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WAVE AND DOWNRUSH INTERACTION ON SLOPING STRUCTURES

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ABSTRACT

A proposal is made for a design of the cover layers of nonvertical coastal structures by applying hollow structural elements. The respective cavity is oriented more or less parallel to the slope face and thus permits the inside passage of the downrush water of breakers. The purpose of the new designed structure is to avoid interaction processes between the particle kinematics of near surface water of incomplete standing waves in front of the structure and the washing movement of previously broken waves on the slope face. The effectiveness of such a working principle is traced back to a *selective reflection* effect, realized by model investigations. Applying this new type of elements, slopes can be designed steeper and/or crown heights lower.

INTRODUCTION

Transfer mechanisms of wave induced loadings on sloping structures represent one of the most important topics of coastal and harbour engineering research activities since many years.
There are several phenomena known to be responsible for failures of revetment structures: periodically differing pressure fields on both sides of revetment elements, impact forces due to breaking waves, wave run-up and overtopping, up- and downrush velocities etc.. All of them are dominated by the *breaker height*. There is, however, a phenomenon *affecting the breaker height*, which has not been considered sufficiently in the past:

> The interaction processes between the washing movement on the slope face and the wave induced particle movement in front of it.

To the author's knowledge up to now no structure has been designed so far with the objective to influence the above mentioned effect in such a way that wave induced forces and/or wave run-up heights on the structure will be minimized.

PHYSICAL PHENOMENON

The assumption is made that the movement of the mass of water in front of a sloping structure (such as seawalls, revetments, groins, jetties and breakwaters) can be regarded as an oscillating continuum, characterized by different natural frequencies according to the actual geometric bounderies (water depth, slope angles). In this arrangement the source of excitation is realized in the waves coming from sea, and the different degrees of freedom are represented - on the one hand - by the deflections associated with a set of individual partial standing waves (partial clapotis) and - on the other hand - by the washing movement due to run-up and run-down of broken waves on the slope face. The total oscillating system is being assumed to be similar to an elastic chain consisting of several oscillators with different natural frequencies.

PROPOSAL

In any coupled oscillating system the influence on one degree of freedom has an effect on the remaining degrees of freedom. Hence, the author has proposed to separate the washing movement from the remaining flow field in order to avoid interaction processes between them (Büsching, 1991)[1]. As a matter of principle this can be achieved by double sheathing structures, consisting of an inner and an outside coverlayer with a cavity between them.
Fig.1 shows the axionometrical view

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of the principle arrangement of a hollow structure, forming an integrant structural element of a sloping structure per unit meter shoreline.
In Fig.2 a vertical cross section of a coverlayer configuration is shown completed by a sheathing structure and Fig.3 contains the principle arrangement of hollow structural elements with openings at their upper sides.

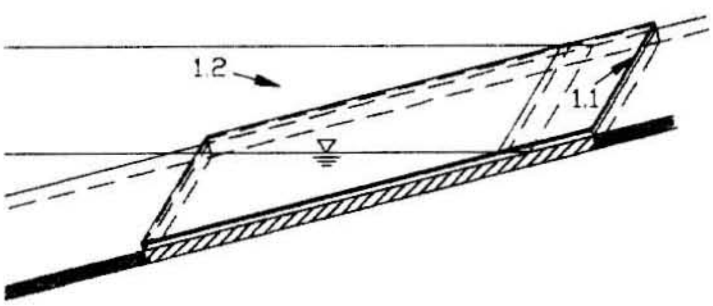

Fig.1: Cavity per unit meter as an Integrant Part of a Sloping Structure

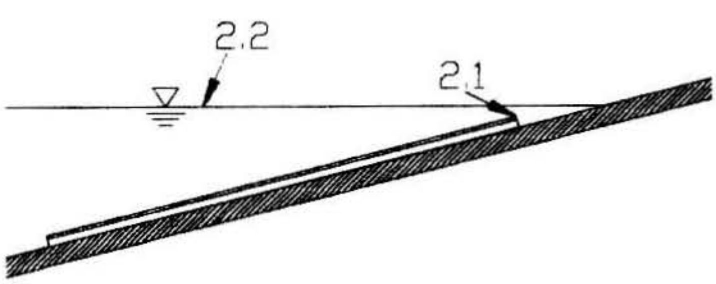

Fig.2: Sheathing above Existing Cover Layer

Accordingly the respective cavities consist of hollow structural elements, which are at least partly closend on their circumference and thus permit the inside passage of the downrush water of breakers.
In paticular such arrangements allow the water, after breaking being present above the edges (1.1), (2.1) or (3.1), to be led back below reference water levels (1.2), (2.2) or (3.2).

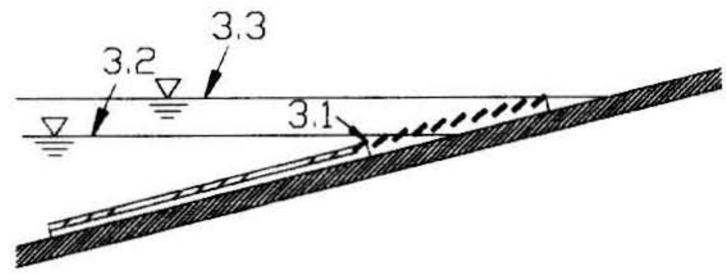

Fig.3: Partly Permeable Sheathing above Existing Cover Layer

As has been proved by model investigations, such a device is suitable not only to *reduce breaker heights and run-up heights* but also to influence the breaker type and its position on the slope face.

