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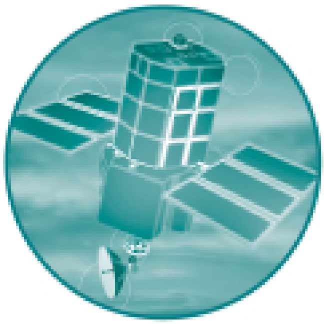

Innovation in the use of Coastal Rock Protection

Results of a Research Scoping Study

R&D Technical Report

FD2401

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Department for Environment Food and Rural Affairs

Environment Agency

Defra/Environment Agency
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September 2000

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Publishing organisation

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Dissemination Status

Internal: Released internally
External: Released to public domain

Statement of use

This document provides guidance to Defra, the Environment Agency and the wider UK coastal research community on the potential for, and barriers to, the wider use of coastal structures with limited foundations or layers.

- Keywords – coastal structures, rock, foundations, innovation

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Executive Summary

This report presents the findings of a scoping study by a team led by HR Wallingford into issues that influence the present and future use in the UK of 'Coastal Rock Structures on Unprepared Foundations'. During the course of the scoping study possible advantages of constructions with limited layers or foundations were identified and an Industry Workshop was held to discuss the issues concerned and ways forward. The workshop identified advantages and disadvantages of these types of coastal structures, and suggested ways to overcome barriers to innovation. Many of these were of a more widespread nature, but specific suggestions on methods to improve the use of coastal rock structures with limited foundations or layers are provided.

This report highlights limitations in guidance presently available and suggests programmes of research that could be adopted to improve this situation. The first, short term programme, is concerned with making the best use of the considerable body of experience available in the UK, but presently neither analysed nor disseminated. It is anticipated that this study could be commissioned relatively quickly and would be completed inside one year. Proposals for longer term research aimed at improving basic and advanced levels of understanding have also been suggested. These longer term advances have greater potential to change the way coastal rock structures are designed, but will take longer to feed into engineering practice.

It is noted that many of the rock structures and schemes considered in the course of this study have been constructed within the last 10 or 15 years and may therefore never have been subject to their design conditions. Whilst information has been derived from the performance of these structures to date, there is no certainty that the structures will continue to perform in the same way in the future.

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1. INTRODUCTION

1.1 Background to the scoping study

Rock armouring is frequently used in the UK to protect existing vertical or steep walls, embankments, beaches, cliffs and fill material against the effects of waves (direct and/or overtopping) and currents. In some instances concrete armour units may replace rock armour, but whilst common in Japan, this occurs less frequently in the UK. Armouring to shoreline structures may also be used to eliminate or reduce beach scour in front of or adjoining the defence structure. Detached or nearshore breakwaters or reefs have been used to reduce wave action at the shoreline, reducing wave overtopping and/or enhancing beach performance. Other structures such as rock groynes, bastions or rock headlands have been constructed to control or modify beach movement, again to reduce overtopping and/or erosion at vulnerable points along the shoreline.

In all these instances, the requirements of the armoured structure are to:

a) deliver improved hydraulic performance such as reduced wave transmission or overtopping
b) halt, reduce or modify sediment movement on-/off-shore and along-shore
c) maintain the structure configuration within acceptable limits over a required life
d) avoid any deleterious effects at or adjoining the defence, including alteration to hazards presented to users or excessive change of appearance

In many instances, armoured structures designed to “standard” codes or guidance include layers of different sizes of armour/rock. The rock or other armour material may have been specially selected to conform to given quality standards. These structures may also require removal of local beach material and/or addition of ground improvement or filter materials to form the structure foundation. Yet some armoured coastal structures have been constructed around the UK without many of these features, offering simplifications in material supply and construction, and possibly at significant savings in costs. Whilst some of these “simpler” structures have suffered damage in service, it is believed that many of them have performed well, giving hydraulic performance and/or stability apparently at variance with the implications of established “design rules”.

It may therefore be deduced that present design guidance and practice sometimes include excessive conservatism in aspects of performance/resistance, and design performance standards required for some coastal structures are rather higher than the performance actually required to discharge their primary function.

This report describes a scoping study for MAFF completed by a research team led by HR Wallingford to address the viability of constructing rock coastal structures on unprepared foundations without the use of underlayers, or with minimal preparation. The study considered issues of design, construction and ownership including:

- structure performance
- ease of construction
- maintenance requirements
- economics, construction and whole life
- health and safety during construction and in service
- overall environmental effects

The study has developed suggestions for short-term and longer term research programmes.

1.2 Study team

The research topic "use of rock on unprepared foundations" was identified by the Penning Rowsell research review as being of particular interest under the MAFF/EA Engineering Theme. Under a short contract with MAFF, HR Wallingford led a study team which included designers, client authorities and contractors in this scoping study. Input was sought from a broad range of consultees at a project workshop, including interested environmental bodies and end users.

HR Wallingford was also able to bring experience of previous research projects where liaison with industrial steering committees and consultees has been fundamental, for example:

- construction risk in coastal and river engineering
- revetments exposed to wave attack
- guidelines for the sustainable use of new and recycled materials in coastal and fluvial construction
- whole life costs and sustainable project procurement in port, coastal and fluvial engineering

The HR Wallingford team was led by William Allsop, Manager of the Coastal Structures Group, and part-time Professor (associate) at University of Sheffield; assisted by Matt Crossman, a coastal engineer in the Engineering Support Group with previous experience in a firm of consulting engineers. Support was given by Jonathan Simm, Manager of the Engineering Support Group, and previously editor to the CIRIA/CUR "Rock Manual", the CIRIA "Beach Manual", and the "Construction Risk" Manual.

Andrew Bradbury of New Forest District Council represented the views of owners. At NFDC, Dr Bradbury has been responsible for design, construction and ongoing maintenance of a number of rock structures, including those placed directly on a clay foreshore. He is also Technical Chairman of the SCOPAC group of south coast maritime authorities and thus has a wider knowledge of developments in the coastal zone.

Philip Barber of Shoreline Management Partnership has been responsible for design and construction of a number of innovative rock structures around the UK coast and has made use of rock on unprepared foundations at sites at Llanelli and at the Wirral.

Paul Starr of Scott Wilson Kirkpatrick has been involved in the rock protection for the new airport in Hong Kong and brings to bear wider international experience in strategy studies, environmental assessment and in geotechnical engineering.

The views of contractors were provided by Will Shields of Dean & Dyball, who has extensive experience of the construction of rock structures on UK foreshores using land-based plant, and Ron Gardner of Boskalis Zinkcon in respect of construction of offshore and nearshore structures primarily using marine plant.

