CHAPTER 24

AIR ENTRAINMENT AND ENERGY DISSIPATION IN BREAKERS

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SUMMARY

Even in shallow water, only a part of wave energy is lost by turbulent viscosity and bottom friction, most of wave energy transfer takes place in the narrow zone of surf at the shore.

Till to the point of breaking, the theoretical conception of an one-phase flow may be applied to the problem. From beginning of breaking, however, the effect of aeration can not be neglected.

From a simple physical consideration, the sudden reduction of wave height and wave energy inside the surf zone can be explained by the entrainment of air bubbles into the water. Except compression and surface tension effects, most of wave energy is stored at first by the static energy of the air bubbles which are driven into the water.

Using idealized assumptions for calculation (uniform concentration of air bubbles a.s.o.), it can be shown that in a plunging breaker the wave energy is dissipated on a very short way (less than on wave length), for a spilling breaker however, this way is of the order of some wave lengths.

After formation of the air-water-mixture, the energy of the air bubbles is transformed by the microturbulence of the eddies in the turbulent wakes behind the uprising bubbles.

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So turbulence spectrum also is connected with the air content of the water, this shall be of importance for the sediment transport.

For model investigations of breaking waves heavy scale effects are to be expected from the air entrainment.

THEORETICAL CONSIDERATION

Inside the surf zone, wave heigth and energy are reduced suddenly by strong interactions, it shall be demonstrated here that the major part of wave energy is spent by surface interaction = air entrainment. For this demonstration, only simple assumptions and linear wave theory are used, the results would be essentially the same for higher order theories.

The total energy of a wave with the heigth H and the length L is on the width b

$$E = \frac{1}{8} \cdot \gamma \cdot b \cdot L \cdot H^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and a reduction of wave height dH gives the reduction of wave energy dE

$$dE = \frac{1}{4} \cdot \gamma \cdot b \cdot L \cdot H \cdot dH \quad \ldots\ldots\ldots\ldots \quad (2)$$

The wave length L shall be stated to be constant during breaking.

This loss of (static and dynamic) energy must be transformed into other sorts of energy, so in turbulent motion and at last into heat by friction. But before the energy is going into turbulence, there is a transfer mechanism by air entrainment and foam production.

Fig. 1 shows a column of water with the heigth y and a volume of air Δy, when mixed together in such a matter, that there is a nearly uniform distribution of air bubbles in the water, the air concentration c, related to the vo-

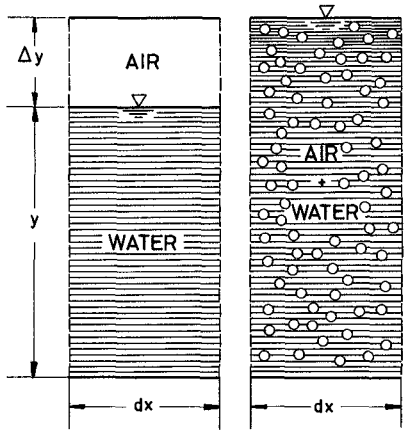

FIG. 1. - ENERGY CONSUM BY AERATION

lumen with the height y + Δy, is

$$c = \frac{\Delta y}{y+\Delta y} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Neglecting the density of air, the static energy to bring a volume of air into the depth d below water surface is the same like to bring an equal volume of water into the height d above surface. For the length dx, the width b and an (uniform) air concentration c therefore is (Fig. 1)

$$dE_{stat} = \gamma \cdot b \cdot dx\left(c \cdot \frac{y^2}{2} + \frac{\Delta y^2}{2}(1-c)\right) \quad \ldots\ldots\ldots\ldots \quad (4)$$

air in water; water with air above level y

and with Δy from Eq. 3

$$dE_{stat} = \gamma \cdot b \cdot dx \cdot \frac{y^2}{2} \cdot \frac{c}{1-c} \quad \ldots\ldots\ldots\ldots\ldots \quad (5)$$

This is only the static energy which is necessary to transfer the water column y and the air column Δy into a foam column y + Δy (Fig. 1), additionally, energy losses by effects of (adiabatic) compression, surface tension and friction during the movement of the bubbles occur, these effects, however, are of small order compared with the static energy from Eq. 5.