STRUCTURAL PERFORMANCE

New designs of coastal or habour structures can be based on the *integrant* arrangement of cavities to be oriented more or less parallel to the slope face.
On the other hand *prefabricated* cavity structures, to be fixed to existing supporting structures, can often provide a more economomical solution. In both cases it is, however, easy to meet the coincident requirements of permeable or impermeable revetments (perpendicular to the slope face).
Hollow revetment elements - whether partly open at their upper and/or bottom sides or closed at any side - can be made of concrete, steel or compound materials, even by the use of synthetic materials.
Hollow concrete elements preferably can be used for the cover layers of revetment structures. In the case of breakwaters or similar structures bigger size *hollow armour units* can be designed, simultaneously forming the basic supporting system.
From the large variety of proposals contained in the respective patent documents (Büsching,1989[2], 1990[3], 1991)[4] two examples only are outlined briefly below.

HOLLOW CONCRETE REVETMENT ELEMENTS

The use of structural elements, made of concrete, in general should be restricted to highly loaded partitions of dike or sloping harbour

structures only. This objective can easily be met in using hollow revetment elements, as they are required in the vicinity of the design water level only.
With respect to the working function, however, the moulding of the inlet openings and of the cross-sectional area of the tubular members are essential. In order to prevent possible blockages the cross-sectional area has to be increased, according to the hydraulic requirements. In this context it has to be pointed out that the system disposes of a mechanism acting against blockages:
If a partial blockage occurs this will result in a malfunction of the system. In this case the system responds with encreasing amplitudes in its pronounced degrees of freedom - say increasing wave heigts and increasing washing movements on the slope face. This effect attributes to the instationary process counteracting sedimentation and consolidation anyhow. Moreover there is an influence resulting from the altitude level of the lower edge of the hollow structure relative to a limiting level, up to which wave run-up can act in the sence of a flushing movement.
The later effect can be intensified by an appropriate moulding of the lower edge of the hollow structure.

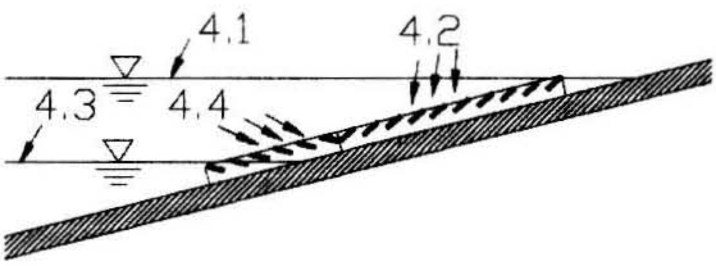

Fig.4: Swash Openings in the Upper and the Lower Part of a Hollow Revetment Structure

An adequate moulding can bee seen from Fig.04.: Near water levels (4.1) (design level) the openings (4.2) support the inlet of backrush water, whereas during periods of lower (tide-)water levels (4.3), near the lower edge of the hollow structure, the openings (4.4) support the inlet of the uprush water.

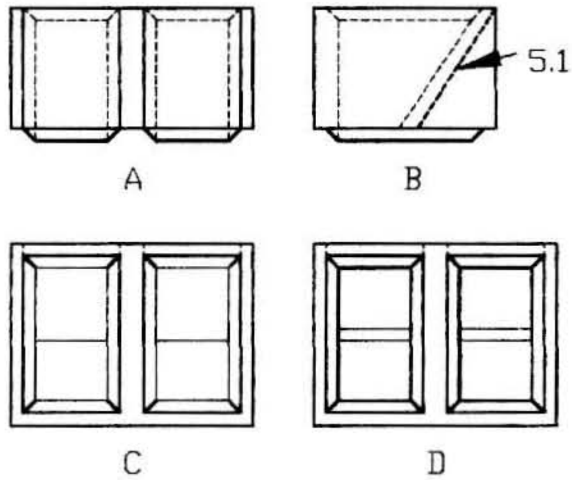

Fig.5: Hollow Concrete Revetment Element; Plan View (A), Side View (B), Upstream View (C), Downstream View (D)

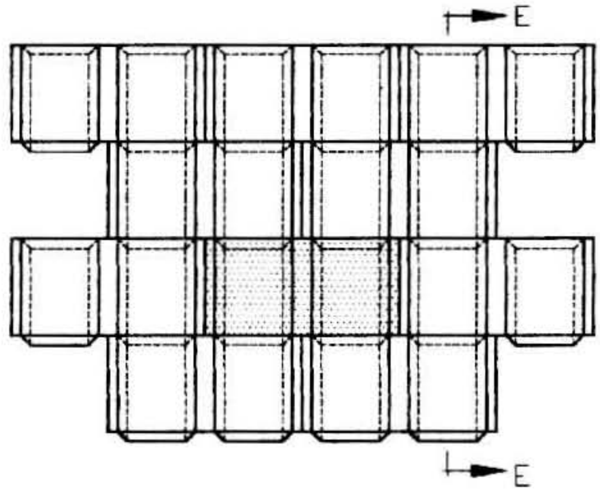

Fig.6: Plan View of Interlocking Hollow Concrete Revetment Elements

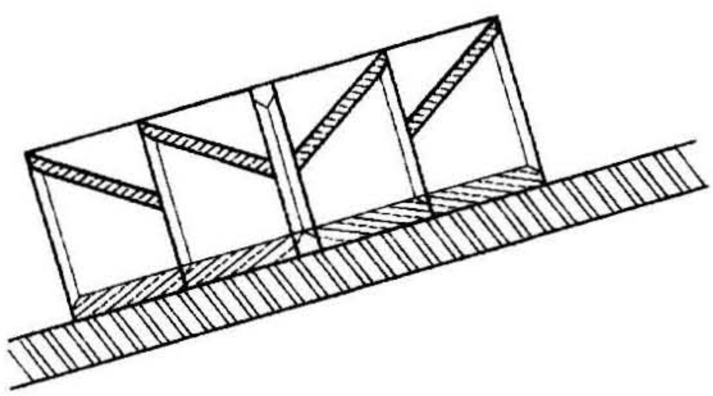

Abb.7: Sectional View of Interlocking Hollow Concrete Revetment Elements

Fig.5 shows a hollow concrete revetment element with corresponding mouldings at its upstream and downstream ends. As to be seen from Fig.6 the mouldings are of such a kind that interconnections exist between every 5 concrete elements.

