UNDERWATER-FILTER-SYSTEMS: AN INNOVATIVE REEF FOR COASTAL PROTECTION

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1 INTRODUCTION

About 45% (rd. 500.000km) of the world's coastline are affected by permanent erosion. Of the 100.000km sandy coast alone, 70% has shown net erosion over the past few decades. It is one of the most crucial problems in coastal engineering to sustain the coast as a natural ecosystem and also to maintain the beaches for recreational purposes. Therefore, artificial reefs and innovative reef concepts are getting more and more attractive for coastal protection, especially at tide free coastlines. Beside "soft measures" like nourishment or beach drainage there are a large variety of traditional "hard" structures such as seawalls and submerged breakwaters. They are often designed as rubble mound structures. The problems with this type of structures are – beside their considerable need for construction material – scour and other stability problems when exposed to severe wave actions.
An interesting alternative to these conventional "hard" structures is a submerged filter-system composed of two or several submerged permeable vertical screens with predetermined porosity and spacing (Fig. 1, Fig. 2). They are invisible for viewers from the beach and do not affect the water exchange between open sea and sheltered area.

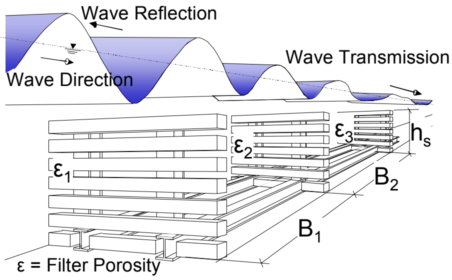


Fig. 1: Three-Filter System with screens of different porosity

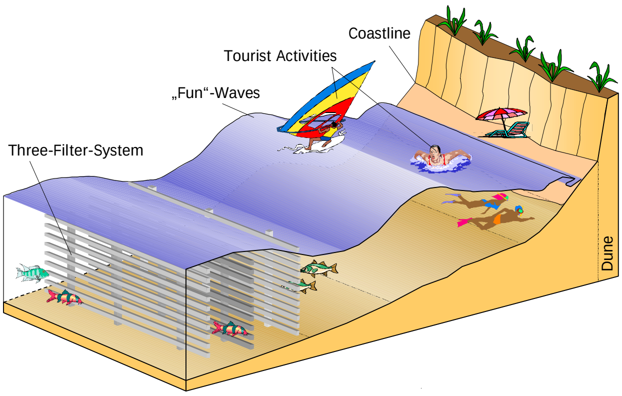
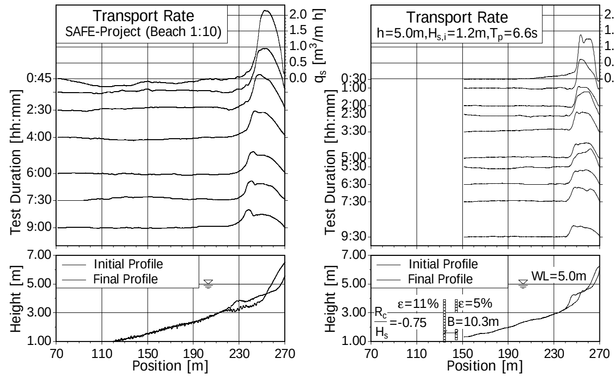


Fig. 2: Three-Filter-System for beach protection (beach with tourist activities)

An extensive research programme, supported by the German Federal Ministry for Education and Research, has been performed in small- and large-scale facilities to study both the hydraulic performance and the wave loading of submerged permeable walls (single and multiple wall structures). In this paper, focus will be put on the results of large-scale model tests (i) to demonstrate the efficiency of submerged filter systems against beach erosion and (ii) to derive design formulae for the description of the hydraulic performance and the wave loads.

