CHAPTER 188

EFFECT OF SUBMERGED BREAKWATER ON PROFILE DEVELOPMENT

Martin D. Groenewoud[1], Jan van de Graaff[2], Edward W.M. Claessen[3] and Stephan C. van der Biezen[1]

ABSTRACT

The project "Dynamics of Beaches" is carried out by a network of six European Universities within the framework of the Human Capital and Mobility Program of the European Union. The aim of the project is to improve the existing knowledge on physical processes governing the nearshore zone due to effects of submerged breakwaters. Within the project hydrodynamic and morphological experiments have been carried out.

This paper discusses the results of the experiments that took place in a wave flume and the large wave basin at Delft University of Technology. The experiments were carried out with movable beds and varying wave conditions.

INTRODUCTION

Structural erosion and dune erosion during severe storm surges threaten large parts of coasts. Proper protection of threatened coasts is often an important aim in coastal engineering practice. Apart from this type of protection, sometimes new reclaimed areas have to be protected from attacks from the sea.

Coastal engineers must always select the proper protection method out of the many available methods; e.g., beach nourishments, series of groins, series of offshore breakwaters, submerged breakwaters, seawalls and revetments. In order to apply a specific method its physical effects on the surrounding area should be well known.

[1] Researcher; Delft University of Technology; Stevinweg 1; 2628 CN Delft; the Netherlands

[2] Senior scientific officer; Delft University of Technology; Stevinweg 1; 2628 CN Delft; the Netherlands

[3] formerly Msc. student DUT

One of the promising methods of coastal protection is the use of submerged breakwaters. Within the framework of the Human Capital and Mobility program of the European Union six universities [Barcelona (Spain), Thessaloniki (Greece), Ghent (Belgium), Liverpool (U.K.), Cork (Ireland) and Delft (the Netherlands)] work together in solving some of the unknown aspects related to the use of submerged breakwaters along sandy coasts.

The primary aim of this project called "Dynamics of Beaches" is to obtain a valuable database which is available for further modelling studies.

In the research program many experiments in wave flumes and wave basins have been carried out by the partners with the main emphasis on the effects of a submerged breakwater on hydrodynamics. Table 1 gives an overview.

Laboratory	Facility	Bottom	Waves
Barcelona	Flume	Rigid	Irregular
Liverpool	Flume	Rigid	Regular/Irregular
Cork	Basin	Rigid	Irregular
Delft	Flume	Movable	Regular/Irregular
Delft	Basin	Movable	Regular

Table 1 Overview experiments "Dynamics of Beaches" project.

This paper discusses the results of the experiments in Delft with main emphasis on the wave flume experiments. First a general evaluation of the applicability of submerged breakwaters is given.

OBJECTIVES OF APPLICATION

The erosion of coasts can often be divided in two types of problems, viz.:

1 - Structural erosion

Structural erosion of a stretch of coast means that the stretch loses sediments at a regular basis. Typical for structural erosion is the fact that it is an irreversible process. In a certain cross-shore profile the amount of sediment diminishes as a function of time. Eventually all parts of the profile will suffer from this type of erosion.

Often a gradient in the longshore transport is the cause for this erosion. Fig.1 shows a simple schematization of the coast. If $S_b > S_a$ then the shoreline will retreat.

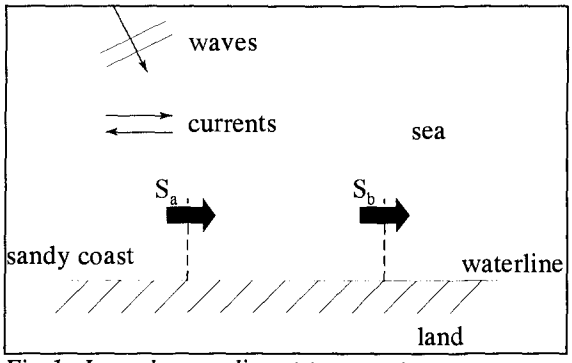


Fig.1 Longshore sediment transport

2 - Retreat of coastline during severe storm surges

A retreat of the (sandy) coast can take place during severe storm surges. Typical for this type of erosion is that it is a reversible process. Sediment is lost from the upper part of the profile to the shoreface, but will be transported in opposite direction again during calm weather conditions.

