, much of the design guidance is for this type of mitigation measure and examples of guidance on thickness, width and stone weight for revetment toes are provided. Alternative mitigation measures include rock dumping, gabions, linked precast units, soil improvement and beach renourishment.

The approach to mitigation schemes is often practical and empirical. Further information on the performance of mitigation schemes is needed in order to assess how successful the approaches are. The performance of a selection of mitigation schemes should be looked at in some detail. It would be useful if this work could also be tied into an ongoing survey programme to maximise the benefits from funding. Designers / coastal managers are encouraged to state the assumptions made about beach lowering, and to define a minimum beach level for triggering intervention. Beach lowering happens on such a wide range of time scales and space scales that the entire process cannot reasonably be modelled in a single numerical or conceptual model. Therefore a variety of approaches should be taken to address these issues and the first steps should be taken towards the development of a probabilistic risk-based method of assessing the safety of coastal defence structures.

There is a dynamic interaction between a beach and a coastal defence structure. Relatively few studies have considered the interactions between beaches and structures (preferring to study one or the other). Areas to consider using physical and numerical modelling are the flow through structures and beaches, suffusion (with material retention) and foundation support, including settlement and liquefaction. Most studies have concentrated on sand beaches and impermeable structures. More work is needed to determine the relationship between scour depth, structure type and sediment type. In order to safely minimise the cost of coastal defence structures, the minimum safe size of toe protection and the minimum safe depth of toe excavation should be investigated.

There is a shortage of large-scale laboratory and field data on toe scour. Both should be collected to fill gaps in existing knowledge. In particular, the development of the depth of scour during storms is of interest. Any field experiment devised should be tied in with existing survey programmes to maximise the use of resources.

Key strands from the above have been presented in a section of the report outlining recommendations for research. Research into scour and the performance of structures could potentially lead to cost savings should it show that less conservative designs for coastal structures would be appropriate. There are therefore considerable potential longterm returns from investment in beach lowering research, and the dissemination of knowledge and guidance.

R&D Outputs and their Use

The main outputs from the scoping study were the Technical Report for Users and a proposal for further research to form Phase 2. This report contains reviews of existing knowledge, methods for predicting beach lowering and mitigation measures. It includes preliminary advice on scour mitigation, plus conclusions and a list of research needs, which have been used to define a larger research program, for Phase 2.

Scientific report (maximum 20 sides A4)

Toe scour is blamed for the failure of many coastal structures (CIRIA, 1986) but toe scour holes are infrequently observed in the field (e.g. Griggs et al., 1994). This leads some, such as Weigel (2002a, b, c) to believe that a beach will go through the same cycle of erosion and accretion, whether it has beach control structures or not. Many studies of toe scour have been carried out, but the results have been highly varied. Therefore, this scoping study was commissioned to improve understanding of beach lowering in front of coastal defence structures. The objectives of the report were:

- To identify the generic elements and processes involved and the research and development needs
- To provide preliminary guidance on the mitigation of scour.

Coastal defence structures are commonly constructed because of coastal erosion. This erosion will continue, despite the presence of the seawall. The seawall neither adds nor removes sand, although it does impound or imprison it, preventing it from entering the coastal sediment transport system. Seawalls can cause local toe scour during storms, but there is no evidence that coastal defence structures delay the recovery of beaches. Beach lowering is a process that takes place on a number of different timescales (years, seasons, storms) and which combines cross-shore and longshore sediment transport. This report concentrates mainly on toe scour, which is the short term lowering of beach level close in front of a coastal defence structure. The overall lowering of beach levels, which occurs at longer timescales and over larger spatial scales, is referred to as general beach lowering. Most beach lowering studies have considered toe scour only and have treated it as a purely cross-shore transport phenomenon.

There are indications that toe scour may be a short-lived phenomenon, with scour holes generated during storms filling in within a few hours as the storm subsides. This would explain why few scour holes are observed or surveyed at low tide. Toe scour has been reproduced in several small-scale laboratory experiments (e.g. Fowler, 1992) which have treated it as a wave-driven, cross-shore, often bedload transport dominated phenomenon. There have been few laboratory toe scour tests that have generated suspended sediment transport despite the fact that bedload and suspended load scour occur by different mechanisms and occur in different places (e.g. Irie and Nadaoke, 1984). It is therefore questionable whether small-scale bedload transport experiments provide reliable design guidance on toe scour depths at full scale (Tørum *et al.*, 2003).

Design relationships for scour depths in sand beaches (unless otherwise stated) at a vertical seawall, subject to normal incidence waves include those from Xie (1981, 1985) Fowler (1992) Powell and Lowe (1994) for shingle, Powell and Whitehouse (1998) O'Donoghue (2001) for bedload and CEM (2002). Even if the empirical equations derived from laboratory tests are taken as reliable, there is still no design equation for the following cases:

- oblique incidence waves at vertical walls
- oblique incidence waves at sloping impermeable walls
- oblique incidence waves at permeable sloping walls (such as rubble mound breakwaters).

In most of these cases toe scour can be estimated from normal-incidence vertical wall cases, either by taking this as the likely worst case or by adjusting it according to rules-of-thumb. In other cases, such as breaking waves at normal incidence on a sloping impermeable wall the only design guidance comes in the form of rules-of-thumb. There is little evidence of these formulae being used in the design of coastal structures or in the design of mitigation measures, indicating a lack of belief in these methods amongst designers.

