CHAPTER 150

RESPONSE OF SEADYKES DUE TO WAVE IMPACTS

A. Führböter[1], H. H. Dette[2] and J. Grüne[3]

ABSTRACT

Damages on seadykes and revetments are mainly caused by wave impacts due to breaking waves. These impact forces act on small areas for a very short time and cause crater-like formations, when the forces are transmitted instantaneously to the side-walls of cracks in the cover of dykes or through joints into and below revetments.

In this paper the results of investigations on impact forces are presented. A comparison of field data and laboratory data proves considerable differences, which must be explained mainly by the different air entrainment for prototype and small-scale conditions in the breaking waves. Both the data from field and small-scale model emphasize, that the slope of the dyke or revetment is responsible at first for frequency and magnitude of the impact forces.

Furthermore the effect of impact forces is demonstrated by the results of investigations on the stability of stone revetments with joints.

---

1) Prof. Dr.-Ing., 2) Oberingenieur Dr.-Ing., 3) Dipl.-Ing.,
Leichtweiss-Institut für Wasserbau of the Techn. Univ. Braunschweig, Germany, Div. of Hydrodyn. and Coastal Eng. and members of Sonderforschungsbereich 79 of the Techn. Univ. Hannover

INTRODUCTION

The wave impact force due to breaking wave is the main factor causing damages on seadykes and revetments at a level around the highest storm surge stillwater level.

These impact forces occur, when the water particles of the breaker tongue are stopped abruptly by the outer layer of dykes or revetments. The impacts stand out for very high pressures during a very short time (10^{-2} to 10^{-3} seconds) on small areas. This cause consequences, which are like detonations of the surface materials of seadykes. The effects of impacts are presented schematically in Figure 1 for different types of seadykes and revetments.

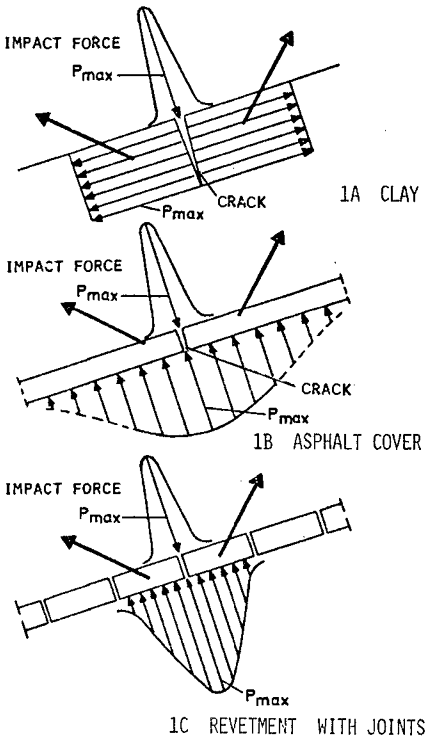

Fig. 1 Effects of wave impacts on seadykes and revetments

On dykes made from or covered with clay, a crater-like formation can be caused, when the impact force hits directly upon a crack in the clay surface (Fig. 1 a).
Even more dangerous effects may occur, when these impact forces act on cracks of asphalt covered sand core dykes. The total force is transmitted instantaneously to the sidewalls of the cracks and into the sand core beneath the asphalt cover. In combination with thixotrope effects of this water-saturated sand, also caused by the impacts, a suddenly destruction of the dyke may be possible (Fig. 1 b).

Similar effects occur on revetments made from artificial concrete blocks with joints (Fig. 1 c).

The above mentioned effects occuring on the outer layer of dykes or revetments will become even more complicated when these covers are placed on natural or artificial filter layers.

Figure 2 and Figure 3 show some typical damages in the field caused by impact forces during heavy storm surges. Fig. 2 gives an example for a crater-like formation. The diameter was about 6.0 m, the depth about 2.0 m. The significant wave height during the attacking storm surges in 1973 has been hindcasted to 0.75 m.