1.3 Objectives of the study

The objectives of the study were as follows:

1. Examine the merits of construction of rock structures in the coastal environment where the rock is placed directly onto an unprepared bed without use of an underlayer, with regard to:

    - ease of construction and maintenance,
    - long-term performance such as settlement and scour,
    - environmental impacts, and
    - safety considerations both during and after construction.

2. Conduct consultation with interested parties by means of an Industry Workshop to ascertain industry views on the requirements for such construction and experience to date of implementation.

3. Report on the findings from Objectives 1 and 2 and give recommendations for future research, including commenting on the most promising avenues that are likely to lead to practical results.

1.4 Outline of this report

This report is intended to provide a concise summary of the relevant issues and to summarise suggested future research directions. Much of the material documenting the Industry Workshop is therefore contained within the Annexes.

2. STUDY METHODOLOGY

2.1 Consultation planning

At the start of the study some effort was put into ensuring that the consultation was undertaken effectively. A comprehensive list of consultees including representatives from Maritime Local Authorities, the Environment Agency, consultants, contractors and key environmental organisation was drawn up. Letters introducing the project, explaining its objectives and inviting participation at the Industry Workshop or written comments were sent to all consultees. In addition HR Wallingford advertised the Industry Workshop on the internet and through an international coastal discussion email list. A total of more than 200 information leaflets were dispatched

Study team members were asked to address specific issues, relevant to their particular skills and experience, and provide information for the informal Briefing Note. A meeting was held with the MAFF project manager on Thursday 11 May, and this briefing note was discussed at a project team meeting on Friday 12 May 2000. The Environment Agency was not explicitly represented at those meetings due to the short timescale in which they were arranged, but were represented at the Industry Workshop. The project team meeting used structured brain-storming of the key issues and factors relevant to the project to produce a register of issues and their perceived importance, together with possible ways in which each issue might be further investigated. The output from the project team meeting was used by HR Wallingford to produce a final Briefing Note (see Appendix A) which was issued to all participants prior to the Industry Workshop to provide a basis for discussion.

2.2 Industry Consultation

A one-day Industry Workshop was held on 13 June 2000 to discuss the key issues identified by the study team; establish present design practice; and identify arguments for and against the use of rock on unprepared foundations. Details of the Workshop including copies of the presentations by study team members are summarised in Appendix B. Over 50 delegates registered for the workshop with Owners (Local Authorities and Environment Agency), Consultants, Contractors and Suppliers/Shippers all well represented. The larger-than-anticipated number resulted in some logistical problems during the discussions, but it was considered important to provide the widest possible opportunities for participation by everyone interested in the topic.

The workshop started with presentations from team members covering aspects of the design and construction of rock structures as well as reviewing some unconventional structures already constructed and presenting ideas for the development of structures in the future. There followed presentations from participants on the use of grouted rock and the experience of Christchurch BC in using unconventional rock structures.

The participants were then divided into three groups by role (designers, clients, contractors & suppliers) each led by two members of the study team. The groups spent some time discussing how rock has been used for coastal defence in UK and what advantages innovative structures might offer. Each group reported back briefly and written comments from individuals were also encouraged. For the next stage of the workshop new groups were formed, each comprising a mix of different roles. The purpose of these discussions was to identify barriers making the adoption of more innovative structures difficult, and requirements for future research.

During the discussions, there was some difficulty in focusing on issues related to the topic of the scoping study. A number of issues of more general concern were raised on general problems of encouraging innovation in a difficult business climate, standards of design, as well as acceptance of risks and maintenance. The debate was therefore more wide-ranging than had originally been envisaged and many reasons given for not using more innovative rock solutions stem from industry-wide problems rather than from specific technical issues relating only to this class of structures. Inherent in some of the discussions were however concerns over the long-term performance of these types of structures, and of the prediction of performance under realistically variable conditions. The main issues raised during the workshop are discussed in section 4 below.

2.3 Collation of information and reporting

Following the workshop various information, including some supplied by the workshop participants, was collated and discussed, allowing the main conclusions from the study to be synthesised. This scoping study report was then prepared.

3. KEY ISSUES

Early within the study process, a series of questions crystallising the main issues of the study were developed. These were originally addressed by the informal briefing note and team workshop, and modified as the study progressed to form the basis of the briefing note for the Industry Workshop. Following the workshop and a period of reflection, more comprehensive discussions of each issue are presented below.

3.1 What is implied by "innovative or unconventional" construction in the context of this project?

For the purposes of this project, the study team adopted an inclusive definition to include any rock or armoured structure, typically nearshore breakwater or reef; rock groyne, bastion or headland; revetment, armoured mound/slope, or armour fillet, where one or more of the following apply:

- The structure/foundation does not include multiple layers of varying sizes/gradings
- Requirements for filter/separator performance have been simplified
- Potentially low or unpredictable long-term performance might be accepted
- Certainty in long-term performance might be offset against low initial cost
- Allowance might be made for repair/refurbishment/enhancement in stages over the structure life

The need for long term "performance" implies that, over its life the structure must:

- Deliver accepted levels of hydraulic response and/or sediment trapping at accepted probability levels
- Retain sufficient of its original configuration to maintain confidence (technical and public) in its future performance

3.2 Why do conventional designs include prepared foundations and layers?

Prepared foundations are used for a number of reasons including:

- To protect against general erosion or local beach movement (scour)
- To provide geotechnical bearing capacity and stability to avoid overall settlement
- To prevent or limit differential settlement across a structure

Incorporation of two or more gradings of rock within a layered construction may be adopted to:

- Enable filter criteria to be met, ensuring that where fine material is used for the core or substrate of the structure, it does not get washed out causing settlement
- Ease construction by ensuring that the required final profile can be achieved using a defined armour layer thickness
- Ensure stability of the armour layer by providing a 'keyed' surface and increase the overall structure permeability to wave action (compared with smaller/less permeable materials)
- Reduce cost by incorporating a core or layer(s) that may be purchased, transported, placed and profiled relatively easily

3.3 Does omission or simplification of foundations or layers save time, reduce cost, or provide other benefits?

The omission or simplification of foundations and layers is thought to offer significant savings in some circumstances, depending on the location of the structure relative to water level range (tide and surge).

3.3.1 Floating Access

For structures requiring marine access, considerable savings may arise from reducing/eliminating preparation of foundations and from simplified construction (possibly including bulk placement of rock). Marine construction is typically 5-20 times more expensive than land-based construction unless very large volumes of materials are being transported, so these savings may be particularly significant. Elimination of difficult/multiple operations and reduced exposure (due to shorter construction times) would result in reduced hazard during construction. There would also be benefits through a reduction in the risk of storm damage during construction and easier repair of damage, if a single grading of rock was used. The use of geotextile in locations where there is only floating access is particularly difficult and expensive.