The second type of erosion should in principle not be battled by submerged breakwaters. During storm surges the combination of wave set-up, wind set-up and high (spring)tide leads to a high water level. The height of the submerged breakwater relative to water depth will become smaller. The influence of the breakwater will decrease at the time its presence is needed mostly. Therefore submerged breakwaters are not a proper solution to that kind of problem. It is stressed that of course the level of the crest is very important in this case.

Undesired structural erosion can be battled either by 'hard' or by 'soft' measures. 'Hard' measures are supposed to interfere with the sediment transports in such a way that the erosion is reduced or stopped at all. Well-known examples of such methods are: groins, offshore breakwaters, dikes etc. The erosion problem often is shifted to the adjacent leeside of the structure, which is a serious disadvantage of these types of countermeasures.
'Soft' measures (e.g. artificial nourishments) can avoid the disadvantage of leeside erosion. Nourishments, however, only treat the symptoms of the erosion; no permanent solution can be offered by these methods.

The general desire to solve erosion problems has stimulated the research of more structural solutions to the problem.

One of the promising methods is the use of submerged breakwaters. Basically the submerged breakwaters are supposed to reduce the wave heights landward of the structure. Because of this the wave-driven longshore current will be reduced. The decrease of the wave-driven longshore current will in principle lead to a reduction

of the longshore transport capacity. By fine-tuning the dimensions of the breakwaters (e.g. crest-height, gap size, orientation etc.) the desired reduction in transport capacity can be achieved. In other words, structural erosion can be avoided. More detailed descriptions of the effect of offshore breakwaters in general can be found elsewhere, e.g.: CUR, 1997; Pilarczyk and Zeidler, 1996.

The experiments as carried out in the framework of the 'Dynamics of Beaches' project are meant to increase the knowledge about the effects of submerged breakwaters on hydro- and morphodynamics.

THE DELFT EXPERIMENTS IN A WAVE FLUME

Experimental set-up

Several agreements concerning the experiments were made between the different partners of the Dynamics of Beaches project. Wave conditions and breakwater layout were in principle defined for a (fictitious) submerged breakwater at scale 1:1.

The experiments were carried out in one of the wave flumes of the Laboratory of Fluid Mechanics at Delft University of Technology (DUT). The dimensions of the wave flume are: length: 32.0 m; width: 0.8 m; height: 1.0 m.
The wave board is able to generate irregular waves. Because of the dimensions of the wave flume it was decided to perform the experiments at scale 1:15. Prototype wave conditions and breakwater layout were scaled down. Only the scaled parameters of the experiment will be mentioned in this paper.
The layout of the flume is shown in Fig.2. The layout of the cross-section of the submerged breakwater is presented in detail in Fig.3. According to the test programme the experiments were done with and without breakwater with a 1 in 15 slope and a movable bed. The bed consisted of sand with D_{50} = 95 μm (D_{10} = 76 μm, D_{90} = 131 μm) which is relatively fine for sand along a beach. The purpose of using this type of sand is that the ratio between bed transport and suspension transport will be closer to the ratio that would occur if the experiments were performed at scale 1:1.
Because the erosion near the seaward toe of the breakwater was not a research topic, the first part of the slope is made out of concrete (see Fig.2). An advantage of a concrete slope seaward of the breakwater is that possible amounts of sediment transport over the breakwater can be measured very accurately.

Five different wave conditions with varying wave heights and wave periods (A through E, see Table 2) were defined in the Test Definition Report. By means of varying wave height and wave period the influence of these parameters on hydro- and morphodynamics can be investigated. One wave condition with regular waves was added (test F) to the program. In this way a coupling between the results of these 2DV tests and the 3D tests with regular waves can be made.