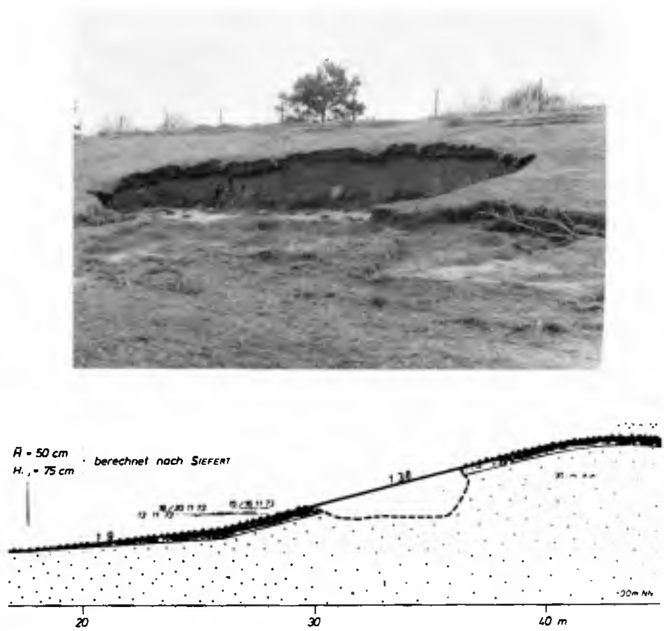

Fig. 2 Damage of clay-covered sand dyke due to wave impacts (after Forschungs- und Vorarbeitenstelle Neuwerk)

Fig. 3 Damage of a stone revetment due to wave impacts

First investigations of BAGNOLO 1939 (1) and DENNY 1951 (3) proved, that the occurrence of impact forces only can be described statistically. DENNY 1951 (3) showed, that by using regular waves the frequency distribution can be described with the normal distribution. This distribution even for regular waves is affected by the random effect of the breaking process itself. In prototype additionally the random effect of the breaker point due to random waves takes part, so that two random effects are superimposed to the occurrence of impacts.

INVESTIGATIONS ON IMPACT FORCES

In Germany in recent years some investigations on this phenomena have been carried out: FÜHRBÖTER 1966(4,5)simulated the impact forces of breakers in laboratory; results of field investigation and small-scale model tests are described by FÜHRBÖTER 1971 (6) and BOELKE, RELOTIUS 1974 (2).

FULL-SCALE LABORATORY TESTS

The laboratory tests of FÜHRBÖTER 1966(4,5) were carried out in prototype scale. This has been done by simulation only of the breakertongue collapsing on the dyke surface. Figure 4 shows the prinziple of the simulation.

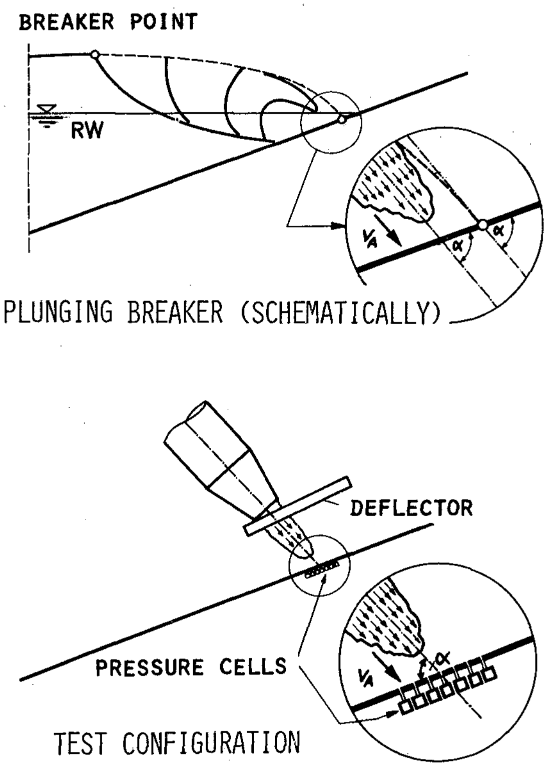

Fig. 4 Prinziple of the full-scale laboratory simulation of wave impacts (FÜHRBÖTER 1966)

The test equipment consisted of a pipe with a deflector for simulation of the breaker tongue and a surface with pressure cells for simulation of the dyke. The test conditions corresponded to wave heights of 1 to 3 m. In Figure 5 as an example of the test results the frequency distribution of the maximum pressures p_{max} has been plotted, in the lower part as an histogram, in the upper part as a log-normal distribution. The essentials of these tests were at first the verification of a normal distribution for occurrence of impact forces and secondly the demonstration that already a thin water-sheet due to the backflow of the preceding wave is damping the impact force magnitude (Fig. 6). For a thickness of the water-sheet of 0.1 m no more impact forces have been observed.