3.3.2 Drying Access

Savings offered in situations where the structure is accessible by land-based plant during the tidal cycle are probably less than those for marine access, but may still be significant. There may be a requirement to use a layer of granular material to improve trafficability and ensure that the plant does not damage the beach unduly. Savings may arise from reductions in the number and complexity of construction operations and of inter-operation checking. As with floating access there would be considerable benefits arising from the use of a single grading of rock.

3.3.3 Dry Access

Cost savings are likely to be least for locations with predominantly dry access since layer control and placement of materials is easiest. There are, however, still potential savings at such locations in simplifying material ordering, production, handling and placement, although these may be outweighed by reducing the proportion of the quarry yield used within the structures.

3.3.4 Material costs

Historically smaller gradings of rock forming core and/or underlayers were significantly less expensive, per unit volume, than armour layers, probably because large rock was seldom used. Over the last 15 years, this cost differential has decreased markedly in the UK, although rock costs are still variable, depending on the distance from the works to the quarry, method of transportation and placement requirements/tolerances.

3.4 Can such structures be built safely/reliably?

There are a number of cases around the UK where structures have been constructed using minimal preparation of foundations and/or reduced layers. In general these structures are thought to have performed adequately, but in some situations, construction of such structures may probably be unsafe or without a significant cost advantage.

Emergency works and locations where beach levels are expected to improve significantly with time (possibly through beach nourishment) may provide suitable circumstances for the use of these structures. In locations where there is easy public access to structures, safety of users will be a more important design consideration and the desirability of a construction that features large voids may be less attractive. In these cases, the scope for reduced preparation of foundations or bulk placement of rock may be reduced.

There are particular difficulties in excavating deep foundations and toes in beaches, since the volume of material that must be removed may be considerable and access is often restricted to a short tidal window. Where people are required to enter the excavation (to lay geotextile for example) problems are exacerbated since the excavation must either be supported or battered to a safe angle. Again, simplification of the design to remove significant excavation may generate safer and simpler working.

The Construction (Design and Management) Regulations, 1994, impose a number of responsibilities on the different parties, and have led to more detailed consideration of the safety issues, both during construction and 'in service'.

A research and development report was prepared for the then National Rivers Authority in 1996 entitled 'Public safety of access to coastal structures'. The report was intended to provide background legal and hazard information to engineers involved in the maintenance, inspection and design of coastal structures. Although it is understood that the report was distributed within the Environment Agency, none of the attendees at the Industry Workshop had a copy, and release to external organisations was (and still is) restricted. The report discusses legal issues and offers general advice with respect to hazard mitigation, but relatively little in the way of specific design guidance is presented. A second stage of the project, to develop 'a decision support system or framework to assist in achieving nationally consistent and acceptable responses to safety hazards' was proposed, although there is no evidence that this was ever undertaken.

3.5 Can such structures be designed in accordance with present guidance?

Design guidance for coastal rock structures includes documents such as the CIRIA Rock Manual, Simm (1991); the now out-dated US Shore Protection Manual, CERC (1984); BS 6349: Part 7, BSI (1991); and 'Revetment systems against wave attack' by McConnell (1998). All of these documents suggest or imply a need for the inclusion of prepared foundations and filter layers within the design procedure.

Whilst these documents are intended to be used as guidelines by knowledgeable and experienced engineers, their recommendations are often erroneously interpreted as definitive. Their (over-) use can therefore lead to inclusion of underlayers or prepared foundations in situations where they may not be required because there is no guidance as to how the requirement for filter layers or prepared foundations can be determined.

Despite the design guidance, structures with neither prepared foundations nor underlayers are believed to have worked in certain circumstances. The success of such schemes is probably due to use of substantial local knowledge and the experience of those responsible for their development. Those apparent successes (as yet unmeasured or tested) do not however allow this performance to be extrapolated to schemes in other locations.

3.6 Is research information available to support the (future) development of improved design guidance for innovative structures?

Information from basic research which would support the future development of new design guidance is relatively sparse, and must be inferred from studies for rather different structure types. For instance, studies on embankment dams have led to some improvement of knowledge of the processes of suffusion, and work on land drainage has improved guidance on fine material movement. Those studies have however been biased towards steady flows, and it is not known if they give more onerous conditions than reversing flows with occasional peaks.

Under EPSRC's Coastal, Estuarine & Waterway programme (CEWE), a joint project by Bristol and Brighton Universities (Drs. Loveless & She respectively) is studying beach processes on mixed sediment beaches, and Professor Holmes at Imperial College is studying swash hydrodynamics on mixed sediment beaches. Those projects are due for completion between September 2000 and June 2001. Whilst those studies may generate some results of indirect relevance, their research topics do not bear directly on the issues identified in this study. Two recent research projects of some relevance to this study have recently been completed for MAFF, as follows:

3.6.1 Scour at coastal structures

Studies at HR Wallingford to develop improved methods to predict the onset and extent of scour at vertical walls were reported by Carpenter & Powell (1998) in HRW report SR 506, with results also published in the CIRIA Beach Manual edited by Simm et al (1996) and the Thomas Telford manual on scour edited by Whitehouse (1998). The paper by Powell & Whitehouse (1998) for the MAFF conference describes each of the main forms and causes of scour, and summarises the best prediction methods. The main causes of scour are summarised:

- reflected wave energy increasing wave effects in front of a structure
- diffracted waves and/or vortex flows around the heads of structures
- concentration of tidal or wave-induced currents along the front of a structure

Laboratory studies were undertaken to determine scour behaviour in shingle beaches fronting vertical walls, and to consider qualitatively the influence of seawall slope and permeability (rock armour v mass concrete) on the scour process. Subsequent studies for sand beaches were undertaken using a numerical model calibrated against field data obtained from Blackpool and laboratory data (at large scale) from Oregon State University.

Results from both studies are presented as iso-parametric plots linking dimensionless scour depth (s_d/H_s) to mean wave steepness ($s_m = H_s/L_m$) and dimensionless toe depth (h_t/H_s). Very similar trends are found for both sand and shingle, confirming earlier "rule of thumb" guidance that the maximum scour depth is approximately equal to the unbroken wave height for waves of steepness $s_m \approx$ 2-4%, and that maximum scour occurs when the toe depth equals approximately 2 H_s (~1.5 H_{max}). Results also suggest that the potential for scour is greatest under waves of long period, low steepness, although the more extensive dataset for shingle beaches does identify a secondary domain for storm waves of steepness $s_m \approx$ 6% when h_t is approximately zero.