2 EFFICIENCY AGAINST BEACH EROSION

One of the main objectives of the research programme was directed toward demonstrating the efficiency of an underwater-filter-system against beach erosion. A two-filter-system (filter porosity seaward ε=11% and landward 5%, screen height h_s=4.0m and spacing B=10m) was installed in front of an equilibrium beach profile with a beach slope 1:10. The efficiency against erosion was investigated under storm surge conditions corresponding to a water level of h=5.0m and a TMA spectrum with a significant wave height of H_s=1.20m and peak period of T_p=6.6s (test duration of 10h). The conditions as well as the equilibrium beach profile (adjusted to a water depth of h=4.0m) were identical to the test conditions of the MASTIII SAFE-project ("Performance of soft beach systems and nourishment measures for European coasts"). These investigations provide a very good reference for comparing the erosion of the beach with and without the protecting filter-system. In Fig. 3 the cross-shore sediment transport rate is shown for both cases (protected and unprotected beach) at different stages of the test.



(a) Beach without Protection [after Newe 2001] (b) Beach with Filter-System

Fig. 3: Comparison of cross-shore sediment transport without beach protection (a) and with a filter system (b)

The transport rate at the unprotected beach is up to more than twice the rate at the protected beach, especially in the beginning of the storm event. After a test duration of 10h, the eroded volume above the high water level (h=5.0m) for the protected beach is only half as much as for the beach without protection. Beside the reduced transport rate and the reduced recension of the shoreline, the sediment is also transported less far seaward at the protected beach than at the beach without any protection (Oumeraci et al. 2001).
The paper will show how the design of filter-systems can account for the morphological performance, in addition to the hydraulic performance. As shown in Fig. 3, a high efficiency against beach erosion can already be achieved by using only two filter walls. A larger number of screens will improve the performance, but needs more space and also increase the costs.

3 HYDRAULIC PERFORMANCE

The extensive investigations of submerged filter systems included first systematic tests on submerged single filter screens of different porosity ranging from ε=0%, 5%, 10%, 20% for large scale (GWK) to 43% for middle scale experiments. Test with regular waves (wave height H=0.5m-1.5m, wave period T=3s-12s) were used for understanding the physical processes. In this paper, tests with irregular waves (significant wave height H_s=0.5m-1.25m, peak period T_p=3.5s-12s) are analysed. The hydraulic performance of each structure determined by using the water elevations recorded by a group of wave gauges in front (wave reflection H_r) and behind (wave transmission H_t) the submerged structures. From this, the reflection coefficient (C_r=H_r/H_i, with H_i=wave height of the incident wave), the transmission coefficient (C_t=H_t/H_i) and the dissipation coefficient (C_d=$(1-C_r^2-C_t^2)^{0.5}$) could be calculated.

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Even if submerged single filter screens dissipate a significant part of the incident wave energy (E_i) it was obvious, that the total amount of energy dissipation is limited. A decrease in wave reflection is directly associated with an increase in wave transmission (Koether et al. 2000). Single filter screens can approximately be calculated with $C_r=1-C_t$ (Koether 2001).

The situation is quite different for filter-systems. In this case it is possible to increase the hydraulic performance by selecting a correct spacing between the screens ($B/L_p \approx 0.25$ with L_p=wave length of peak period T_p) and proper filter porosities. By means of variation of these two important parameters (i) the wave energy dissipation at each screen and (ii) the interference of incident and reflected waves can be better controlled. At the conference the wave damping mechanisms will be presented in detail. The investigations have shown, that the relative spacing B/L_p has a decisive influence on the performance of the system. The agreement between the measured and the calculated reflection and transmission coefficients is already satisfactory, when taking into account the interference of incident, transmitted, reflected and re-reflected waves. Comparable results were already found by Sawaragi & Iwata (1978) and more recently by Bergmann (2001) for emerged multi-chamber-absorber-systems. Fig. 4 demonstrates the additional amount of wave energy dissipation for a three-filter-system as compared to a submerged single wall. Unlike single filters, filter-systems provide both, a reduced wave reflection and a reduced wave transmission. With an optimised three-filter-system it is possible to dissipate up to rd. 85% of the incident wave energy depending of the relative structure height h_s/h.