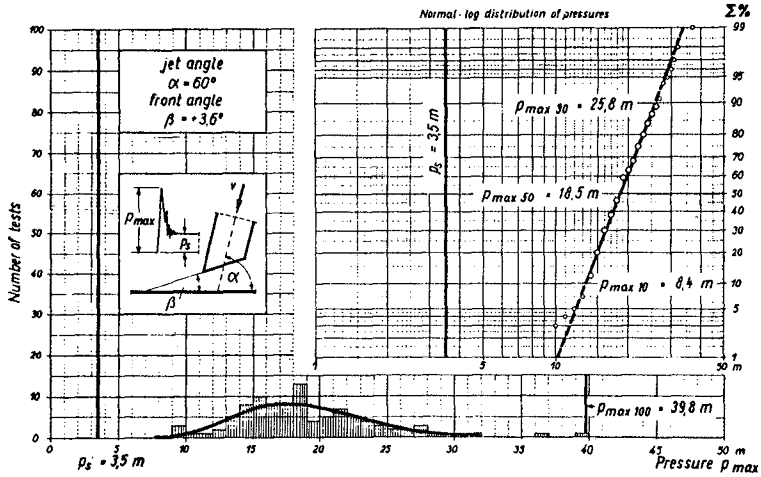

Fig. 5 Frequencies of maximum pressures p_{max}
(FÜHRBÖTER 1966)

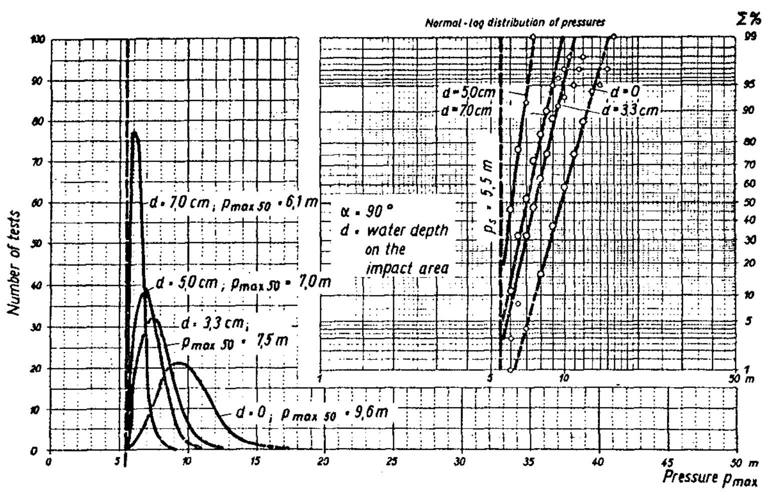

Fig. 6 Damping effect of a water-sheet
(FÜHRBÖTER 1966)

FIELD INVESTIGATIONS

Field investigations have been carried out at the storm surge barrage of the Eider-river in Germany. At one adjacent asphalt covered sand dyke, which has a slope of 1 to 6, an additional testsection with a slope 1 to 4 has been added for research purpose (Figure 7). On both slopes pressure cells have been installed in steps of 0.25 m in vertical direction.

Fig. 7 Asphalt covered sand dyke of the Eider storm-surge barrage with test section (pressure cells before fitted in the asphalt cover)

Fig. 8 shows the time history of the occurrence of impact forces during one of the heavy storm surges of 1973 for both slopes. The influence of the slope comes out very clear as well for the total number of the impact forces as for the magnitude.

More distinct this effect comes out in Figure 9, which shows a comparison of the field data of three storm surges.
For a slope 1 to 4 a further comparison of laboratory and field data is