The above (physical and numerical) modelling has regarded toe scour as a short-term wave-driven phenomenon caused by cross-shore transport of sand (or shingle). Case studies in the UK have often indicated that longshore transport plays an important and sometimes even dominant role in beach lowering in front of coastal structures. Variations in beach level due to changes in longshore transport tend to have longer timescales than toe scour (up to the centuries required for coastal realignment).

Many of the mitigation schemes implemented around the UK have involved protective aprons at the toe of a pre-existing structure. Consequently, much of the design guidance is for this type of mitigation measure and examples of guidance on thickness, width and stone weight for revetment toes are provided. Alternative mitigation measures include the following:

- Rock dumping for bed stabilisation. This can be a crude form of apron or toe berm that fills the scour hole, but has no filter layer or geotextile so is subject to winnowing
- Mattresses. These can be of two main types: flat gabions and linked precast units. They absorb energy, are flexible enough to fit an irregular seabed, are cheap to fill and relatively easy to lay. Neither has a filter layer or geotextile so both forms are subject to the winnowing of bed material
- Soil improvement to increase bearing capacity and reduce scour potential. An example of this, which is in use at a few sites, is beach drainage (Shaw, 2003). In the UK there have been three beach drainage installations: a full scale trial at Holme-Next-The-Sea (Norfolk), a commercial system at Towan (Cornwall) and an experimental system at Branksome Chine (Dorset)
- Beach renourishment. In many cases the long-term development of beach levels depends more on longshore transport than on cross-shore transport. In some such cases beach nourishment has been the solution to scour problems.

The approach to mitigation schemes is often practical and empirical. Further information on the performance of mitigation schemes is needed in order to assess how successful the approaches are. The performance of a selection of mitigation schemes should be looked at in some detail. It would be useful if this work could also be tied into an ongoing survey programme to maximise the benefits from funding.

Designers and coastal managers are encouraged to state the assumptions made about beach lowering, and to define a minimum beach level for triggering intervention. Beach lowering happens on such a wide range of time scales and space scales that the entire process cannot reasonably be modelled in a single numerical or conceptual model. Therefore a variety of approaches should be taken to address these issues and the first steps should be taken towards the development of a probabilistic risk-based method of assessing the safety of coastal defence structures. Such an approach would be developed to give information on the range of possible beach levels to be expected in different scenarios. It will require further development of fragility curves for generic structure types.

There is a dynamic interaction between a beach and a coastal defence structure. Relatively few studies have considered the interactions between beaches and structures (preferring to study one or the other). Areas to consider using physical and numerical modelling are:

- Flow through structures and beaches
- Suffusion and material retention
- Foundation support, including settlement and liquefaction.

There is a shortage of large-scale laboratory and field data on toe scour. Both should be collected to fill gaps in existing knowledge. In particular, the development of the depth of scour during storms is of interest. Any field experiment devised should be tied in with existing survey programmes to maximise the use of resources.

There should also be some consolidation of recent research to determine the relative importance of hydraulic induced scour and pressure induced liquefaction on bed levels/properties at the toe of coastal defences. Most studies have concentrated on sand beaches and impermeable structures. More work is needed to determine the relationship between scour depth and sediment type.

Key strands from the above have been presented in a section of the report outlining recommendations for research. Research into scour and the performance of structures could potentially lead to cost savings should it show that less conservative designs for coastal structures would be appropriate. Burgess (2003) compiled the following approximate potential cost savings for each kilometre of coastal defence:

- Reducing toe depth by 0.5m could save £50,000
- Reducing crest level by 0.2m could save £50,000
- Reducing armour thickness by 0.2m could save £100,000
- Steepening structure slopes from 1 in 2.0 to 1 in 1.5 could save £150,000.

There are therefore considerable potential longterm returns from investment in beach lowering research, and the dissemination of knowledge and guidance. In order to safely minimise the cost of coastal defence structures, the minimum

safe size of toe protection and the minimum safe depth of toe excavation should be investigated.

The scoping study has produced a Technical Report, FD1916/TR1, which is publicly available. The contents of this report are as follows:

1. Background and objectives of study
 - 1.1 Statement of problem
 - 1.2 Objectives of this research project
 - 1.3 Method statement
 - 1.4 Layout of report
 2. Review of existing knowledge
 - 2.1 Introduction to beach lowering around the UK
 - 2.2 Review of literature and UK case histories
 - 2.3 Conceptual framework
 3. Literature review of methods for predicting beach lowering
 - 3.1 Mechanisms and parameters controlling toe scour
 - 3.2 Kinematics in front of a reflective structure
 - 3.3 P-type and N-type sediment transport
 - 3.4 Wave-induced liquefaction near seawalls
 - 3.5 Prediction methodology
 - 3.6 Scale Effects
 - 3.7 Summary of scour experiments
 4. Review of mitigation measures
 - 4.1 Precautionary measures (at design/ construction stage)
 - 4.2 Monitoring methods
 - 4.3 Intervention measures – localised
 5. Conclusions and research needs
 - 5.1 Summary of beach lowering report
 - 5.2 Conclusions and recommendations
 - 5.3 Potential cost savings
 6. References and Bibliography
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| Appendix 2 | Scour Depth Design formulations |
| Appendix 3 | Details of Tell-Tail scour monitors |