FR 1272 - I

RG/99/E/04

SUMMARY

1.0 Title
Investigation of Wave Structure of Porous Coastal Structures

2.0 Research Institute
Civil Engineering Department, University of Moratuwa.
Experimental investigations conducted at Lanka Hydraulic Institute, Katubedda.

3.0 Chief Scientific Investigator
Prof. S. S. L. Hettiarachchi

4.0 Period of Contract
Project commenced on 1st February 200 in agreement with the NSF.
Project completed on 31st May 2003.

5.0 Scientific Background and Objectives of the Project

5.1 Scientific Background
The ability to predict the wave reflection, transmission, run-up and run-down for various types of coastal structures plays an important role in their hydraulic design. These parameters together with the hydraulic, geotechnical and structural stability of the individual components and of the structure as a whole, will determine the overall performance of the structure both in the short term and in the long term.

Prediction of the hydraulic performance of coastal structures could be made using two principal approaches namely

i) Mathematical Modelling
ii) Empirical equations based on model test results

Although advances have been made in the computation techniques of mathematical modelling, the development of this subject has been restricted by a lack of understanding of the physics of wave action on and flows through porous coastal structures. One of the principal shortcomings in the field of understanding wave-structure interaction of porous coastal structure is the absence of results from large-scale physical model tests, which represent near prototype conditions. Advances in mathematical modelling have been restricted by the limitations and the degree of accuracy of important quantitative expressions describing critical aspects of flow through porous structures. Basic research on specific aspects of wave structure interaction arising from detailed observations on large scale hydraulic model studies at scale of 1:10 to 1:20 are considered necessary to obtain an improved understanding of wave-structure interaction.

5.2 Objectives of the study
The objective of the research study is to obtain an improved understanding of wave-structure interaction of porous coastal structures leading to the design of more efficient and economical rubble mound coastal structures for harbour construction and coast

protection. In particular attention will be focused on the potential use of cost effective concrete armoured breakwaters which have not been used in Sri Lanka. In the case of harbour structures both external and internal structures will be studied.

6.0 Investigative Methods

6.1 Literature Review and Re-analysis of data

An extensive literature review was conducted on a wide area of topics relevant to the study. In particular experimental results from previous investigations were re-analysed to obtain specific information on the hydraulic behaviour of wave-structure interaction.

6.2 Experimental Work

Experimental work included very detailed large-scale investigations on different types of multi-layered trapezoidal breakwater cross-sections, in particular, cost effective concrete armoured structures. A series of tests were also carried out on vertical homogenous structures consisting of rock.

6.3 Mathematical Modelling

Mathematical modelling will relate to analytical modelling of wave-structure interaction and the development of the models will incorporate the findings from the results of previous investigations and the experimental investigations conducted for this study.

Development of analytical mathematical models would be primarily carried out for wave structure interaction of vertical homogenous structure consisting of rock. The model results were compared with experimental data to determine the effectiveness of mathematical models, their applicability in the overall context and their limitations.

6.4 Field Work

Field visits were undertaken to investigate the present status and performance of rubble mound breakwaters at small craft harbours along the southwest coast. Both recently built structures and those built previously were investigated in the context of planning of the proposed experimental investigations.

7.0 Conclusions and Recommendations

7.1 Wave Structure interaction in relation to wave disturbances in harbour basins

The relevance of selecting the appropriate type of structural configuration to overcome the undesirable impacts of wave reflection is highlighted. Attention is focused on the need to have maximum energy dissipation characteristics while reducing the influence of wave reflections. The performance of two forms of low reflection alternatives are discussed.

The first form is the piled quay over armoured rubble slopes. They are found to be efficient in maintaining low reflection coefficients. The influence of relative pile spacing and the effects of constructing such a structure on a part-depth caisson are discussed in relation to specific model studies.

The second form is the use of vertically faced structures that itself include sufficient porosity, so as to allow significant energy dissipation within their body. The study has identified different types of such structures used in practice and has described important aspects of the hydraulics of wave-structure interaction. The study summarises selected results from experimental programmes on the hydraulic performance of a range of such structures. This includes stacked voided blockwork consisting of Cob and Shed hollow block concrete armour units, usually used as the principal armour for sloping breakwaters.