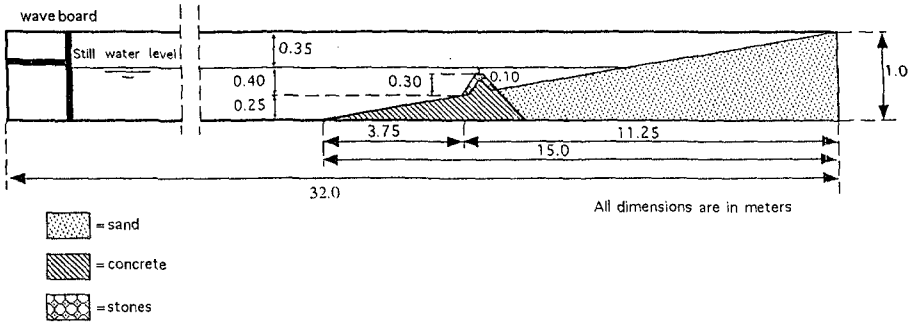
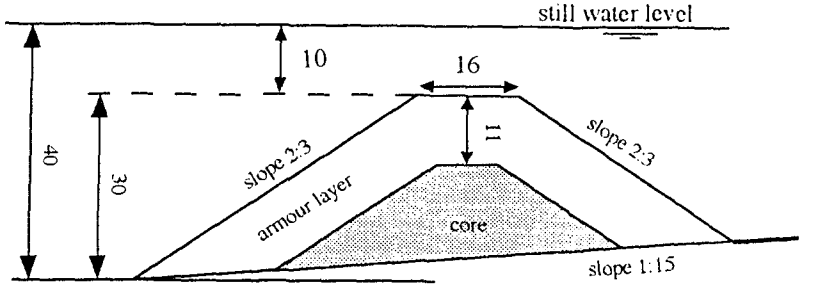


Fig.2 Layout experiment (wave flume DUT).



All dimensions are in centimeters

Fig.3 Layout of the breakwater in detail.

Six experiments were carried out without breakwater, each of them with one of the predefined wave conditions (A through F). The same strategy was repeated with the breakwater present. By using similar conditions for the tests with and without breakwater it is possible to make a true comparison between both situations.

Wave condition (irr. waves)	**F/H_s (-)**	**H_s/L_{0p} (%)**	**T_p (s)**	**H_s (m)**	**h (m)**	**F (m)**	**H_s/L_p (%)**
A	1.00	1.50	2.07	0.10	0.4	0.1	2.61
B	1.00	2.67	1.55	0.10	0.4	0.1	3.67
C	1.00	3.84	1.29	0.10	0.4	0.1	4.66
D	0.75	2.61	1.81	0.133	0.4	0.1	4.06
E	1.50	2.56	1.29	0.067	0.4	0.1	3.01
Wave condition (reg. waves)	**F/H (-)**	**H/L_0 (%)**	**T (s)**	**H (m)**	**h (m)**	**F (m)**	**H/L_p (%)**
F	1.00	2.67	1.55	0.10	0.4	0.1	3.67

Table 2 Wave conditions

Each experiment lasted for 7.5 hours. The period of 7.5 hours was divided in four intervals with durations of respectively 0.5, 1.0, 2.0 and 4.0 hours.

The following types of measurements were carried out:

- wave height measurements (electrical resistance method)
- flow velocity measurements (electromagnetic fluid-velocity meters, (EMS))
- sediment concentrations measurements (transverse suction method with intake tubes)
- profile measurements (electronic profile follower)

The wave height, flow velocity and sediment concentration measurements were carried out during the different intervals at specific places (see Fig.4). Profile measurements were carried out between these intervals. Some of the results will be presented. (For a detailed description of measurements and results reference is made to Claessen and Groenewoud, 1995).

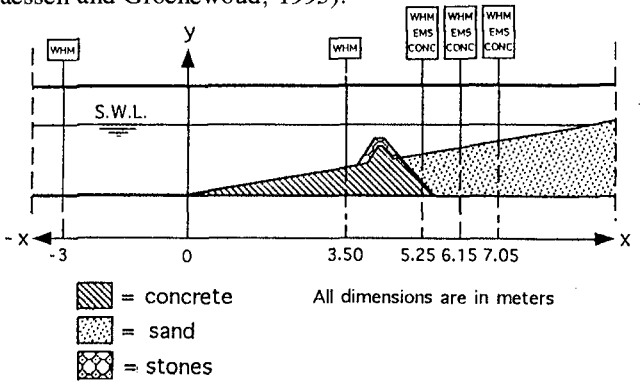


Fig.4 Cross-section of the flume and measuring positions

Analysis of results

As an example some of the results of the experiments with condition D (H_s = 0.137 m and T_p = 1.81 s) will be presented.