In order to support the inflow of water, the top sides (5.1) of the elements are inclined.
Fig.7 shows an arrangement of such elements placed on a slope homologously. The same elements can be used for a configuration similar to that described in Fig.4. However, an additional element has to be used to fit in the joint area.

Fig.8: Prototype Scale Models of Hollow Concrete Elements

In Fig.8 alternative hollow concrete elements are shown to be used for tests on a natural scale, being performed at the breakwater site of the harbour entrance of Baltrum Island/North Sea.
In addition, the positive side effect of an *increased air entrainment* can be studied here. It can be supposed that this effect on the one hand will diminish the probability of shock pressures, and on another can improve the near slope water quality.

HOLLOW ARMOUR UNITS

It is well known that reflection from sloping breakwaters becomes less when the permeability of cover layers (consisting of Tetrapods, Dolosse, Tribars, Quadripods, Seabees or similar armour units) has been increased. From this fact it can be concluded that the positive effect of such structures is *not only* due to the energy dissipation processes taking place in the different parts of the breakwater, but also the interaction processes described above appear to be reduced in such permeable cover layers: After wave breaking a considerable part of the water masses, present on the breakwater, is at first transferred *into* the structure. As the outflow from the structure takes place below the water level and moreover the phase lag is changed, the respective interaction with the near surface particle kinematics of the following wave often is reduced.
It can, however, be supposed that the total loading conditions will be improved further more by a more efficient (uniform) drainage system. Hence, also hollow armour units, containing efficient hydraulic cross sections should be taken in into consideration for breakwaters or similar structures.

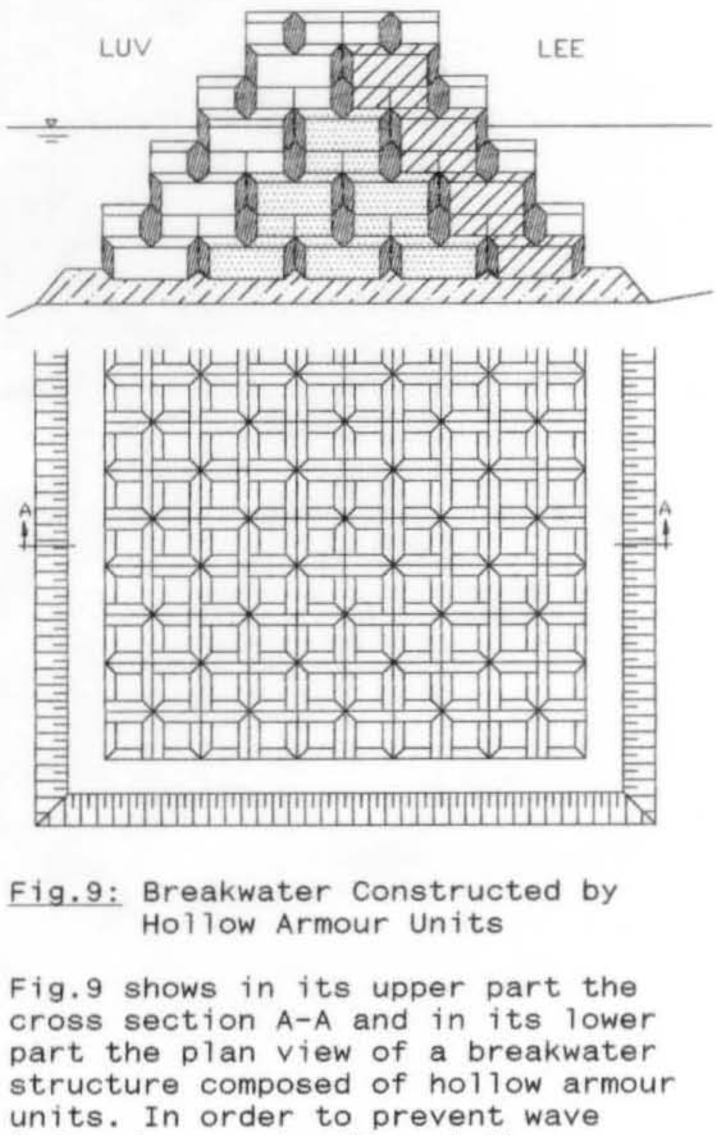

Fig.9: Breakwater Constructed by Hollow Armour Units

Fig.9 shows in its upper part the cross section A-A and in its lower part the plan view of a breakwater structure composed of hollow armour units. In order to prevent wave induced currents through the structure, the armour units are filled up with a suitable material in the core section. Similar material can also be filled into the units of the harbour side slope, whereas the armour units at the ocean side remain empty in order to permit the favoured inside passage of the downrush water.

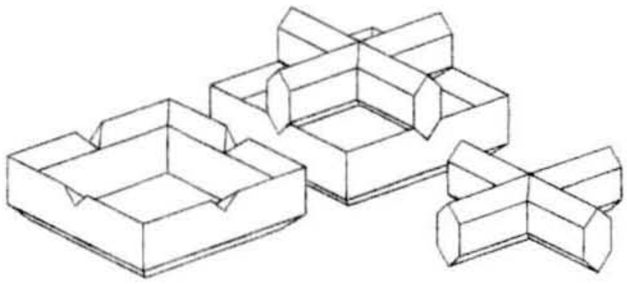

Fig.10: Hollow Concrete Armour Unit Composed of two Components

The structural element of the breakwater contained in Fig.9 is to be seen in the middle part of Fig.10. This can be moulded on the whole by reinforced concrete; preferably it is composed, however, from the components placed on its left and on its right hand sides. Apparently the