3.6.2 Armoured structures on steep beaches

In recent years in the UK, there has been a trend towards "soft defences" where sand or shingle beaches (supported by beach control structures) reduce wave action at the defence line. Beach control structures often include rock armour groynes, bastions or headlands, for which design rules have historically been extrapolated from breakwater design methods, and have been found insufficient. A number of rock armoured structures on the UK south coast suffered armour damage above levels that might have been predicted.

Work with local authority and other designers identified weaknesses in current design methods, and assisted the design of a series of laboratory tests to quantify armour movement on structures constructed on steep beaches. The results of tests on a range of rock armoured structures were described Jones & Allsop (1995) in IT 413. Analysis of those results was difficult initially, but when extended by data from other European sources gave revised prediction methods to take account of steep beach slope, see Allsop et al/Jones et al (1994). Design advice for the sizing of rock armour on steep beaches was then included by Allsop & Jones (1995) in the HRW report SR 289 and papers by Allsop et al (1994, 1996). The study results identified locations of increased damage to rock layers, and developed correction factors to standard prediction formulae to take account of thin armour layers and of steep beach slopes. For steep bed slopes, the test data suggests that armour sizes in sensitive areas should be increased by a factor of 2.2 on mass relative to the size calculated by van der Meer's equations (1983) to maintain the same levels of armour stability. It should be noted that in all instances, the analysis used measured values of the "local" incident wave height which would normally be much less than the deep water unbroken wave height.

3.7 Is there any on-going research?

A number of on-going research projects may be directly or indirectly relevant to the use of innovative rock structures. The EPSRC Coastal Estuarine & Waterway Programme (CEWE) funded 24 grants covering about 18 projects (at least 6 multi-institute). Details can be reached via the EPSRC web site at: http://www.epsrc.ac.uk/epsrcgrants/portfolio.asp. A number of those projects cover physical processes in the coastal zone, but are primarily focussed on sediment movement and modelling of morphology. Two such projects were noted in section 3.6. Other research projects for which the study team had details are described below:

3.7.1 Packing, voids and rock armour

HR Wallingford is undertaking a research project investigating the influence of packing on the layer thickness, porosity and stability of rock armour. Model tests and full scale trial constructions will be used. This study was commissioned by the Department of Environment, Transport & Regions and is expected to be completed in 2002.

Empirical formulae by Hudson (1958) or van der Meer (1983, 1995) have been developed to size rock armour against wave attack, and have attained widespread acceptance within the coastal engineering community. These formulae give a limiting block weight required to withstand a design wave condition. Supporting methods determine the limiting dimensional properties of rock armour layers, important for determining the quantity of rock required for an armour layer of particular thickness. Despite the fact that the design procedures for rock armour layers are long established, there still remain areas of considerable uncertainty, particularly in estimating their dimensions and bulk densities. To illustrate the problem it is worthwhile to consider differences in the design thickness of an armour layer. For irregular rocks, suggested values of the thickness coefficient k_t range from 0.75 to 1.15, implying considerable uncertainty in the total weight of armour needed. Such discrepancies have serious implications for both cost and performance of rock-armoured structures, and often lead to contractual disputes.

The need for rock armour to be tightly packed together, or otherwise, is of serious concern. Owners tend to prefer tight packing as it looks neat and allays public concerns about risks to people being trapped in voids. Designers perceive tight packing as increasing stability and reducing potential storm damage and consequent maintenance. Both parties however, tend to neglect the consequential reduction in energy dissipation, and hence the increased reflections and overtopping that such placement will cause. Contractors note high costs of re-handling required for tight placement (increasing unit costs per tonne by 10%) and high costs of additional material (perhaps 10 - 20%) which may not be needed for the defined performance.

In confined spaces, tight packing may offer advantages in reducing the thickness of armour or in being able to use rock of limited individual weight. For such reasons, single layers of tightly packed armour have been used overseas, and may thus be considered within the UK.

The current research project at HR Wallingford is investigating the effects of parameters such as rock shape and packing density on properties of the armour layer in terms of its dimensions and its performance. The project will examine single layer rock armour. The project results will provide ‘best practice’ guidance to remove ambiguities from the design and construction process. The specific objectives of the project are to investigate the influence of rock shape and packing on:

1) Thickness and as-placed density of armour layers
2) Hydraulic performance of armour layers, as regards stability and wave energy dissipation

3) Costs of structures
4) Aesthetic and health/safety aspects of structures

The effect of the following variables are being investigated:

- The size and grading of the rock
- The rock shape
- The method of placement, including the type of placement equipment, human factors and time considerations
- The client/engineers requirements for rock packing

The project is being conducted in three phases:

Phase 1 ~ Full Scale Tests

Full scale test panels have been constructed at quarries and coastal sites using carefully graded and measured armourstone, of different shape and size distributions. Variability in layer thickness and void porosity were measured for different placements. Larvik Armourstone, Bardon Aggregates and Forster Yeoman provided rock for these tests and test panels were constructed by Dean & Dyball.

Phase 2 ~ Dry Model Tests

Dry model tests involve construction of model rock-armoured structures at HR Wallingford to replicate full-scale work in Phase 1. These tests will investigate scale effects on the dimensional properties of armour layers. This phase is due for completion during autumn 2000.

Phase 3 ~ Hydraulic Model Tests

Hydraulic model tests to quantify the effect of rock shape and packing on hydraulic performance of armour will be commenced in winter 2000/2001 in one of the wave flumes at Wallingford. Armour movement and overtopping performance will be quantified. Particular attention will be given to single layer armour, as this is an area in which relatively little guidance is available.

3.7.2 Acceptable risk levels for use in hydraulic design standards

Acceptable risk levels are crucial as, combined with design life, their identification allows suitable levels of loading and response to be set. It is hoped that this study being undertaken for the Department of the Environment, Transport and the Regions will help in the integration of different discipline contributors to the design process in water engineering and help to deliver better value to clients/users by:

- Reducing the costs of over-design arising from over-conservatism
- Reducing unexpected additional whole life costs from under-design or inadequate appreciation of risk levels
- Reducing the risks to health, safety and the environment from under design

The research is based on real experiences from Engineers by using structured interviews and case study histories to identify three items:

- Levels of risk currently accepted by designers and clients
- Methods presently adopted to analyse these risks
- Weak links in the process

3.7.3 Whole life costs and sustainable project procurement in port, coastal and fluvial engineering

A major complication in the design process is the uncertainty in maintenance costs and the extent to which structures may have a 'beyond nominal design life' durability. This objective of this study is to provide better estimates of whole life costs for use during the project appraisal stage. The research is being supported by the Department for the Environment, Transport and the Regions and will facilitate improvements concentrating on three parallel strands of activity leading to published guidance:

- Identifying a project appraisal methodology for maintenance costs and actual life durability
- Compilation of a database of maintenance and recurring costs for different materials and systems
- Evaluation of the impact of decisions on procurement and environment on whole life costs

The benefits of more accurately predicting, and thus reducing whole life costs using the guidance generated by this study will be associated with reducing capital, maintenance or disruption costs.