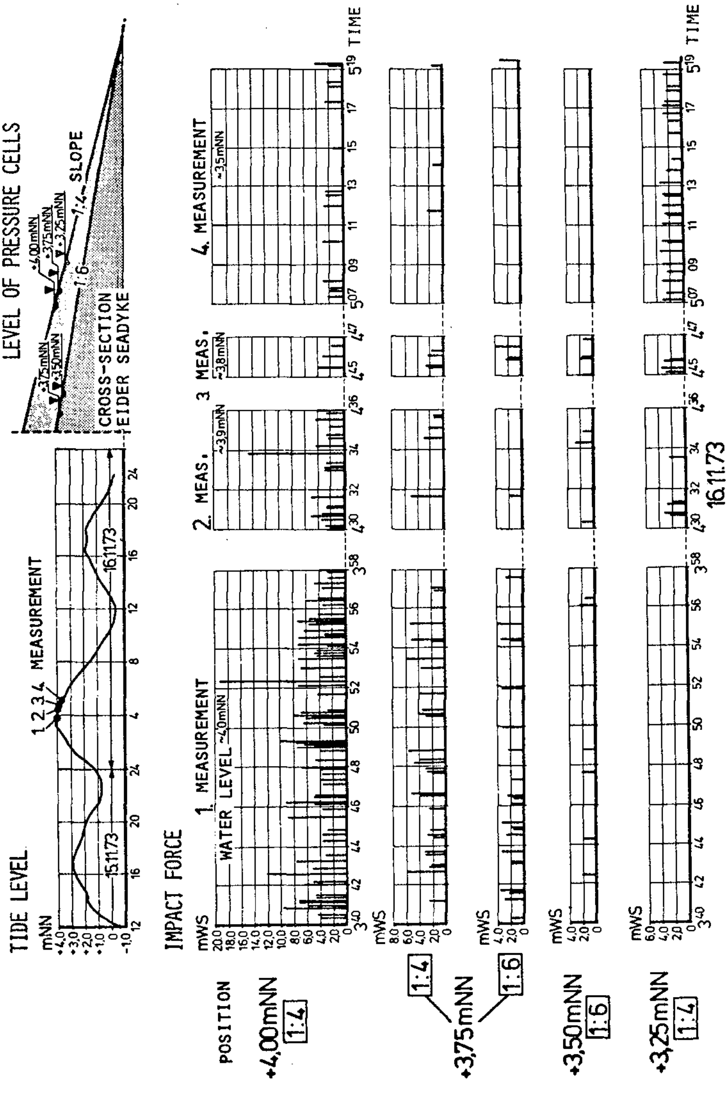

Fig. 8 Time history of impact forces during the storm surge of 16.11.73 (BOELKE, RELOTIUS 1974)

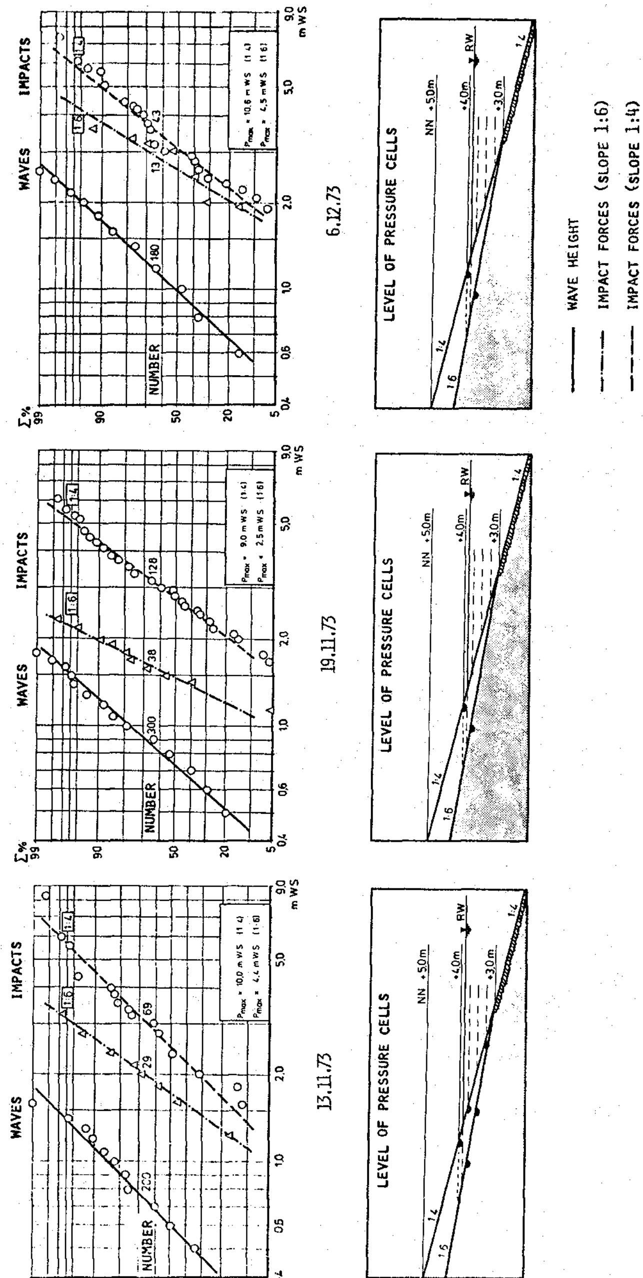

Fig. 9 Field data of three different storm surges (BOELKE, RELOTIUS 1974)

plotted in Fig. 10. The impact force distributions have been plotted as a multiple value compared to significant wave height H_s. The smallscale model tests were carried out with waveheights of about 0.2 m (approximately a scale 1 to 10 compared to field data); the field data were obtained for wave heights of 0.9 to 1.8 m and the prototype scale simulation in laboratory, which is mentioned before, corresponded to wave heights of about 1.0 to 3.0 m. This comparison confirmed theoretical treatments, that the impact forces cannot be reproduced in magnitude of transferred quantitatively for prototype conditions due to the different air entrainment in dependence of the absolute magnitude of waveheight.

