Technische Universität Braunschweig

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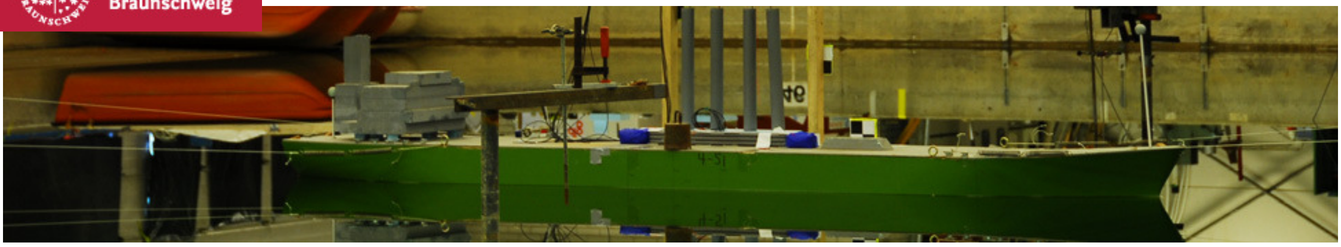

Polyurethane Bonded Aggregate Revetments for Shoreline and Slope Protection

1. Motivation & Objective

Polyurethane (PUR) bonded Aggregate (PBA) revetments represent a new type of cover layer developed under the name "ELASTOCOAST" by Elastogran GmbH from the BASF-Group for the use as a protective structure for embankment in coastal, estuarine and riverine environments. The revetment is composed of mineral aggragate (crushed stones) fixed together by a two components polyurethane adhesive. As a result a stable, flexible and durable bonding is obtained which is colourless and environmentally neutral. The thin PUR-film fixes the stones together on their contact prints only, so that a lightly permeable open structure results. The primary advantages of PBA revetments as compared to conventional revetments are related to their high porosity and their elastic bonding which result in a high dissipation of the water waves as well as in lower structure crests and smaller thicknesses of the revetment. Although several studies on PBA revetment and pilot projects have been conducted in the Netherlands and Germany no guidelines are yet available for the design of PBA revetment against wave loads. Therefore preliminary investigations using numerical modelling and large-scale model tesing in the Large Wave Flume (GWK) of the Forschungszentrum Küste (FZK) in Hannover were conducted for Elastogran GmbH.
The primary objectives of these investigations are to understand the functioning of PBA revetments and based on the understanding of the involved physical processes to develop prediction formulae for the hydraulic performance (wave reflection, run-up and run-down), for the wave load on and beneath the revetment as well as for the response of the structure (flexural behaviour) and its foundation (pore pressure).

2. Programme & Methodology

Based on preliminary study using numerical modelling (Oumeraci et al. 2009) more than 35 tests with regular waves and about 40 tests with irregular waves were per-formed in the Large Wave Flume (GWK) of the Forschungszentrum Küste (FZK) in Hannover, Germany. Initially two Model Alternatives A and B (see Fig. 1) were installed side by side in the wave flume and tested simultaneously using the same incident wave conditions (regular waves only). After the failure of Model Alternative A which occurred at an unexpected early stage under regular waves ($h = 3.90$ m, $H \approx 1.3$ m and $T \approx 5$ s), Model Alternative A was replaced by Model Alternative C (Fig. 1), so that the full testing programme could be performed from both regular and irregular waves with Model Alternatives B and C built in the wave flume side by side. A total of 88 measuring channels were used including 48 pressure transducers, 15 wave gages and other transducers such as run-up gages, displacement meters, current meters, etc. Both regular and irregular wave tests were analysed with the objective of deriving empirical formulae/ diagrams for (i) the reflection performance of the ELASTOCOAST revetment, (ii) the wave run-up and run-down, (iii) the pressure induced by the waves on and just beneath the revetment, (iv) the pore pressure in the sand core beneath the revetment.

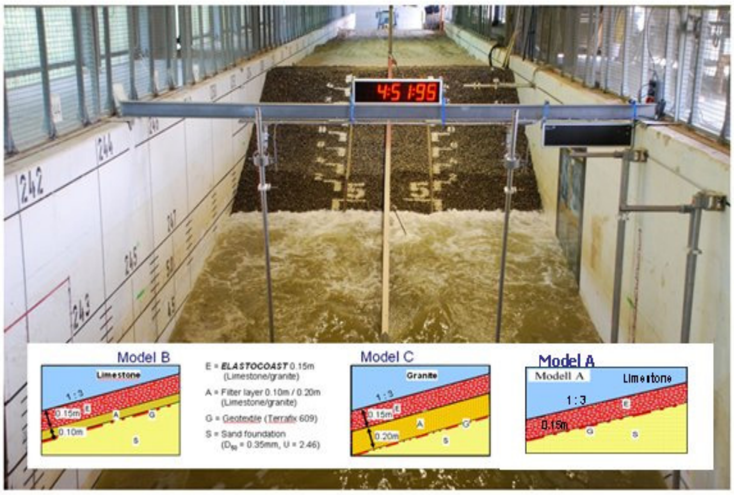

Fig.1 Large Wave Flume (GWK), Hannover. Breaking wave on PBA revetment

3. Results

Hydraulic Performance:
Prediction formulae are developed for wave reflection, wave run-up and run-down as a function of the deep water surf similarity parameter ($\xi_{m-1,0}$) showing that they are between those of a conventional smooth impermeable revetment and those of a conventional rubble mound structure. Depending on the range of the surf similarity parameter considered, a reduction of wave run-up of 25% to 50% can be achieved by PBA revetments as compared to smooth unpermeable revetments.