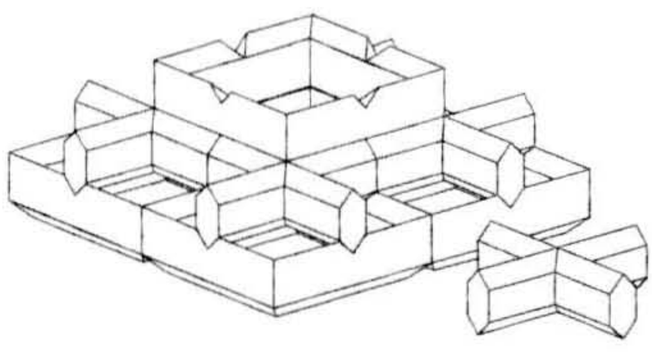

Fig.11: Binding Effect of Hollow Concrete Armour Units

execution of such a construction will require a higher degree of accuracy than random placing of many other armour units. On the other hand there are advantages resulting from the fact that wave absorption is more effective, slopes can be performed steeper, crown heights lower and the demand for weight of the individual armour unit is reduced. In particular the binding effect between the units appears to be improved; the pulling out of single units - as known from Tetrapods - seems not to be a relevant matter of attention, see Fig.11.

MODEL INVESTIGATIONS

Model investigations (scale 1:5) of slopes inclined $1:6 \le 1:n \le 1:1.7$, are being performed in the Hydraulic Laboratory of Bielefeld Univ. for Applied Sciences. The scope of this particular presentation is limited to some information on the setup and on the results with respect to irregular waves acting on slopes $1:n = 1:3$ only. The entire results will be presented in detail in an additional publication (Büsching, 1992)[5].

MODEL SETUP

The particular model arrangement is oriented at prototype conditions corresponding to the habour entrance of Baltrum Island/Noth Sea. Here an 8 m high breakwater is under construction in a water depth of about 4.5 m (MHW). The objective of the breakwater is to prevent waves *from* the harbour entrance and further more to reduce reflections *in* the harbour. Therefore it was decided to carry out rather comprehensive investigations comprising impermeable smooth slopes and such equipped with a hollow revetment configuration to be seen from Fig.12.

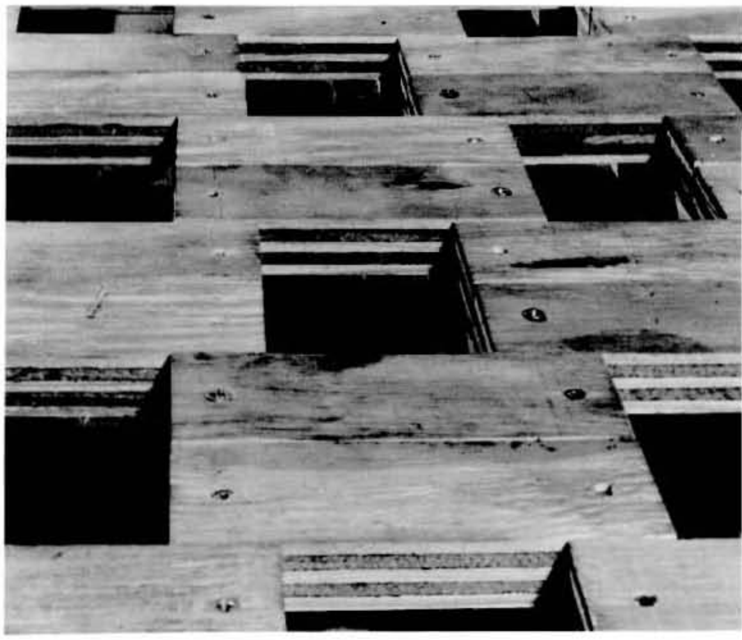

Fig.12: Model of Hollow Slope 1:3 to Be Tested for the Harbour Entrance of Baltrum Island

The measurements, this publication is based on, have been carried out by Blees and Stühmeier (1991)[6]. Because of the water depth conditions to be considered in the model, an input wave spectrum was used, similar to those measured near the breaker zone of Sylt Island/North Sea (Büsching, 1976)[7]. Hence, in the model input spectrum the energy densities are concentrated around a median frequency f = 0.56 Hz. In order to get more detailed information on water level deflections at some distance from the structure, the tests have been carried out comprising 90 wave probe stations equally spaced 10 cm in a line in front of the slope structure.

RESULTS

In the following the contents of a few graphs will be explained briefly. Values shown refer to the model 1:5. In particular the values of the integrated spectrum area [p*Hz], representing wave energy, contained in the individual response spectrum at the respective probe stations, have not yet been transferred to values of [m^2/Hz].
As expected, it can be seen from Fig.13 that the total wave energy, contained in the frequency range $0.03 \leq f \leq 1.4$ Hz, has its maximum in the breaker zone. This maximum is, however, followed by a steep drop to a minimum near the foot of the slope. Further away from the slope face the energy content oscillates almost periodically with the distance from the slope (upper curve).

Plotting the energy contents of 4 adjacent narrow frequency ranges (as specified in the graph) with the distance from the slope, rather smooth curves are found, resembling the time history of a free vibration of a damped mechanical system. Hence, from these curves the coincident presence of different partial standing waves in front of the slope can be inferred, see further below. Reflection coefficients, extracted from those curves, are to be seen in Fig.14. The respective graphs for the slope with the hollow revetment configuration are shown in Fig.15 and Fig.16. In order to give an overall inpression on the efficiency of the hollow revetment structure versus a smooth structure, Fig.17 presents spectral mean reflection coefficients. That reflection coefficients result from those, shown in Fig.14 and Fig.16 respectively, by averaging with weighting factors according to the energy content of the attributing frequency components.