3.8 Are there significant environmental/sustainability issues?

There are a number of environmental issues relating to the use of rock in general for coastal defences, but most of those issues will be common for all types of conventional or unconventional rock structures. A number of potential environmental differences have been identified, but it should be noted that their relative importance will be highly dependent on the particular works, site location, and operating procedures:

- Increased turbidity and suspended sediments resulting from bulk placing of rock
- Reduction in fines generation/movement as a result of reduced foundation preparation
- Reduced quarry extraction and wastage from revised usage of different graded materials
- Improved use of rock by modification and/or re-use of rock structures using single gradings placed on the surface of the beach, reducing total volumes of material extracted

4. PAST EXPERIENCE AND PRESENT PRACTICE

4.1 Use of rock in UK coastal defences

Since the early 1980's the use of rock for coast protection and flood defence in the United Kingdom has increased dramatically. Although historically rock was used for harbour breakwaters and slope protections, it was only in the last 20 years that rock armouring has been significantly used for coastal defence works around England and Wales. Early applications included revetments installed along the River Dee in 1978 and the offshore breakwater at Leasowe Bay and Rhos-on-Sea i, and armouring to the seawall at Blue Anchor Bay, Somerset. These advances were noted at a seminar at Wallingford reported by Allsop et al (1986). In 1991 the joint CIRIA/CUR "Manual on the use of rock in coastal and shoreline engineering" (Rock Manual) was published in UK and the Netherlands. This manual presented 'state of the art' design methods, and provided guidance for the design and specification of rock structures.

Since the publication of the Rock Manual the use of coastal rock structures has gained wider acceptance within the industry, and engineers have been able to design these structures without detailed knowledge of the research on which the design guidance is based.

4.2 Present UK design practice

One of the topics discussed at the Industry Workshop conducted for this scoping study was the basis on which coastal rock structures are presently designed. Whilst noting that there is now substantially better guidance available than in the early 1980s, there was a widespread view that present design guidance is sometimes contradictory, and is limited to relatively few structure configurations and responses. In practice, most design calculations or decisions are based on guidance in the 'Rock Manual', BS 6349 or the 'Shore Protection Manual'.

When considered more carefully, it can be seen that there are wide disparities between the design philosophies that are actually adopted, particularly in design life and standards of performance. Some owners (generally Maritime Authorities) have considerable knowledge of local conditions and of solutions which appear to work well in their particular area through 'trial and refinement'. It is believed that the resulting structures often have low capital cost, but possibly high on-going maintenance requirements. Conversely, consulting engineers may be employed by owners/clients with less comprehensive knowledge of local conditions. Consultants will generally be retained to solve a particular issue in a limited time-frame. Schemes/structures designed under such conditions are often more conservatively designed, possibly with higher capital costs but reduced maintenance requirements.

One rule of thumb quoted during the Industry Workshop suggested that costs for any given scheme are approximately determined according to the following ratios:

> 70% at conceptual design (strategy study phase)
> 20% at detailed (scheme) design
> 10% during construction on site

Although no evidence was provided specifically to support this, it was accepted as broadly representative and confirmed that innovation needs to take place early in the design/concept process rather than just during construction. It is apparent from this that the most significant gains may be made from ensuring that strategic studies and outline designs consider a wide range of different options, and gather sufficient data to support the development of alternative schemes.

4.3 Barriers to change

It was apparent from the workshop that the designer (often a Consulting Engineer employed by the client, but sometimes an 'in house' engineer) makes the main decision regarding the form and type of structures adopted for any particular scheme. It is therefore no surprise that many of the barriers to change identified during the Industry Workshop were focused towards the designer and client.

It was broadly accepted that the combined effects of pressures from professional indemnity insurance (PII), compliance with recognised best practice, and competitive fee bidding has resulted in many consultants favouring capital intensive, conservative schemes. Clients lacking knowledge or resources to monitor or maintain adequately less robust structures may also favour these schemes either consciously or unconsciously. Although it is a requirement for grant aid from MAFF that costs throughout the scheme life must be considered, it was felt that there was seldom sufficient information on which to base these estimates. It was particularly argued that whole-scheme costs include the design element, and that artificially reduced design fees do not generate best value. Other common concerns for designers included the dangers of inadequate ground investigation, inflexible design briefs or criteria, and preconceived (but not supported) ideas held by some clients.

There was also discussion regarding the extent to which designers are able to innovate if they must carry much of the risk, but share little of the benefits. It was felt that recent developments such as design and build or the private finance initiative would help in providing greater incentive to optimise schemes and allow greater sharing of risk and savings. These contractual arrangements also allow the contractor to share his knowledge and understanding of the construction process with the designer, resulting in more efficient and buildable solutions.

The predictability of the performance of schemes was also raised and it was acknowledged that although some physical and numerical modelling can give good indications of how a scheme may be expected to perform, the results depend critically on the quality and extent of the input information, and on the modelling methods chosen. It was agreed that schemes should be designed and detailed in a manner that allows adjustment, and that monitoring and analysis of performance should be used to adjust the scheme where possible. It may however be noted that relatively few schemes discussed in this workshop had been subject to detailed modelling, with for most schemes only a few responses studied in relatively simplistic numerical modelling.

The lack of guidance currently available regarding flows and currents within rock structures and thus the extent to which filters are required was also identified. It was pointed out that although filters may be required in one part (e.g. the toe) of a structure, there are almost certainly other parts of the same structure (e.g. in the middle of the base) where they are not actually needed, but have conventionally been adopted.

In considering movement of material under hydrodynamic loadings, it was particularly noted that few design rules for these types of structures determine an actual response, instead they simply estimate a limiting value, below which (or above as appropriate) an unwanted response is deemed not to occur, or to be unlikely. The most immediate examples are filter rules which give notional limits, but do not describe the process of movement of fines. Coupled with difficulties in predicting the driving forces (wave induced flows/pressures), this has resulted in an inability to predict performance for non-standard designs.