Wave loads on and beneath revetment:
Depending on the surf similarity parameter ($\xi_{m-1,0}$) tested ($\xi_{m-1,0}$=1.6-6.6) a wave load classification is proposed, including impact load ($\xi_{m-1,0}$=1.6-2.5), non-impact load ($\xi_{m-1,0}$>2.9) and transition zone ($\xi_{m-1,0}$=1.6-2.5). A parametrization for both impact load and non-impact load is developed in time and space as shown exemplarily in Fig. 2 for impact load on the revetment

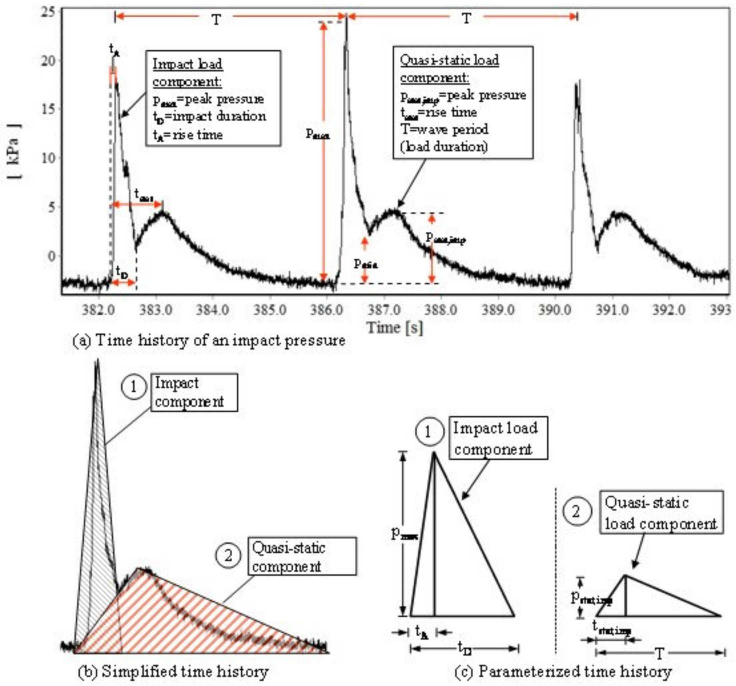

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Fig.2 Temporal Parametrization

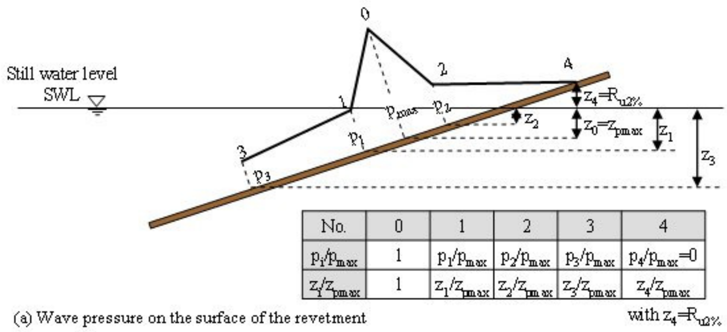

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Fig.3 Spatial Parametrization

As depicted by Fig. 2 peak pressure pmax and its location zpmax along the slope represent the key parameters, since both are used as reference parameters for the calculation of other parameters of the parametrized wave load. For the prediction peak pressure pmax, its location zpmax of all other in time and space on and just beneath the revetment prediction formulae are developed for both impact and non-impact loads.
Wave-induced pore pressure in the sand core beneath the revetment prediction formu-lae are also developed transient pure pressure induced by the wave load at different depths in the sand core as a function of the surf similarity parameter. Surprisingly no impact pressure component is transmitted into the sand core, so that all pure pressure recorded in the sand core have primarily a quasi-static character for all types of wave loads in the revetment. The residual pore pressure is also analysed, showing that he is less relevant for the stability of the revetment than the transient pore pressure.

Flexural displacement

Prediction formulae are developed for the flexural behaviour of the PBA revetment tested as a function of the maximum wave load pmax for both impact and non-impact loads, showing that the latter induces much larger displacement than impact load and that the smallest displacement occurred for Model C with the thickest filter layer.

Stability analysis

Based on the analysis of the failure of Model A, it is shown that transient pore pressure induced by the waves in the sand core beneath the revetment may lead to soil liquefaction if the weight of the revetment and the filter layer is not sufficient to provide the required effective stress.

4. Practical application and further research

The results of this study will be used in the design manual "Polyurethane bonded aggregate revetments" which is progressed (Arcandis, 2009). Moreover, the results can also be used for the design of similar types of bonded permeable revetments.
A more process-oriented analysis of the experimental data supported by numerical modelling is planned within a PhD-Thesis which will possibly be followed by further hydraulic model testing in order to develop more generic prediction formulae for impermeable and permeable revetments as a function of different porosities, slope steepnesses and roughnesses.

5. References

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