Profile measurements

The initial profile has a 1 in 15 slope. This relatively steep profile is far from equilibrium. Fast adaptations were therefore expected. After a test duration of 7.5 hours equilibrium is not yet reached. Aim of the tests was to see at what rate the adaptations would take place and what the influence of a submerged breakwater under varying wave conditions would be.

Fig.5 shows as an example the profile development of experiment D without breakwater. The other experiments without breakwater showed similar trends in profile development; erosion takes place around the shoreline and the sand is transported in offshore direction where a bar is formed. The size of the bar increases in time; the center of the bar moves seaward.

Fig.6 shows the profile development of experiment D with breakwater. Again, erosion around the waterline takes place. Part of the sediment settles against the breakwater. A bar in between the waterline and the breakwater is also formed.
Fig.7 compares the profiles after 7.5 hours of both experiments. The scourhole is less pronounced in case of the experiment with breakwater. The submerged breakwater clearly forms an obstacle for the sediment moving in seaward direction. Without the breakwater more sediment has moved in offshore direction.
Fig.8 shows the sediment transport through the vertical indicated in Fig.7. The transport in offshore direction was smallest for the experiment with breakwater. Other experiments gave similar results.

The experiments in the wave flume are strictly 2 dimensional. Therefore the mass flux due to (partly) breaking over the submerged breakwater has to return through the same cross-sections.

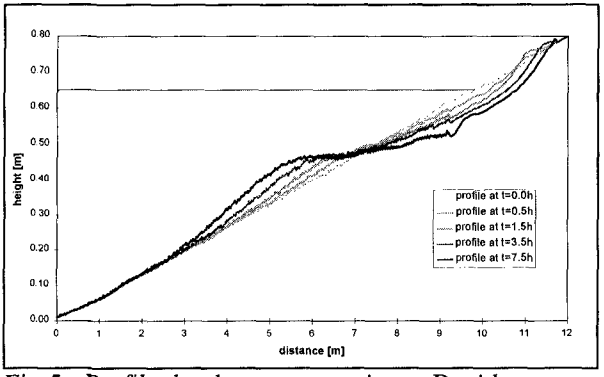


Fig.5 Profile development experiment D without breakwater (H_s = 0.137 m, T_p = 1.81 s)

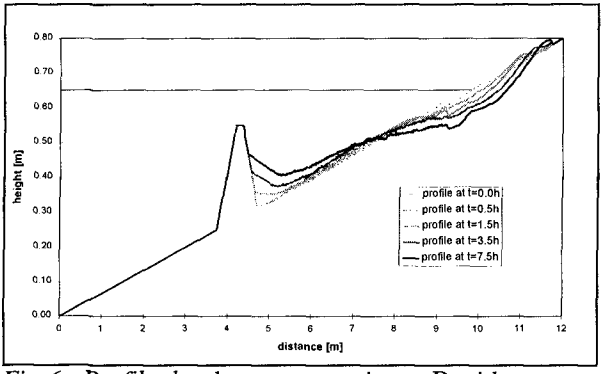


Fig.6 Profile development experiment D with breakwater (H_s = 0.137 m, T_p = 1.81 s)

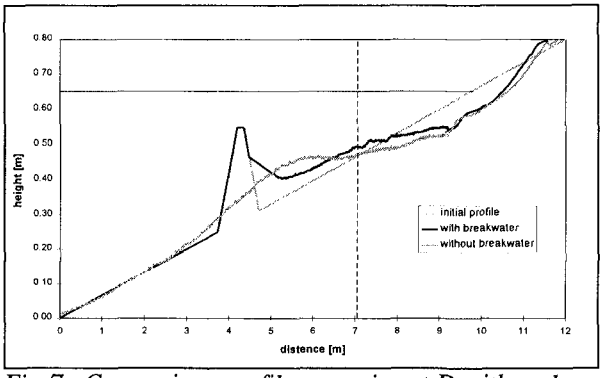


Fig.7 Comparison profiles experiment D with and without breakwater (H_s = 0.137 m, T_p = 1.81 s)