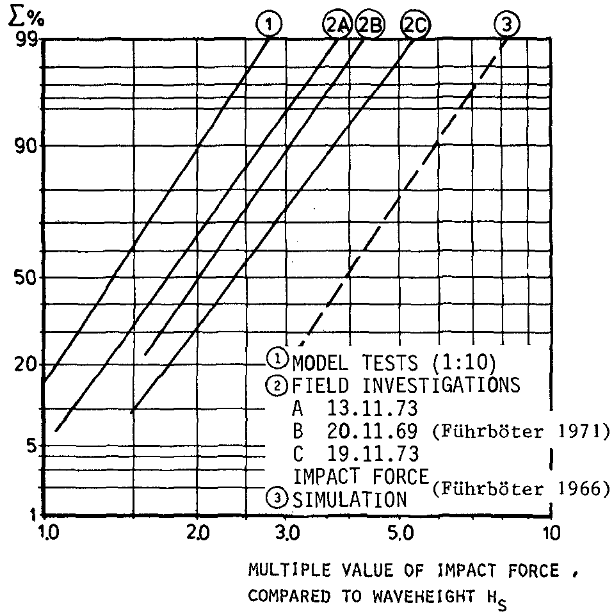

Fig. 10 Comparison of results for investigations on impact forces (slope 1:4) (BOELKE, RELOTIUS 1974)

MODEL TESTS

Additionally to the field investigations further feedback model tests were carried out in order to know at which horizontal distances ± Δh from the

still water level impact forces do occur.
For different slopes 1 to 4, 1 to 5 and 1 to 6 Figure 11 shows the results. On the horizontal axis $\pm \frac{\Delta h}{H_s}$ is equal the vertical distance of the impact attack from the still water level referred to the significant wave height H_s. The number of impacts within a sequence of 100 waves is defined as multiple value of H_s ranging from k = 1 up to 2. It was found that the main impact forces can be expected approximately in the range of Δ h equal half the significant wave heights H_s below the still water level.
Furthermore secondary-impact forces occur additionally around the still water level and above. This can be explained by the effect, that the water particles on the dyke surface are elevated due to the collapsing breaker tongue and plunged down again on the surface.

INVESTIGATIONS ON THE STABILITY OF REVETMENTS

The results of impact force investigations have been confirmed by investigations on the stability of revetments made from concrete stones.

With regard to economical considerations heavy quarry stone revetments on seadykes which are stable due to their weight are more and more replaced by various types of light-weight concrete slabs and blocks which are different by the kind of interlocking and by the kind of surface roughness. During heavy storm surges in 1973 and 1976 damages occurred on the concrete block revetment of a new seadyke in the Elbe-estuary. It was observed that the damage started due to the uplifting of single blocks out of the cover layer. This was continued by the washing-out of gravel which was used as filter layer and finally resulted in a damage of the revetment with holes having diameters of several meters (Fig. 12).

In order to explain the reasons for damages the revetment was rebuilt in model and attacked by waves as they have been observed during the storm surge. With the model-scale 1 to 5 it was found that the damage pattern in model was similar to that in nature so that this test series could be regarded as a calibration reference for further and more detailed investigations with regard to the selection of different filter layers.