Problems with public perception of coastal works were also identified. Often schemes, which are providing an adequate standard of defence, are thought by the public to have failed if the defences are not clearly visible, or have moved. The fear of failure (real or perceived) was discussed and it was suggested that clients fear political failure, consultants fear litigation and damage to their professional reputation, whilst contractors may fear losses if a scheme fails. There was a widespread belief that high profile organisations and schemes may be tied to conventional routes and approaches.

It is apparent that results of research do not always reach those involved in commissioning, design, construction or maintenance of coastal rock structures. Events such as the annual Armourstone Users Group, and indeed the workshop conducted for this study, assist in dissemination of information, but do not achieve the widespread acceptance of, for example, the Rock Manual edited by Simm (1991). This problem is illustrated by the difficulty, which the Study Team experienced in obtaining two research publications related to this report. An NRA report by Stickland (1993) on 'Armourstone Foundations' was thought to exist, but only because one of the study team had reviewed another bid for the same research topic. The study report had not been widely publicised or reviewed, but was available from the EA R&D dissemination centre when traced. A second report by Halcrow (1996) on 'Public Safety of Access to Coastal Structures' (see discussion in 3.4) was obtained, but only after significant efforts had been made to convince the relevant parties that it was appropriate to this study.

5. CONCLUSIONS

It is apparent that the presently available design guidance does not represent best practice in all situations and may lead to less economic defences being constructed. A significant number of structures currently 'in service' are not consistent with aspects of the guidance, but very limited formal documentation is readily available.

Design criteria for rock structures are often not consistent with those of other elements of coastal defence schemes such as beach nourishment. This may lead to substantially increased cost and reduced monitoring activities. Some relaxation of performance criteria, such as design life or maintenance requirements may result in lower whole life costs as well as less intrusive structures and schemes.

There are disparities in design practices adopted by different groups of design engineers. Those working for consultants may not have long historical knowledge of the site. They will often be constrained by requirements of Professional Indemnity Insurance and Quality Assurance schemes to use established design methods which tend to be conservative, and may result in schemes with high capital cost but low planned maintenance requirements. Maritime Authority engineers are often better able to develop a detailed appreciation of the conditions and processes at the site, and are more aware of the ongoing maintenance and monitoring resources. This may result in solutions which typically have lower capital costs but carry higher risks of maintenance requirements. Opportunities for the sharing of risk and for a fuller debate on standards of service do not appear to have been fully embraced by many clients, and indeed would be difficult without some 'in house' design support.

It is apparent that there are locations at which it is appropriate and economic to use innovative coastal rock structures with limited or no underlayers/foundations. Examples of locations where such structures are reported to have performed well include Mudeford Sandbank, Hurst Spit and Elmer. There have however been a number of innovative structures which have not performed as well as envisaged, although these are less easy to identify or research. There are problems at present levels of knowledge in defining which locations offer the most potential for such structures. A review of the factors that result in success or failure falls outside the scope of this study, but could form the basis of research which could generate significant improvements in the short-term. At present, it is apparent that success in using less conventional coastal structures is largely a result of engineering judgement and understanding of conditions and processes at work, which have not yet been quantified or expressed.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

Some recommendations regarding the direction of future research have been prepared and are presented within the following sections. In line with the original project remit, no research on the general topics of innovation, risk-sharing or whole-life costs has been identified in this note, although there might be an advantage in so doing. In line with MAFF/EA Theme Advisory Group requirements, an attempt has been made to separate research that can generate benefits in the short-term from those likely to generate longer-term benefits.

6.1 Short term: collation, appraisal and dissemination of existing experience

It is clear from the research in this project that there is considerable information that could be gathered and then be analysed to guide the use of less conventional coastal structures. This exercise would require that design and service performance of a number of past and existing rock structures be analysed against factors such as exposure, delivered performance and life, and maintenance costs.

The success of this work will be highly dependent on a good understanding of performance issues. It will be necessary to provide for significant interaction with wider research on performance issues. It is understood that this wider work will develop a framework within which performance issues relating to specific structures may be considered.

This research would collate existing data held by designers, contractors, clients and/or MAFF. The project would then select example innovative structures for more detailed analysis to categorise their design and service performance. Even where analytical methods cannot yet describe a particular process (say settlement), careful analysis of service performance of these structures against estimates of their lifetime exposure could generate categories for which unconventional or innovative structures can be used in the UK.

The exercise could possibly be combined with Post Project Appraisals and data collected under the following topics:

- Actual maintenance requirements and lifetime costs compared with initial estimates
- Variation of performance and structural integrity of rock structures with time
- Construction techniques and selective placement of rock gradings within the structure
- Use of larger proportions of quarry yield or simplifications in material production

- Adaptability and modification of rock structures (either to suit changing conditions/requirements or in order to optimise a scheme)
- Foundation requirements for different classifications of substrate materials
- Matching the performance requirements of different elements of coastal schemes

It is anticipated that the study might start by identifying selected rock structures constructed in the UK, or perhaps just England and Wales. Basic information (such as owner, construction date, designer, rock size/grading(s) and typical cross-section, foundation type and materials, wave and waterlevel conditions, design life, capital and maintenance costs) would be sought for each structure or scheme. Comments could be sought from the owner or responsible agency regarding the performance. Much of this information would be collected by questionnaires and/or selective interviews with key clients or designers.

Case studies would be used to illustrate successful innovative or non-conventional structures and indicate the circumstances in which similar designs or details may be expected to prove advantageous. The research would help to encourage the use of a broader range of structures and design details to address problems at specific locations, rather than the adoption of 'standard' designs or practices. This should permit the wider adoption of structures that are more adaptable, efficient and environmentally sound, as well as having lower whole-life costs.

It may also be possible to include in this review schemes under consideration by MAFF engineers for approval and/or grant–aid. This might have advantages over using past case studies, recommendations might be implemented immediately, with consequent savings. This would also aid in dissemination of the latest knowledge/techniques to all parties involved in the scheme under review. Such an exercise would however, have to be approached sensitively to avoid difficulties with those responsible for preparation of the design, and the inevitable delay in implementing the scheme(s) in question. The wider success of this type of "active" case study would be dependent on the particular circumstances of the case selected.

As ever, active dissemination of the study findings through publications and workshops/seminars would be important to ensure wider adoption of the study results. Established routes of such dissemination through the MAFF conference can be used to alert users to the availability of new guidance, and to obtaining the relevant reports/papers. National or local seminars/courses could then be used to increase familiarity with the suggested methods.

6.2 Long-term research

There are several areas of more fundamental research, which will contribute to an improved understanding of the processes underlying the design of coastal rock structures. These projects are likely to be implemented in the longer term and may directly improve analytical design methods or models, or allow quantifiable estimates of design life to be developed.