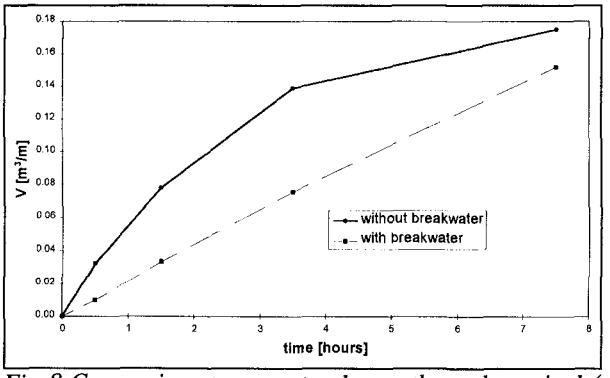


Fig.8 Comparison transport volumes through vertical (x = 7.05 m)

Simulation experiments with 2DV model

The experiments have been simulated with the computer programme Unibest- TC (Unibest is a pogram package of Delft Hydraulics). Measured wave heights and measured profile development have been compared with calculations.

Wave heights: measured and calculated

The results of the wave height measurements have been compared with calculations executed with Unibest-TC. The results of this comparison for experiment D are shown in Fig.9 and Fig.10. (In the figures the H_{rms} have been plotted).

For the situation with breakwater the Unibest-TC model calculates a sudden increase in wave height at the position of the breakwater. In reality the wave height and wave form will change less instantaneously as the effect of abrupt ehanges in the bottom profile.

Profile development: measured and calculated

Unibest-TC predicts the profile development for the situation without breakwater rather well (see Fig.11). Only the retreat of the waterline is not modelled satisfactory. This is due to the fact that the used equations are not valid near the waterline. The differences between measured and calculated development become larger with the breakwater present (see Fig.12). The calculated size of the scourhole lags behind in comparison to the measured development. Again, the retreat of the waterline is not modelled correctly.

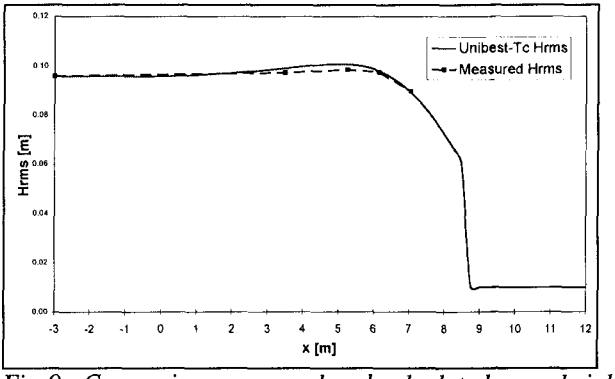


Fig.9 Comparison measured and calculated wave heights experiment D with breakwater (H_s = 0.137 m, T_p = 1.81 s)

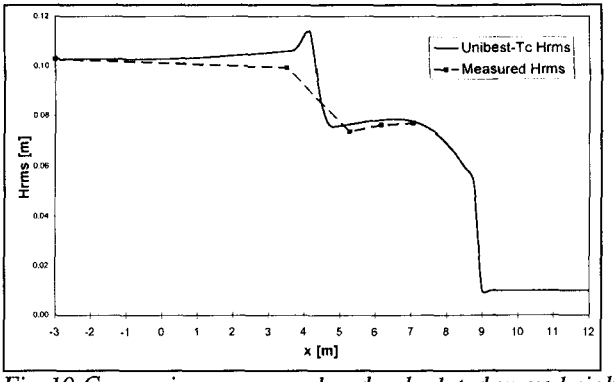


Fig.10 Comparison measured and calculated wave heights experiment D with breakwater (H_s = 0.137 m, T_p = 1.81 s)