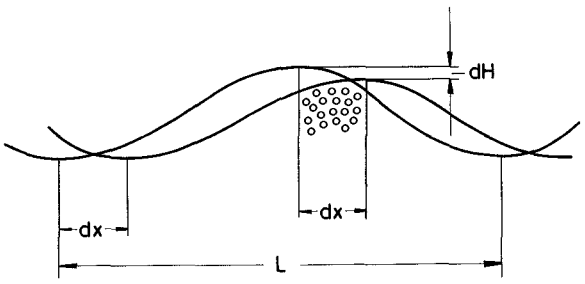

FIG. 2. - WAVE HEIGHT REDUCTION

Now the reduction of wave height (Fig. 2) and the obligate loss of energy from Eq. 2 can be put together with Eq. 5 for the energy from aeration effect, with the assumption, that the energy amount dE on the way dx is spent completely for the aeration of a water column of the same length dx and the height y

$$\frac{dH}{dx} = -2 \cdot \frac{c}{1-c} \cdot \frac{y^2}{HL} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

This is the differential equation for H = H(x), the wave height inside the surf zone, for an evaluation, data are necessary for c and y, if there is no uniform distribution of the air bubbles, integrals have to be formed which represent the static energy of the air content.

But for a study only on the order of magnitude of aeration effect, for two special cases of breakers some rough assumptions can be made, so for the spilling breaker, that the depth of aeration is in a linear relation to the reduction of wave height H(x)

$$y \propto H(x) \quad \text{(spilling breaker)}$$

Then an integration of Eq. 6 gives with $H(x) = H_b$ for x=0 (point of breaking)

$$H(x) = H_b \cdot e^{-2 \cdot \frac{c}{1-c} \cdot \frac{x}{L}} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

For a plunging breaker, in first approximation the depth of aeration y can be considered to be of same order of magnitude as the breaker height H_b and to be constant during the process of breaking.

$$y \propto H_b = \text{const} \quad \text{(plunging breaker)}$$

Here integration of Eq. 6 gives with $H(x) = H_b$ for x = 0

$$H(x) = H_b \sqrt{1 - 4 \cdot \frac{c}{1-c} \cdot \frac{x}{L}} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

On Fig. 3, the results of Eq. 7 and Eq. 8 are presented for air concentrations between 20 % and 40 % which may be probable for breaking waves. It is to be seen that for spilling breakers a way of some wave lengths is necessary for the reduction of initial wave height H_b, for the plunging breaker, however, a part of one wave length is enough for the total destruction of the wave, in agreement to observations in nature.

From wave theory as well as from the mechanism of the formation and the entrainment of the air bubbles, very many questions are open for the problem. Here only should be pointed out that even a simple model demonstrates clearly the importance of the aeration effect for the energy dissipation in surf zones, Eq. 7 and Eq. 8 together with Fig. 3 show that the aeration effect for itself is able to explain the high energy loss in breaking waves.