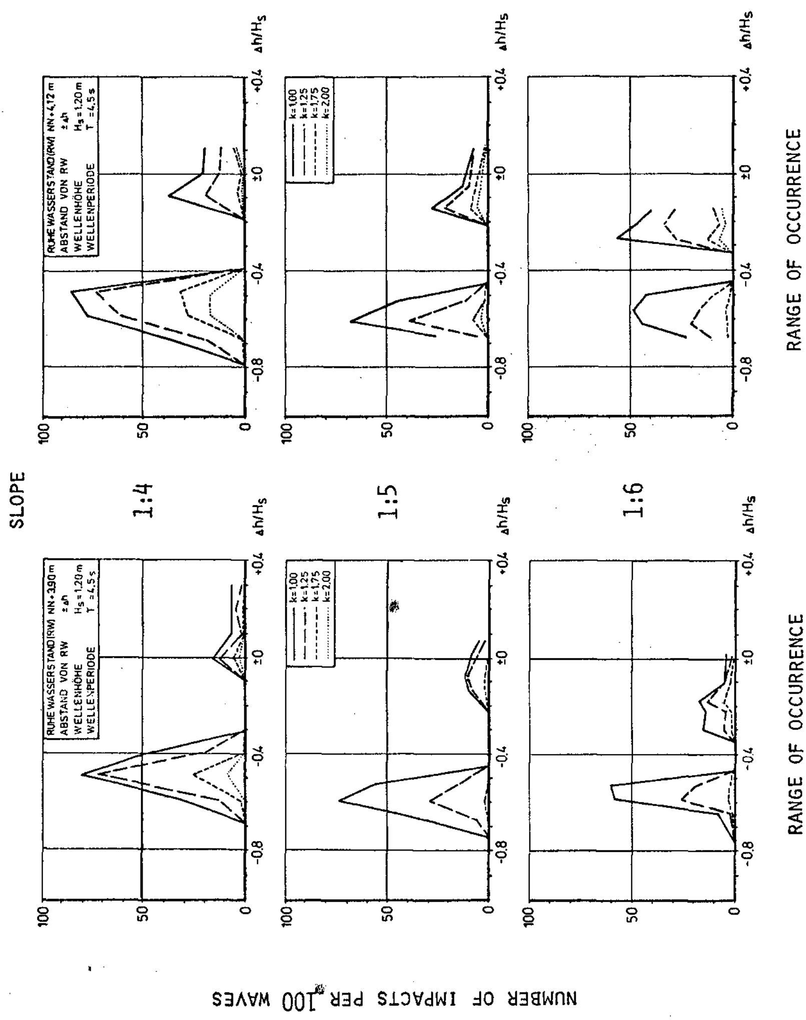

Fig. 11 Results of model tests on the occurrence range of wave impacts (BOELKE, RELOTIUS 1974)

Fig. 12 Typical damage of stone revetments due to wave impacts

One type of concrete stones (type HARINGMAN, prototype seize: 0.5 x 0.5 x 0.15 m) which have been tested, were arranged in three different kinds on the seadykes with a slope of 1 to 3:

revetment I:	the stones are positioned on a 0.15 m thick (in prototype) layer of gravel (threedimensional filter) and a nylon filter mat below the gravel for the protection of the sand core
revetment II:	the stones are positioned on a 0.05m thick (in prototype) layer of gravel (threedimensional filter), which lies on clay
revement III:	the stones are directly fitted on concrete or asphalt

Fig. 13 shows a plan view of the revetment I and II, where the detached stones have been marked. For each test both revetments side by side have been attacked simultaneously by the same waves. These tests confirmed the occurrence

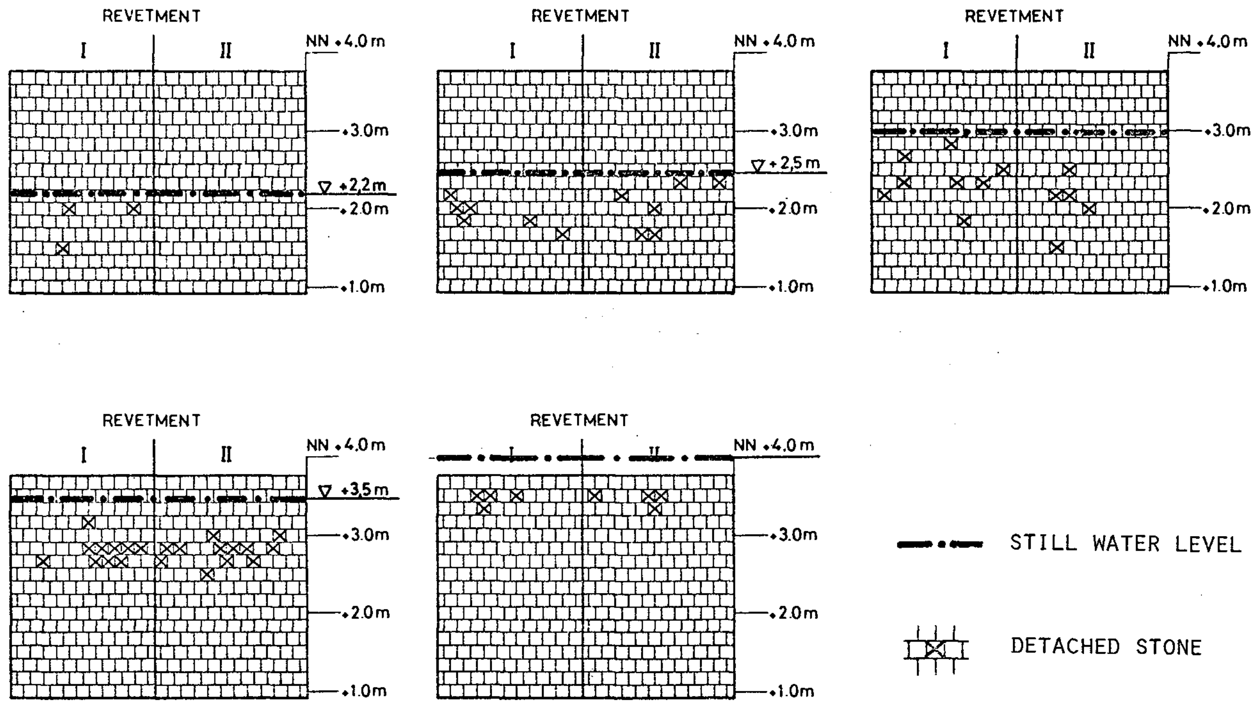

Fig. 13 Plan view of the revetment I and II with detached stones as an example for the range of the occurrence of detached stones

range of impact forces found in the model tests mentioned before. Fig. 14 shows an example of the damaged revetments in the model tests.