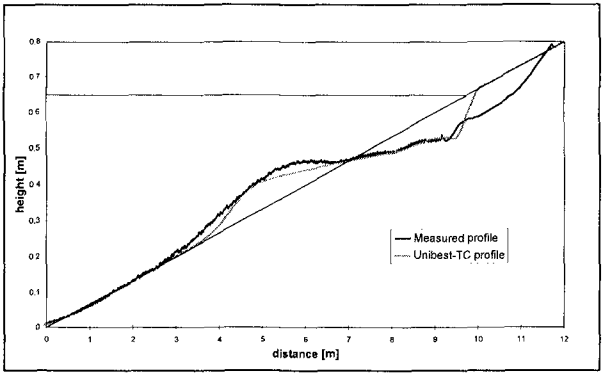


Fig.11 Comparison measured and calculated profiles experiment D without breakwater (H_s = 0.137 m, T_p = 1.81 s) after 7.5 hours wave action

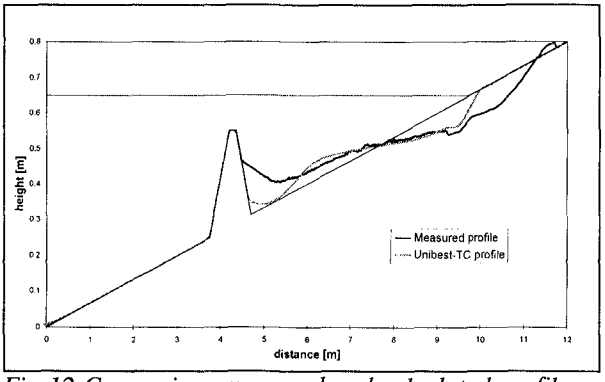


Fig.12 Comparison measured and calculated profiles experiment D with breakwater (H_s = 0.137 m, T_p = 1.81 s) after 7.5 hours wave action

RESULTS OF THE 2DV MOVABLE BED TESTS IN BRIEF

In most cases the presence of the breakwater has reduced the sediment transports in offshore direction. In some cases there was a small amount of sediment transport over the breakwater in offshore direction. This sediment can be considered as lost.

The breakwater causes much dissipation of wave energy. The wave heights offshore have increased due to reflection against the breakwater.

High sediment concentrations were measured behind the breakwater caused by the increased turbulence as effect of wave breaking.

The experiments showed that with the used variety in wave conditions a change in wave height had much stronger effects on morpho- and hydrodynamics than a change in wave period.

The simulations with Unibest-TC showed that the wave height development along the profile is predicted quite well. The calculated profile development differed considerably from the measurements.

It has to be stressed that the experiments in the flume are strictly 2 dimensional. Therefore the mass flux in the top of the breaking waves has to return in the same cross-section. This also applies for waves breaking over the submerged breakwater.

3D MOVABLE BED TESTS

In order to investigate 3D effects near the gaps between submerged breakwaters, or at an end of a long submerged barrier, in the wave basin of the Laboratory of Fluid Mechanics at the Delft University of Technology a segmented type of submerged breakwater was focused upon. Small scale experiments were carried out with regular waves. The experiments were carried out in resemblance with experiments in the Hydraulics and Maritime Research Center in Cork, Ireland. Both universities used the same set-up, except that in Delft a movable bed was applied instead of a concrete slope.

Each experiment starts with the same initial profile, which is steeper than the theoretical equilibrium profile, and covers 7.5 hours of wave action. Three different mean wave heights H were applied: 0.08 m, 0.10 m and 0.12 m, defined at the seaward toe of the breakwater which had a crest submergence of 0.10 m. The mean wave period T was kept constant at 1.55 s. The sediment used in the basin was the same as used in the wave flume (D_{50} = 95 μm).

Experiments were carried out with and without breakwaters. The experiments without breakwaters show a slope adjusting offshore sediment transport, transforming the initial 1:15 slope into an ogee profile which tends to stability after 7.5 hours of wave exposure; a real equilibrium is, however, certainly not reached in 7.5 hours. The experiments were interrupted five times for profile monitoring, to visualize the profile development in time in five steps. For a wave height of 0.10 m, Fig.13 shows the final situation of the bed without breakwaters. The still water level is set at z = 1.00 m.