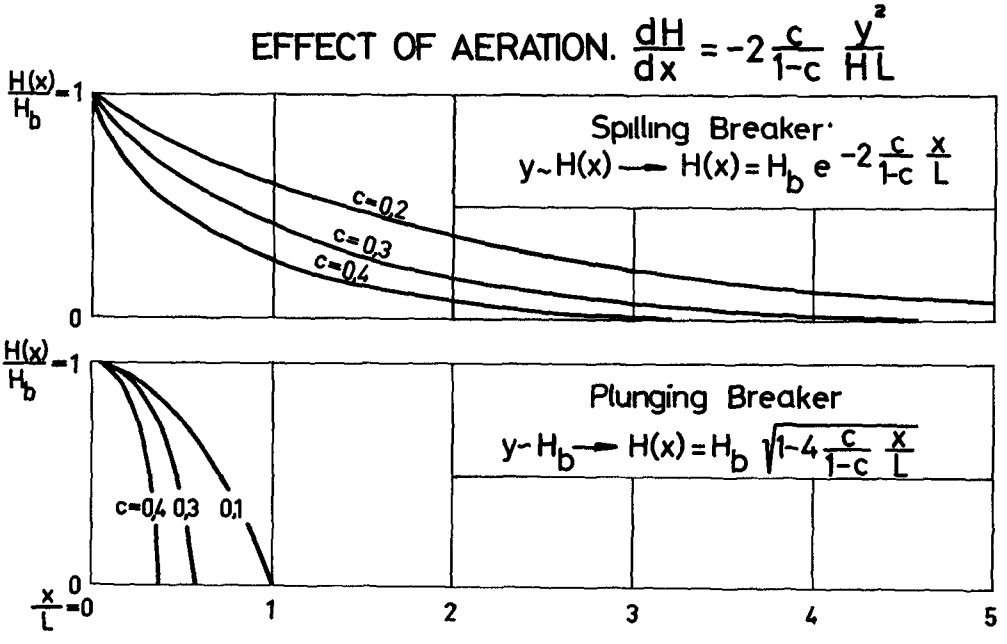

FIG. 3. - WAVE HEIGHT REDUCTION FOR SPILLING AND PLUNGING BREAKERS

DISCUSSION AND CONCLUSIONS

The static energy stored in the air bubbles afterwards is transformed in turbulent mixing and eddy production during the uprise of the bubbles to the surface. So the turbulence spectrum in the surf zone also is connected with aeration.

The amount of air entrainment, i.e. the concentration and distribution of air, is nearly unknown, especially for large breakers, but it seems to be sure that the air entrainment is not only a function of FROUDE's and REYNOLDS' but strongly also from WEBER's number. Surface tension and capillary effects will have influence on the process of breaking more for small than for large waves, for wave heights less than about one inch no areation takes place. The interaction between a gas and a fluid is a well known but very complicated problem even for steady conditions in Processing and Chemical Engineering, for breaking waves the unsteady process makes the difficulties increase, this is valid also for measurement of air concentration and distribution.

Indirectly, the investigations of SKLADNEV and POPOV (ref. 4) give some ideas about the limits for scale models with breaking waves, they found for the special case of wave forces on a concrete slope that there are no scale effects for waves higher than 50 cm, waves from 5 cm till 120 cm were used for the test series, the wave height of 120 cm beeing thought as the prototype. For wave heights less than 50 cm, the forces scaled up after FROUDE's law became higher than measured with the prototype wave height of 120 cm, for waves 3 cm high more than two times. This effect is explained by the authors explicitely by the decreasing air content. Similar considerations about the influence of the air content on impact forces (shock forces) also are given in ref. 1 and 2.

Even the beginning of breaking as "white capping" at the

wave crests is considered by HASSELMANN (ref. 3) to be a "strong interaction" compared with the "weak interaction" by bottom friction. Inside the surf zone, the water-air-interaction must be expected much stronger than the water-bottom-interactions.

Thinking the energy of an incoming wave at the point of breaking to be 100 %, it would be of highest interest to know how much percent of this energy is spent by water-air-interaction because only the difference can be effective for water-bottom-interactions, sediment transport, wave set-up and rip currents, wave run-up a.s.o. Also of high importance is the question how far scale models are able to reproduce these processes, when the aeration effect is reduced by surface tension, the energy for the other effects mentioned above becomes higher than in prototype. So all problems of litoral processes are influenced by the aeration problem.

The production of air-water-mixtures by the different sizes and sorts of breakers therefore seems to be a first order problem for the physical process in surf zones. Measurements of air concentrations and bubble distributions are necessary together with wave height measurements in order to get a knowledge how much of the energy dissipation of a breaker is represented by the aeration effect given by Eq. 6.

REFERENCES

1. FÜHRBOTER, A. Der Druckschlag durch Brecher auf Deichboschungen, Mitteilungen des Franzius-Instituts der Technischen Universitat Hannover, Heft 28, 1966.

2. FÜHRBOTER, A. Laboratory Investigation of Impact Forces, Paper No. 6, Symposium Research on Wave Action, Delft, March 24 - 28, 1969.

3. HASSELMANN, K. Weak Interaction Theory of Ocean Waves, Basic Developments in Fluid Mechanics, Vol. 2, Academic Press Inc., New York 1968.

4. SKLADNEV, M.F. and POPOV, I.Ya.. Studies of Wave Loads on Concrete Slope Protections of Earth Dams, Paper Nr. 7, Symposium on Wave Action, Delft March 24 - 28. 1969.