Fig. 14 Damaged revetment I and II after wave attack

In Fig. 15 and 16 the total number of detached stones is plotted as a function of the number of waves for the three revetments.

Damages occurred for all these arrangements. This can easily be explained by the effect of the impact forces, as the total force is transmitted instantaneously through the joints into the gravel layer.

The worst results were obtained for revetment II with a filter thickness of only 0.05 m (Fig. 15). For the 0.15 m thick gravel layer (revetment I)

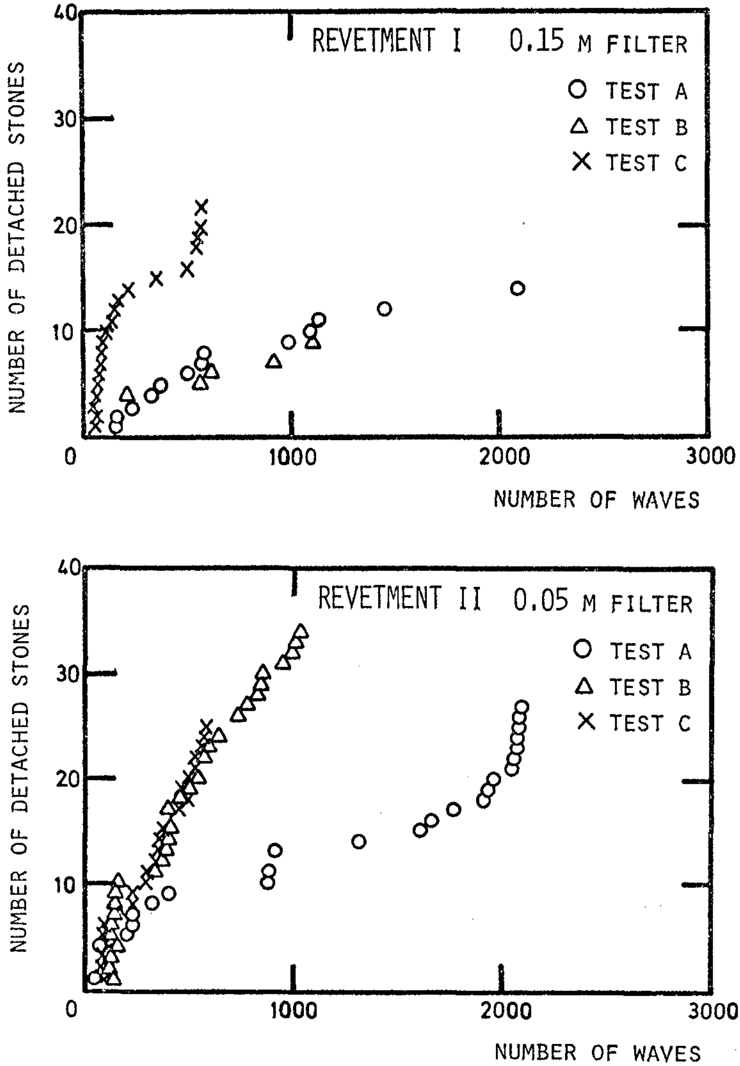

Fig. 15 Detached stones as a function of the number of waves

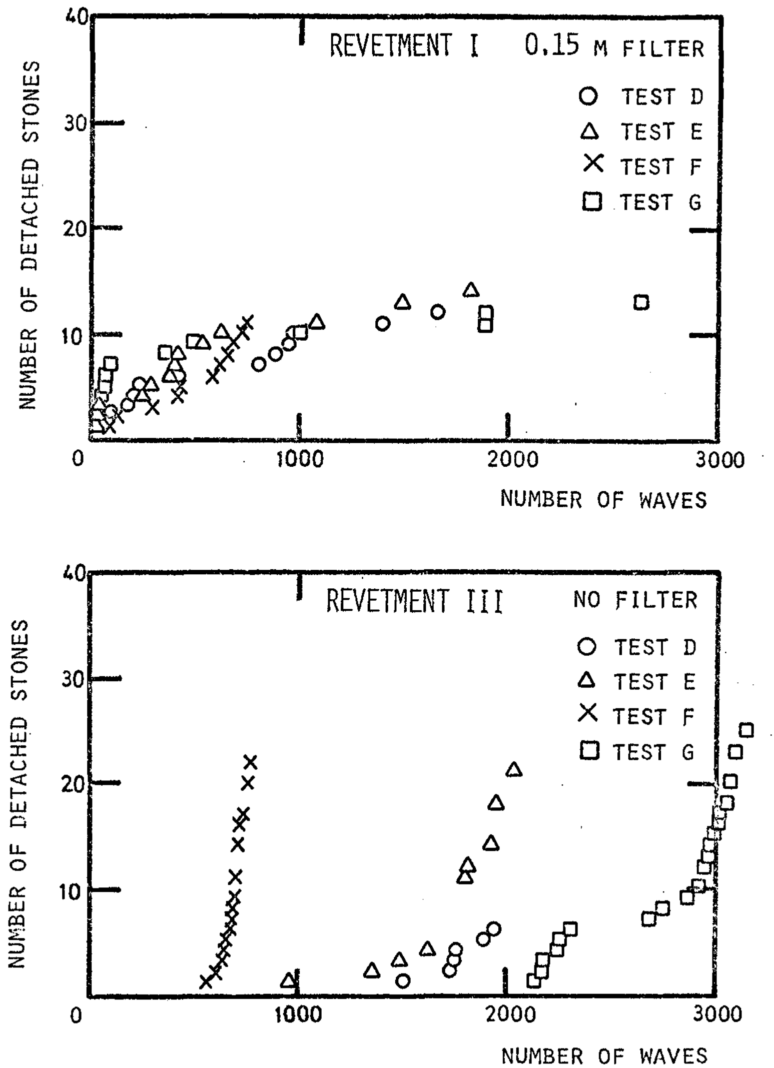

Fig. 16 Detached stones as a function of the number of waves

stabilisations of some damages have been observed, due to a gliding of the stones into the holes of the gravel layer and a guying there. For both gravel filters it was observed, that in addition to the damages due to impacts further damages occurred in that moment, when during the wave trough the water level in the filter was higher referred to the actual level of the wave. This is caused by the less faster draining of the water in the filter layer through the joints of the revetment in dependence of the wave movement. By this effect stones loosened by impact forces were uplifted and then slided down to the bottom of the revetment.

A comparison of revetment I and revetment III shows Fig. 16. The significant result is, that in the first stage of the wave attack there was no damage for revetment III (which has no filter), but after the first damages due to impact forces only this process preceeded faster compared to the other types of revetments.