Repeating the tests with submerged breakwaters installed, the most noticeable observation is a strong offshore flow through the gaps between the breakwaters, apparently compensating for the mass flux over the breakwater crests. Fig. 14 shows the final situation of the bed with breakwaters.

The relatively high offshore velocities in the gaps lead to a profound sediment loss and a much larger retreat of the shoreline than observed without breakwaters. The same effect was found at Palm Beach, Florida, USA (Browder *et al.*, 1996). In an attempt to reduce beach erosion and wave impact on a protective seawall, an experimental submerged breakwater of 1,260 m length was installed in a water depth of approximately 3 m off the Town of Palm Beach, Florida. The profile data documented erosion in the entire monitored area with the greatest erosion landward of the submerged breakwater.

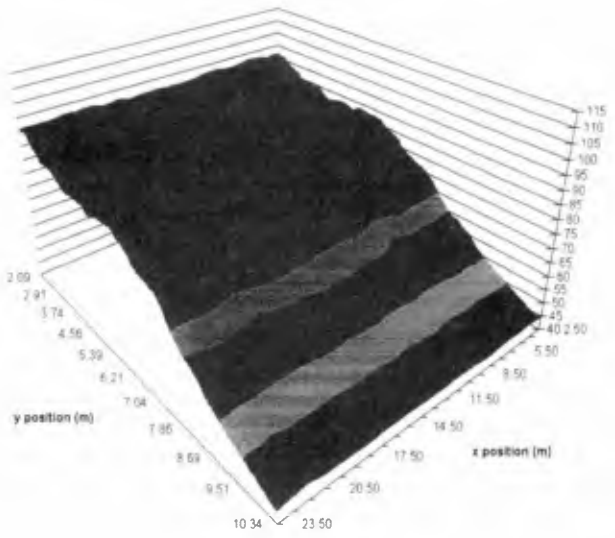


Fig.13 Final situation experiment without breakwaters

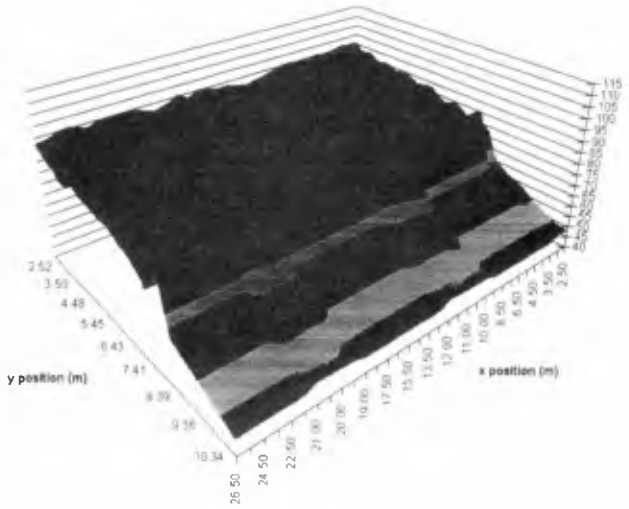


Fig.14 Final situation experiment with breakwaters

The current velocities measured relatively close to the bottom support the hypothesis that a surplus of water is built up landward of the breakwater. This can be seen from Figures 15 and 16.

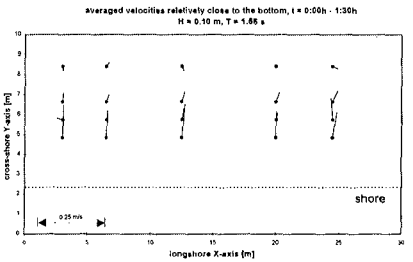


Fig.15 Velocities and directions without breakwaters

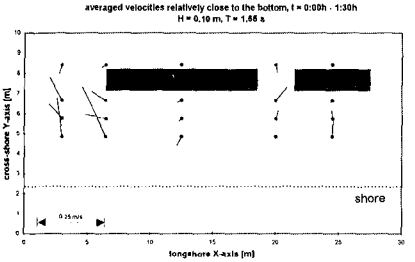


Fig.16 Velocities and directions with breakwaters

In Figs.15 and 16 averaged current patterns relatively close to the bottom are given for the first 1.5 hours, with and without breakwaters. Although the vectors can only provide a rough indication of what the current pattern in the basin will be like, intercomparison of these figures clearly shows the influence of the breakwater segments. The offshore undertow, uniformly distributed over the width of the basin in Fig.15, is channelled towards the gaps between the breakwaters as shown in Fig.16.