6.2.1 Modelling of flows / pressure gradients within porous mounds / slopes

For rubble mound seawalls, groynes, breakwaters and related armoured rubble structures, the primary design parameters are the main armour size required to resist wave attack, and the crest level to limit wave overtopping / transmission. These responses are relatively well understood and design tools to determine limiting armour sizes and overtopping performance using simple empirical formulae, physical or numerical models are now well established. There is however rather less clarity in the performance criteria needed for beach control functions, see 6.2.2.

One structural response that is important in sediment control, but is significantly less well understood, and for which tools are much less well developed, is settlement of the placed rubble itself, and/or settlement of placed materials into the foundation. These settlements are generally driven by internal and/or exiting flows carrying fine particles outward from one layer or layers. Simplified empirical methods to define filter and separating layers to prevent settlement have been developed in geotechnical engineering, with most methods arising from engineering of large rubble dams. Those general methods have been applied to most coastal / marine structures, but for many shoreline structures there is relatively little evidence for their need or effectiveness.

Methods derived to predict filter performance in reservoir dams and related structures generally assume that hydraulic gradients that drive particle movement and filter breakdown are nearly constant, but of gradient / steepness limited to that of the structure side slopes (typically 1:1.5 to 1:4). Because these pressure differences operate on a dam structure over very long time periods, they pervade all parts of the dam and its foundation material as far as their hydraulic conductivity allows. Because the driving conditions change over a relatively small proportion, peak values of the hydraulic gradient seldom represent much increase over average values. With such pervasive pressure gradients, and hence flows, even very low rates of transport of fine materials within or through the dam structure may ultimately lead to significant loss of material, and are hence of concern to the designer.

In contrast, the hydraulic gradients that can move material within or beneath a rubble mound structure subject to coastal wave action are of relatively short duration, frequently reverse, and may occasionally be very steep. It is likely therefore that the processes of filter breakdown and internal transport will vary significantly from the steady-state case. In particular, the short duration and spatial restriction of most severe hydraulic gradients will limit (but not block completely) internal transport of fines.

Research based on historical performance of existing schemes may give some indications on how changes / simplifications to the structures may change their performance (under given conditions). Those studies will not, on their own, directly improve analytical design methods or models, nor give quantifiable estimates of design life. For these issues, it is further improvements are needed for design / analysis methods if long-term performance is to be predicted, perhaps under four general categories:

1) Effects of structure configuration and composition on the overall hydrodynamics (and thus sediment transport) at and around the structure
2) Flows / pressure conditions at the surface of, between and within porous mounds/layers
3) Movement of (finer) materials through porous layers / mounds, including both up-wards leaching of finer foundations materials, but also the sideways transport of (sand or shingle) beach materials through the (upper) layers of the control structure
4) Structural / geotechnical responses of mounds and slopes to flows / pressures and sediment movement

Within these categories, there are a number of hydro-dynamic, sediment movement, and structural / geotechnical responses of concern:

- Influence of outer layer porosity / permeability on run-up/overtopping and reflections
- Propagation of oscillatory and disconnected flows into rubble mounds / slopes / layers
- Influence of permeability of inner layers (itself depending on wave period) on the overall (geotechnical) and outer layer stabilities (armour damage/sliding)
- Influence of armour / core grading on permeabilities
- Description of detailed flows and pressures at and through zones within a rubble structure
- Migration of fines / bed material by the processes of suffusion and/or filter failure under varying / reversing flows
- Influence of abrupt pressure impulses on element movement/stability
- Structural / geotechnical response of mounds to movement of foundation or fill materials

Methods to address these will include, but not be limited to:

- Experimental work on basic processes, especially on movement of fines / sediment by suffusion, filter failure etc
- Field monitoring of example structures with internal/external measurements of hydrodynamic loadings and structural/geotechnical responses

- Hydraulic modelling of structure performance to give bulk responses, especially wave overtopping/run-up, and/or validation data on external and internal pore pressures
- Structural/geotechnical modelling of mound structures
- Numerical modelling of hydro-dynamics, including external and internal flows/pressures; and then of sediment/element movements

The main types of these models must be categorised by the wave processes included (noting also those processes that are excluded). The simplest classification of such numerical models are:

a) Period averaged models which calculate net effects averaged over a (regular) wave period
b) Time-stepping 1-dimensional depth averaged models of wave run-up and/or overtopping
c) 2-dimensional (plan) versions of b)
d) Wave overturning versions of b), 2-dimensional (vertically), but not fully breaking
e) Wave overturning versions of c), 3-dimensional (vertically), but not fully breaking
f) Fully wave breaking versions of b), 2-dimensional (vertically)
g) Fully wave breaking versions of c), 3-dimensional (vertically)

In general these models reproduce solely the water movements. Additional features are possible, but have not yet been enacted, to include armour movements for a dynamically re-shaping slopes, and/or to include sediment movement.

6.2.2 Modelling interaction between coastal rock structures and beaches

The essential role of beach control structures is to limit the response of the beach by restricting longshore and offshore movement of beach material. These reduced beach responses preserve beach levels, hence reducing potential erosion / overtopping. Knowledge on the effectiveness of such structures is not well-developed, and it is clear that the detail / accuracy of prediction methods to describe the effectiveness of particular structures as a function of changes to that structure are far from robust. Further research on structure / sediment interactions is therefore needed to properly quantify the impact on control structure effectiveness arising from changes in position / composition of those rock structures. This work will certainly require detailed observation of existing structures (building on results of the short term research described in section 6.1). It would also, however, be informed by the numerical modelling of flows in and around rock structures, and may benefit from carefully controlled experiments on sediment retention, perhaps using other laboratory testing as well as field trials. This work would focus on describing the structure / sediment interactions more fully, thus enabling designers and owners to understand the implications for overall scheme performance of innovative structures.

6.2.3 Monitoring settlement of coastal rock structures

In support of the studies described above, it may be possible to generate useful information through collection of field data from a number of carefully selected rock structures to assess their settlement. This would complement the work currently being undertaken at HR Wallingford into ‘packing, voids and rock armour’. It is envisaged that instrumentation similar to that used successfully for shingle transport studies could be used to gather information on settlement of individual rocks.

Analysis of the data collected could be used to verify aspects of the numerical modelling and allow the use of different type of foundations within a single structure or adjacent structures to be assessed objectively. It is expected that approximately six months preparation time would be required before a working instrumentation was available, during which one or more suitable schemes would be identified. It is envisaged that the monitoring would last at least three years, although initial findings might be evident more quickly.