CONCLUSIONS

Comparing the upper curve of Fig.13 to that of Fig.15 it can be stated, that the most important effect of the

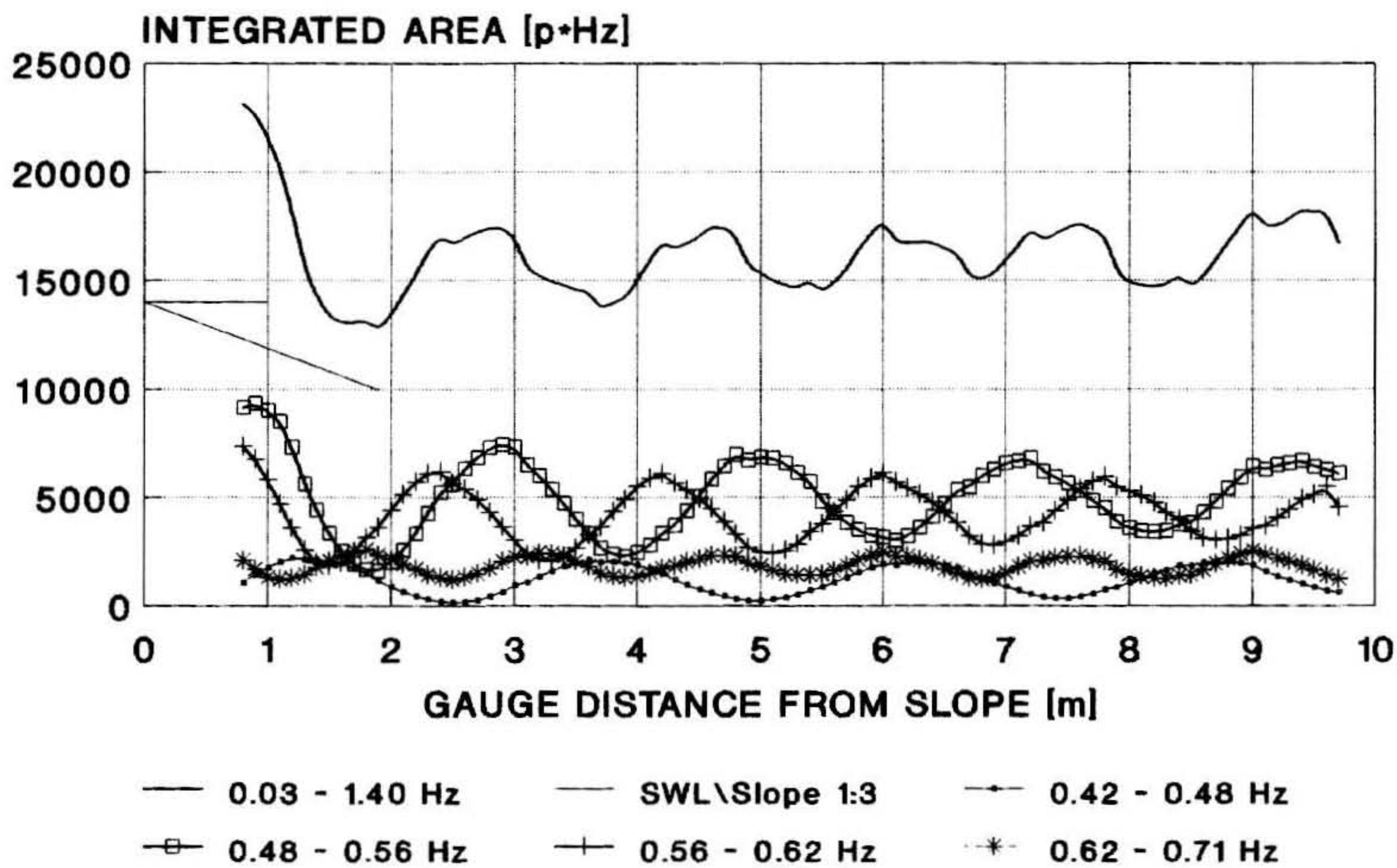

Fig.13: Upper Curve: Total Spectrum Energy with Distance from a Smooth Slope; Lower Curves: Content of 4 adjacent frequency bands