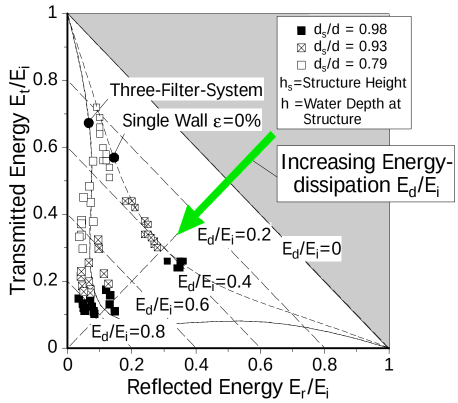

Fig. 4: Reflected, transmitted and dissipated wave energy for a three-filter-system and a single submerged wall

As shown in the next section not only the hydraulic performance, but also the wave loads are strongly influenced by the relative spacing B/L or B/L_p.

4 HORIZONTAL WAVE LOADS

Wave loading and hydraulic performance are closely related. The wave loads of single filter screens as well as each filter inside the system will increase with higher hydraulic performance and vice versa. The horizontal wave load of a submerged single filter screen is about half as much as of the equivalent emerged filter. The wave load essentially depends on the relative water depth h/L_p, the wave height H_i and the nonlinearity of the wave (characterised e.g. by the nonlinearity parameter Π by Goda 1983). The filter screens inside a system are additionally influenced by the relative spacing B/L or B/L_p. The loads of further landward filter screens also depend on the wave attenuation caused by the foregoing screens. Instead of the wave loads at each filter screen, only the resulting wave loads on the whole "monolithic" system will be briefly discussed here. The total load results from summing up the individual loads on each filter and considering their phase relation (Fig. 5).

Although the mathematical formulation of the wave load histories at each filter are unknown, the maximum positive (landward) and negative (seaward) values of the total load can be calculated. Therefore, the maximum loads at each filter have to be added using an derived empirical κ-function which depends only on the relative spacing B/L or B/L_p (Fig. 6).

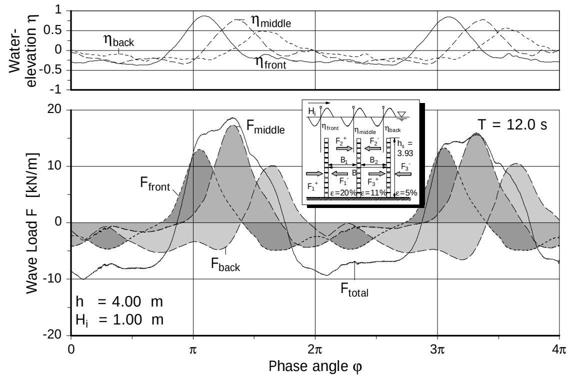

Fig. 5: Total wave load of a "monolithic" filter-system resulting from phase dependent addition of the loads on each filter (for regular wave, T=12s)

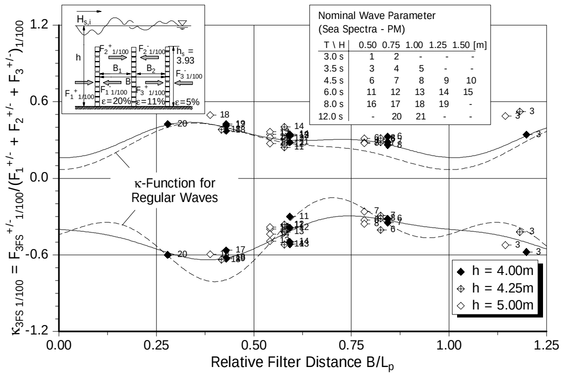

Fig. 6: Empirical κ-function evaluating the total wave load for a "monolithic" filter system from each filter screen

5 CONCLUDING REMARKS

Submerged filter systems represent through the combination of useful properties such as invisibility from the beach, high wave damping, low reflection and cost effectiveness a promising soft alternative for the protection of sandy coast. More over, they allow to sustain the water quality in the sheltered area and to considerably reduce the negative effects on the neighbouring coastal structures (e.g. down coast erosion).

The results presented in this paper on the hydraulic performance and wave loads now provides the required scientific basis for the design of these innovative filter-systems (two or three filter screens).

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