7. ACKNOWLEDGEMENTS

This report was prepared by William Allsop and Matt Crossman, but is based on substantial contributions by Phillip Barber, Andrew Bradbury, Ron Gardner, Will Shields, Jonathan Simm and Paul Starr. The study team are also particularly grateful for significant assistance given by attendees at the study workshop, particularly those volunteered to act as group reporters.

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Appendix A

Briefing note

Appendix A Briefing Note: Why do we prepare foundations and use multi-layer construction?

Most rock armoured coastal structures on or adjacent to beaches are placed on prepared foundations and use multiple layer construction. Examples of such structures are near-shore breakwaters, coastal revetments, and some rock groynes or bastions. Inclusion of under- or filter-layers is primarily to avoid possible settlement and interface breakdown, but may often be simply "because the codes say so".

A number of simplified rock structures have been constructed around the UK, and overseas, using less foundation preparation or fewer layers than may be implied in existing design guidance. These unconventional structures may offer cost savings, quicker and less hazardous construction, but there are fears that durability may be reduced and there are certainly difficulties in reconciling these designs with present codes or manuals. The environmental impact of such structures has not yet been fully assessed.

The aim of this scoping study for MAFF Flood & Coast Defence is to identify the need for research on design, construction and performance of coastal rock structures using unprepared foundations and/or reduced filter layers. It is intended that the consultation workshop will review the potential advantages of such a construction approach, identify design guidance currently available and explore the requirements for future use or research.

The main aspects of the problem and information readily available have been reviewed by the research team. The main issues appear to be crystallised by the following questions, to which initial responses are suggested to initiate discussion. Submissions providing answers to these or related questions, or identifying practical experience and/or research in this area will be of particular benefit. The project is particularly interested in coastal structures designed and built using simplified foundations or omitting other layers. Have these simplifications given savings in construction, how have they performed in service? Has there been any data gathering (completed or underway) that would illuminate this subject, particularly on practical issues like construction speed, production economies, transport, or construction hazard, as much as on hydro-dynamics, filter performance or suffusion of fine materials.

1 Why do conventional designs include prepared foundations and layers?

Prepared foundations provide protection against general erosion or local beach movement (scour). They are also required to provide geotechnical bearing capacity and stability. Layered construction is usually adopted to reduce settlement and breakdown of interface between substrate and structure.

2 Does omission or simplification of foundations or layers save time or cost, or provide other benefits?

The omission or simplification of foundations and layers is thought to offer significant savings in some circumstances, mainly depending on the location of the structure relative to water level range (tide and surge):

Floating Access

For structures requiring marine access, considerable savings may arise from reducing/eliminating preparation of foundations and from simplified construction (possibly including bulk placement of rock). Marine construction is typically 10 or 20 times more expensive than land-based construction so these savings are particularly significant. Elimination of difficult/multiple operations and reduced exposure (due to shorter construction times) would result in reduced hazard during construction.

Drying Access

Savings offered in situations where the structure is accessible by land-based plant during the tidal cycle are probably less than those for marine access, but may still be significant. There may be a requirement to use a layer of granular material to improve trafficability and ensure that the plant does not damage the beach unduly. Savings arise from any reduction in the number of different construction operations and checking required.

Dry Access

Cost savings are likely to be least for locations with predominantly dry access since layer control and placement of materials is easiest. There are still potential savings at such locations in simplifying material ordering, production, handling and placement.

3 Can such structures be built safely/reliably?

There are a number of cases around the UK where structures have been constructed using minimal preparation of foundations and/or reduced layers. In general these structures are thought to have performed adequately, but in some situations, construction of such structures would probably be unsafe and/or without cost advantage.

Emergency works and locations where beach levels are expected to improve significantly with time (possibly through beach nourishment) may provide suitable circumstances for the use of these structures. In locations where there is access to structures, public safety will be paramount and the scope for reduced preparation of foundations or bulk placement of rock may be reduced.

4 Can such structures be designed to present standards/codes?

Design guidance for coastal rock structures in the UK includes documents such as the CIRIA Rock Manual, the Shore Protection Manual, BS 6349 and Revetment systems against wave attack. All of these documents suggest a requirement for the inclusion of prepared foundations and filter layers within the design procedure.

Nevertheless, with substantial local knowledge and experience these structures have been shown to work in certain circumstances. What is not known is the degree of certainty of performance that would be available in other locations.

There is little guidance currently available regarding the extent to which filters are required. For example, where filters are required in one part of a structure there are almost certainly other parts of the same structure where they may not be needed, but have conventionally been adopted in the absence of clear advice.

5 Is information presently available to support development of design guidance?

Information from basic research which would support the development of new design guidance is sparse, and biased towards other structure types, e.g. embankment dams or land drainage. Research in this project so far suggests that case studies, if suitably collated and analysed, could provide useful initial guidance for design of non-standard coastal structures. Topics for which immediate data collection could provide guidance may be:

- Variation in structure performance with time
- Construction techniques and selective placement of rock gradings within the structure
- Use of larger proportions of quarry yield or simplifications in material production

More intensive research would probably be needed to improve comprehensive design guidance on:

- Processes of filter breakdown under cyclic flows
- Propagation of oscillatory flows/pressures into rubble mounds/layers
- Numerical modelling methods for external/internal flows

6 Are there significant environmental/sustainability issues?

There may perhaps be some environmental issues relating to the differences from conventional rock structures:

Increased turbidity and suspended sediments resulting from bulk placing of rock
Reduction in fines generation/movement as a result of reduced foundation preparation
Reduced quarry output/wastage from revised usage of different graded materials
Easier re-use, tuning/modification and/or removal of rock structures using single grades

Appendix B

Notes of Industry Workshop

Consultation Workshop:

Innovation in the use of coastal rock protection

Why do we prepare foundations and use multi-layer construction?

TUESDAY 13 JUNE 2000 AT HR WALLINGFORD

Programme

09:30 Registration

10:00 Introduction to the project
Design Methods
Construction Aspects
Owners View and Innovative Approaches

11:45 Discussion, possibly including short presentations or case studies brought by attendees

12:30 Team Formation & Session 1a: Present Knowledge and Experience
Initial discussions to identify Present Knowledge and Experience

13:00 Lunch
13:45 Optional Tour of Current Model Studies

14:15 Team Session 1b - Summary of Present Knowledge and Experience

14:45 Reporting / Plenary

15:30 Tea & Team Re-formation
Team Session 2 - What needs to change?
Development of Data-collection and Research Requirements

16:15 Reporting / Plenary

16:45 Summary of actions and programme

The presentations that were given at the workshop can be found in the annex to the final report.