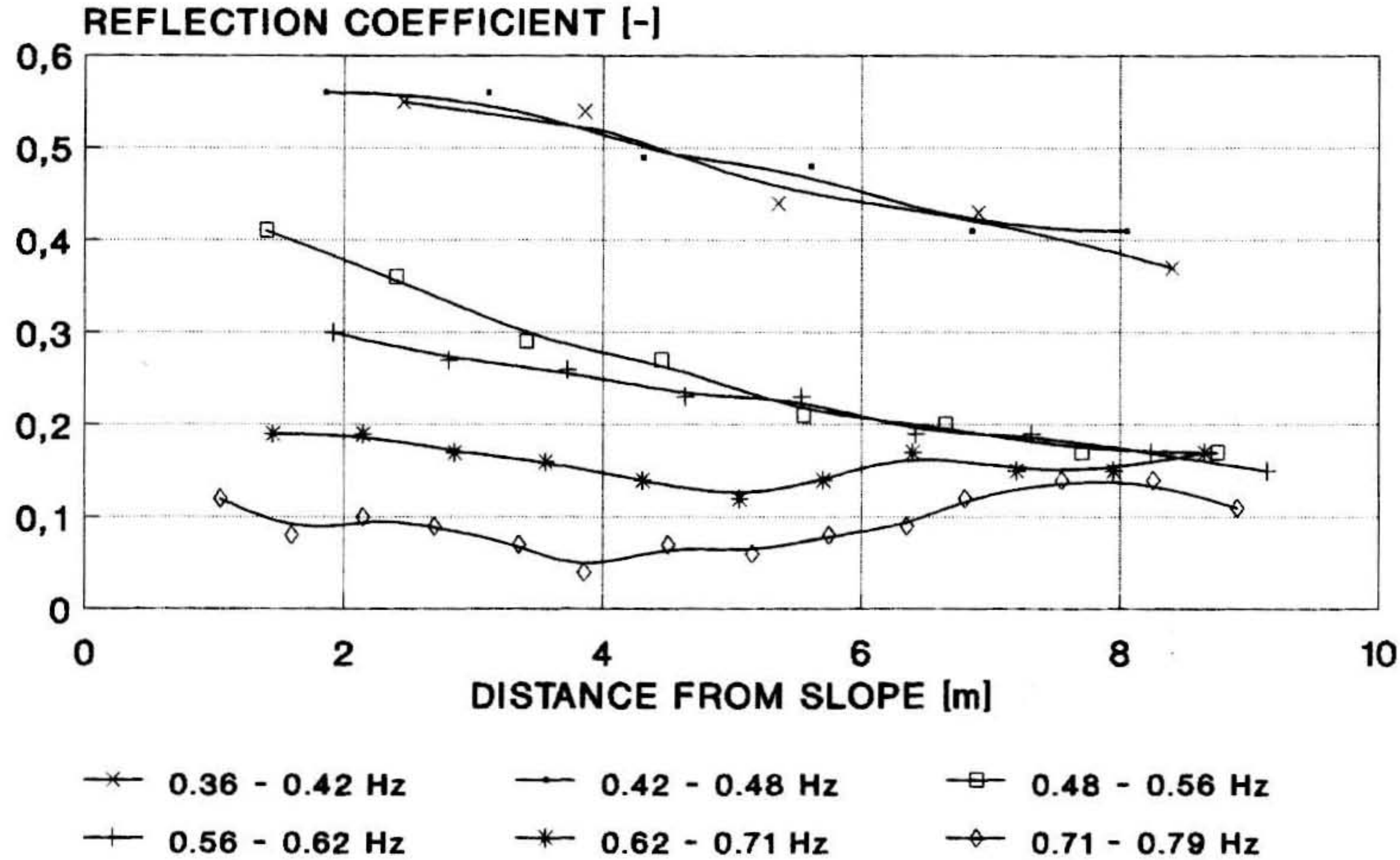

Fig.14: Reflection Coefficients with Distance from a Smooth Slope 1:3

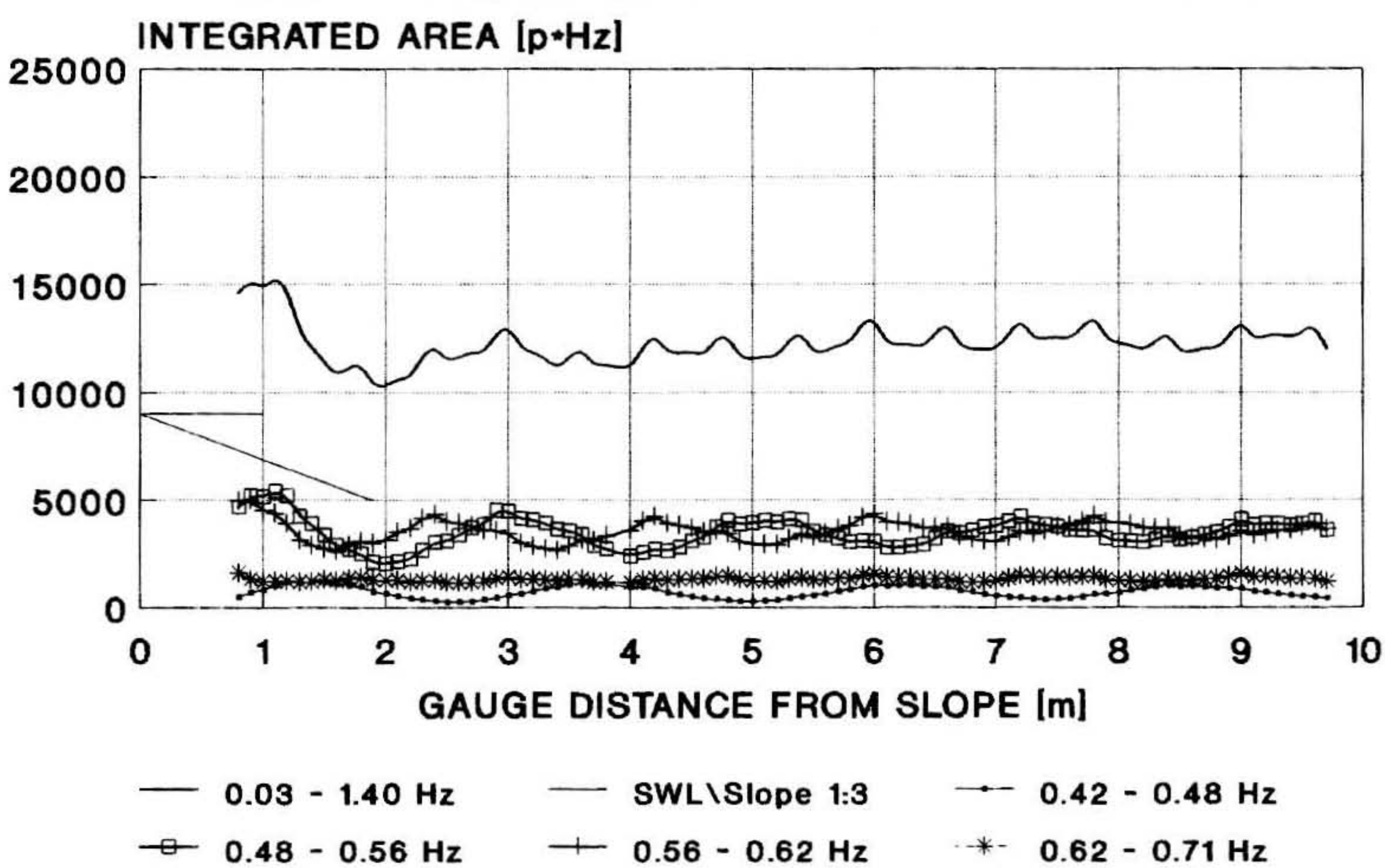

Fig.15: Upper Curve: Total Spectrum Energy with Distance from the Hollow Slope;
Lower Curves: Content of 4 adjacent frequency bands