It has to be stressed that a main objective of tests with a movable bed is to achieve a reliable data set for verification purposes of mathematical morphological models. This comparison has not yet been carried out.

CONCLUSIONS ON THE 3D MOVABLE BED TESTS

Submerged breakwaters seem to offer a number of advantages over conventional coastal protection structures. However, 3D experiments indicate that one should be careful when applying submerged breakwaters with gaps. 2DV experiments often stress the reduction of the offshore sediment transport by the breakwater. This seems to justify the conclusion that the submerged breakwater creates a perched beach. The present 3D results, however, prove that it is important to count for the consequences of gaps between the submerged breakwaters. These can lead to unexpected scouring.

Furthermore, from the 2DV tests it is found that the submerged breakwaters reduce the wave heights in the lee. This is in accordance with the 3D results. In the gaps, however, the waves can pass and diffract around the ends of the breakwater into the lee side of the breakwater. For this reason, the amount of wavc energy at the lee side of the breakwater becomes larger than indicated by 2DV testing.
To summarize, introduction of 3D properties such as gaps between breakwaters and breakwater endings affect the performance of submerged breakwaters as follows:

- the wave energy transmitted to the lee side of the breakwaters is much greater than predicted by 2DV testing (Murphy *et al.*,1996),
- submerged breakwaters allow a mass transport over the crest. The return flow is concentrated in the gaps resulting in local high velocities,
- although submerged breakwaters create a perched beach in a 2DV situation (an infinitely long breakwater), a significant amount of sand is removed from behind the structures and transported through the gaps when applying segmented breakwaters,
- the *exposure ratio*, defined as the ratio of gap width to the sum of the breakwater length and gap width, has a significant influence on the morphodynamic processes occurring in the nearshore region.

The equilibrium state was not reached during the present experiments, so the resulting profile shape after 7.5 hours of wave exposure is still partly determined by the initial steep slope. Therefore, a long term prognosis about the efficiency of segmented submerged breakwaters can not be made on basis of the present results.

OVERALL CONCLUSIONS

Especially the 3D experiments have shown that one should be careful with applying submerged breakwaters. Submerged breakwaters do not seem to be good solutions for an arbitrary structural erosion problem.
The gaps in between of the breakwaters effect the hydro- and morphodynamics very strongly.
Further research is necessary to increase the knowledge about the influence of parameters like gap size (exposure ratio).

ACKNOWLEDGEMENT

The "Dynamics of Beaches" project is sponsored by the Human Capital and Mobility programme (Scientific and Technical Cooperation Networks) of the Commission of the European Union, Directorate General for Science, Research and Development, under contract CHRX-CT93-0392.

REFERENCES

Browder, A.E., R.G. Dean and R. Chen (1996) Performance of a submerged breakwater for shore protection, Book of Abstracts 25th Int. Conf. on Coastal Eng., Orlando, USA.
Claessen, E.W.M. and M.D. Groenewoud (1995) Effect of submerged breakwater on profile development. Delft University of Technology, Fac. of Civil Eng., August 1995.
CUR (Center for Civil Engineering Research, codes and specifications) (1997) Soft sand & hard structures. Gouda, the Netherlands. (in preparation)
Murphy, J.M., A.W. Lewis, C. Wall, J. van de Graaff and S. van der Biezen (1996) Submerged breakwater research as part of the EU Human Capital and Mobility Programme. MAFF Conf. Of River and Coastal Engineers, Univ. of Keele, England.
Pilarczyk, K.W. and R.B. Zeidler (1996) Offshore breakwaters and shore evolution control, A.A.Balkema/Rotterdam/Brookfield.