The important influence of filters has been tested for another type of concrete stones (type TERRAFIX, prototype weight 45 kg). In combination with a thin filter mat (two-dimensional filter) these blocks resisted more than 12.000 waves (H_s in prototype 1.6 m) with no damage.

The above mentioned investigations showed the complex behaviour of different filter layer types. It can be pointed out that filter layers cannot be selected independently of the type of the revetment; there are strong interactions between the different parameters. Further investigations on this subject will be carried out by the authors.

REFERENCES

1. BAGNOLD, R. A. 1939 Interim report on wave-pressures research Journal of the institute of civil engineering, London, 1939

2. BOELKE, S. and RELOTIUS, P. C. 1974 Über die wellenerzeugten Druckschlagbelastungen von Seedeichen im Böschungsbereich zwischen 1:4 und 1:6
Mitt. des Leichtweiss-Instituts der Techn. Universität Braunschweig, 1974

3. DENNY, D. F. 1951 Further experiments on wave pressures
Journal of the institution of civil engineers, Vol. 35, 1951

4. FÜHRBÖTER, A. 1966 Der Druckschlag durch Brecher auf Deichböschungen
Mitt. des Franzius-Instituts der Techn. Universität Hannover, Heft 28, 1966

5. FÜHRBÖTER, A. 1969 Laboratory investigation of impact forces
Proc. of Symposium on wave action
Vol. II. 1969, Delft

6. FÜHRBÖTER, A. 1970 Air entrainment and energy dissipation in breakers
Proc. 12th Intern. Conf. on Coast. Eng., Sept. 1970, Washington

7. FÜHRBÖTER, A. 1971 Zufallsprozesse bei der Belastung durch brechende Wellen,
SFB 79, Jahresbericht 1970

8. FÜHRBÖTER, A., DETTE, H. H., BOELKE, S., RELOTIUS, P. C. 1974 Modellversuche für ein Deckwerk aus Betonformsteinen
Bericht Nr. 266 des Leichtweiss-Instituts der Techn. Universität Braunschweig, 1974
(unpublished)