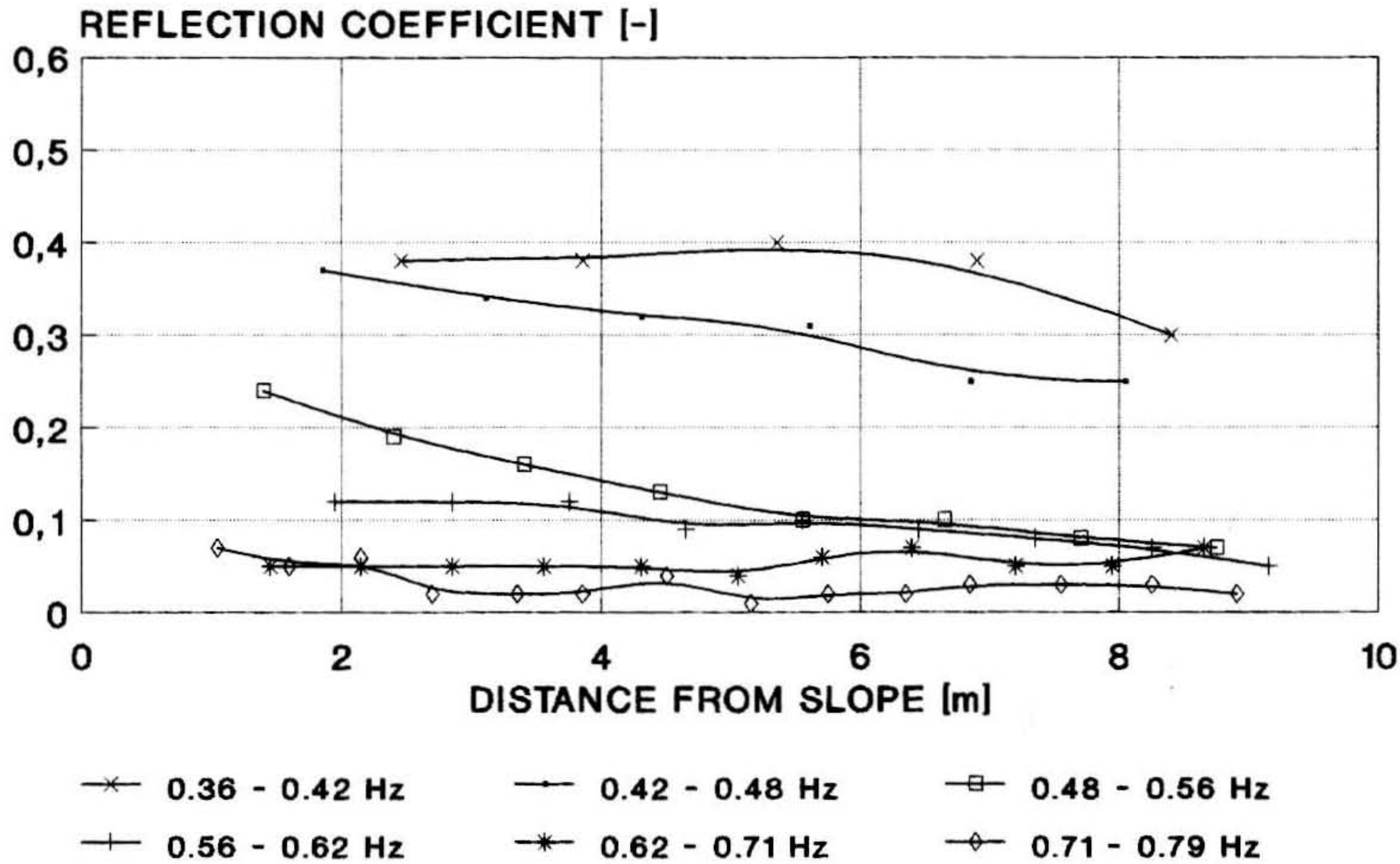

Fig.16: Reflection Coefficients with Distance from a Hollow Slope 1:3

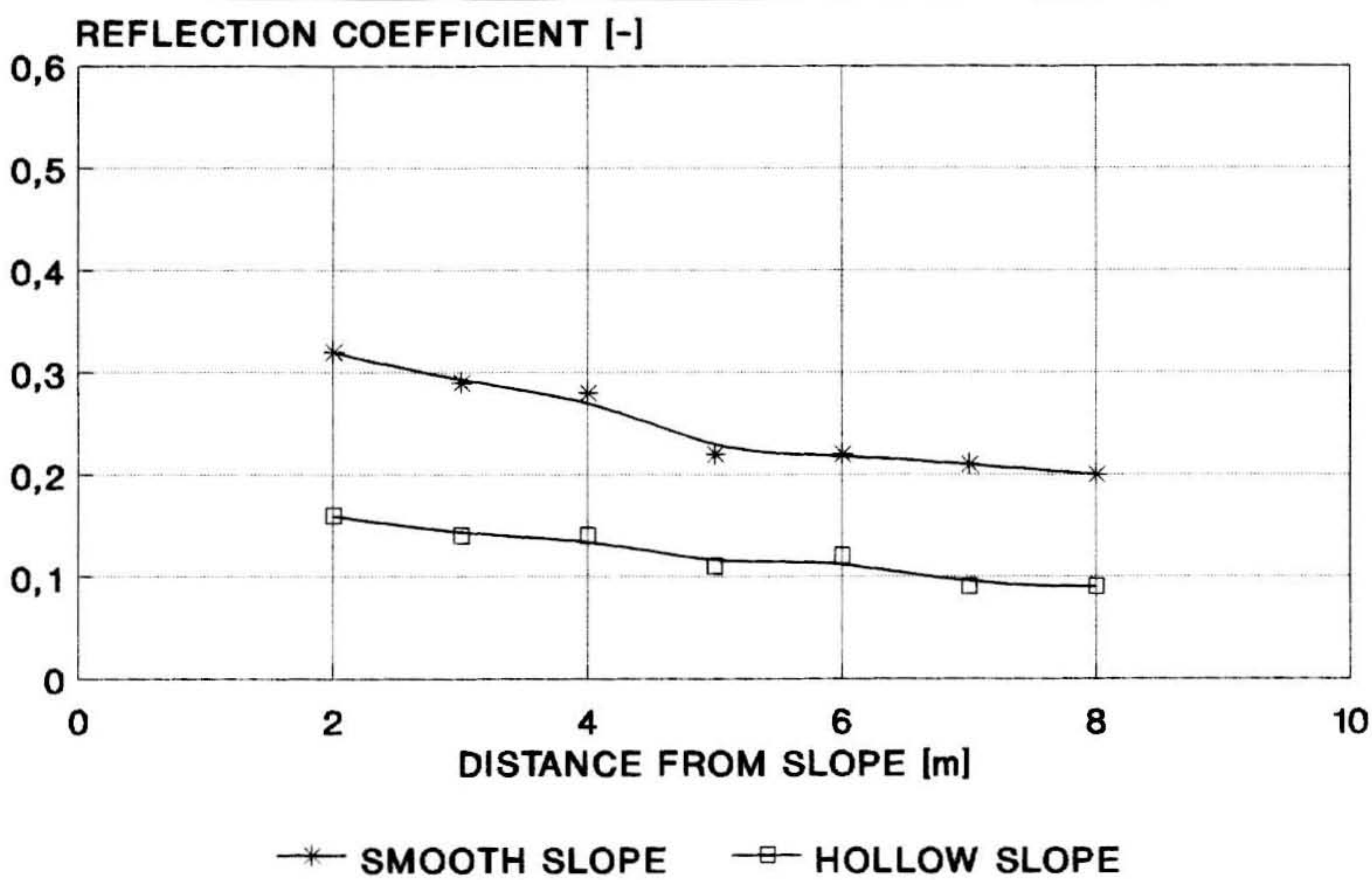

Fig.17: Weighted Mean Reflection Coefficients with Distance from a Slope 1:3

investigated hollow structure consists in the reduction of the total breaker energy to about 60%. Furthermore, the analysis of the curves below, representing the wave energy contained in adjacent frequency ranges, reveals a basic principle:
It can be inferred from the periodic property of those curves that each of them is associated with an individual partial standing wave (partial clapotis). In this presentation of the energy contents with distance from the slope the maxima correspond to the antinodes and the minima to the nodes of such partial clapotis.
Since refraction does not occur in the two-dimensional wave tank, the significance of the minima can be attributed prodominantly to the rate of energy dissipation.
Moreover, with regard to the phase relationship of nodes and antinodes of the superimposed individual partial clapotis, it can be seen clearly that the respective distances from the line of intersection of the stillwater level with the slope face, are larger the longer the attributing frequency components are. This phenomenon can, however, easily be explained considering an irregular wave train moving towards a sloping structure. As the boundary of the slope becomes effective to longer frequency components earlier than to shorter ones, the same is also true to the phenomenon of reflection.
Hence, summarizing it can be stressed:
Contrary to the *refraction* of a light spectrum into spectral colours by a prism of dispersion, a similar splitting up of frequency components, contained in a gravity wave spectrum, occurs due to a kind of *selective reflection* from a sloping structure.