Comparison of external and internal wave characteristics for vertical porous structures of varying length, with and without rear impermeable faces illustrated several important design aspects in relation to their hydraulic behaviour. When waves collide against these structures most of the energy is attenuated within a short distance; of the order of about ten times the characteristic dimension from the front interface. This was more pronounced for steeper waves. Waves of long period and lower amplitude were more effectively transmitted through the structure. In the case of closed block structures the location of the rear impermeable face had a dominant influence on internal transmission coefficients and it was found that as the length of a closed block structure increased, its performance was very similar to the equivalent open block structure. This happens earlier with high amplitude waves having a shorter period.

The study identified the significance of an optimum length which was dependent on the dominant incident wave conditions and the hydraulic properties of the media. Extending the length of the structure beyond this optimum length would be uneconomical as additional length did not contribute to significant further reductions in reflection and transmission coefficients.

7.2 Investigations relating to the performance of single layer hollow block units

A classification of concrete armour units has also been presented prior to the discussion of results. The results refer to the complete hydraulic profile of the respective structures and observations have been made on wave reflection, external and internal transmission, wave energy dissipation, run-up, run-down, overtopping and stability. The results have confirmed the efficient performance of Accropode® and Hollow Block armour units. In particular, the Accropode® has been tested for extreme incident wave conditions and has exhibited very efficient performance. The Hollow Block unit too performed well for the widely varying incident wave conditions used. In the event of concrete armour units being used in the Sri Lankan context, the single layer hollow block type units provide an economic solution while satisfying the required stability considerations.

The investigations have also provided important observations on the response of the design parameters to varying incident wave conditions. In particular, the observations on influence of long period waves should be noted in the context of critical design parameters. The study of energy dissipation characteristics across sections provides the basis for improved design by economising on the geometry.

7.3 Analytical Model and its Applications

Analytical approaches to the problem of wave transmission and reflection through porous media have been based on simplifying assumptions without which solutions cannot be achieved. This analysis cannot strictly be applied to the general case of intermediate or short wave excitation unless the equations of motion are written to account for depth dependence. Then an appropriate numerical technique has to be adopted for the solution of the equations. The simplifying assumptions restrict the analytical solution to a specific domain. However previous investigators have applied their analytical models outside the respective computational domains, thus invalidating simplified assumptions. In such situations, it has been observed that some models have performed well even under these conditions provided they have not moved too far away from the boundaries of the domain. The very positive advantage of an analytical model is that it provides a reliable initial estimate of important parameters crucial to design and these parameters could be further established by detailed numerical modeling.

The analytical simulation of wave motion in porous media provided satisfactory agreement with experimental results for a wide range of porous structures. Several important aspects of physical significance were identified in the comparison. The use and validity of steady flow coefficients under unsteady flow conditions and the proper evaluation of interface losses are two of them. To a great extent both were influenced by air entrainment. Allowances for wave breaking and losses at the interface have to be incorporated in the solution.

From the observations it could be concluded that the analytical model has satisfactory predictability for waves of lower steepness and higher period and this is consistent with the assumptions made. But deviations are observed at high and very low steepness values. This means that the dissipation of energy which occurs under these conditions are not truly reflected in the model. The influence of wave period and wave steepness relating to incident wave conditions and that of geometry of armour, size of surface openings, steady flow permeability coefficients, interface losses relating to geometric and hydraulic parameters have been discussed in detail.

The analytical model could be further refined by obtaining detailed information of permeability coefficients under unsteady flow conditions and a better understanding of interface losses. For this purpose it is recommended that a specific experimental programme be designed and implemented.

The availability of large scale experimental data on wave action through gabion structures, covering a wide range of incident wave conditions and structural configurations will be useful not only to check the validity of the model but to understand the physics of flow through porous structures. Small scale experiments are not truly representative of prototype structures and therefore large scale investigations, as commenced by Hettiarchchi and Amaraweera (2001) should be continued.

It would be appropriate to examine field performance of existing gabion structures used in small craft harbours. Such examination will provide an understanding of the typical field problems relating to their hydraulic performance, durability and overall stability.