All of these findings imply many features that can not be discussed here in detail. This will be done in the forthcoming paper [5], in particular with regard to the *anomalous dispersion* effect found by the author previously [8]. It can, however, be stated that the idea, the author started from, indeed has turned out to be a matter of relevance. The washing movement on the slope face together with the individual partial standing waves can be considered to form a coupled oscillating system. This system, assigned by different degrees of freedom, can be affected by influencing the washing movement on the slope face.
Comparing the reflection coefficients (Fig.14, Fig.16 and Fig.17) a significant reduction is found with respect to all the frequency ranges evaluated. It is, however, apparent that the relative rate of reduction is stronger on the higher frequencies than on lower ones. That means that the coupling mechanism with the washing movement is rather spoilt than energy dissipation is induced at those frequencies. As this is quite contrary to the *increase* of energy densities in surf spectra (due to turbulent mixing at the wave breaking process) (Büsching, 1976)[7], this is another indication that the presumed interaction effect indeed is a prominent feature. Further evaluations are being performed with respect to different *slope angles*.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Büsching, F.: Durchströmbare Böschungsstrukturen, BAUINGENIEUR 66 (1991) 11-14
[2] Büsching, F.: Uferschutzwerk, Deichaußenböschung, Stauwand oder dgl. sowie zugehörige Bauelemente; Anmeldung Deutsches Patentamt Nr. P 3930997.5-25, 1989
[3] Büsching, F.: Uferschutzwerk, Längswerk, Querwerk Wellenbrecher oder dgl. sowie zugehörige Bauelemente; Anmeldung Deutsches Patentamt Nr. P 4011504.6-25, 1990
[4] Büsching, F.: Embankment Protection Structure; European Patent Office Nr. 91103801.6-2303, 1991
[5] Büsching, F.: Random Wave Reflection from Sloping Structures, 23rd Int. Conf. on Coastal Eng., Venice (1992)
[6] Blees, O. / Stühmeier, M.: Wellen und Strömungen vor geböschten Uferschutzbauwerken, Diplomarbeit FH Bielefeld (1991), unpublished
[7] Büsching, F.: On Energy Spectra of Irregular Surf Waves, Proc. 15th Int. Conf. on Coastal Eng., Honululu (1976)
[8] Büsching, F.: Anomalous Dispersion of Fourier Components of Surface Gravity Waves in the Near Shore Area, Proc. 16th Int. Conf. on Coastal Eng., Hamburg (1978)