CHAPTER 87

THE SUBMERGED PLATE AS A WAVE FILTER

THE STABILITY OF THE PULSATING FLOW PHENOMENON

Dr.-Ing. Kai-Uwe Graw **

ABSTRACT

For many applications it is possible to reduce the wave motion in the protected area sufficiently using the submerged plate as a wave filter. The horizontal submerged plate, which hardly obstructs the cross-section of the flow, cannot be explained by the Wiegel approach at all. A strong pulsating flow opposite to the direction of the wave propagation originates beneath the plate during wave attack. New velocity measurements, carried out with an ultrasonic 3D-probe in the region below the plate, make it now possible to explain the principle much more in detail. They show that the flow phenomenon at the plate is very stable, the flow is nearly as strong if the region below the plate is partly closed.

1. REASONS FOR THE INVESTIGATIONS

The protection of coastlines and harbours against wave attack is mainly achieved by the use of solitary breakwaters. Their negative features are that they hinder:

a) the water exchange between the open sea and the protected area (diverted sediment transport, deteriorated water quality) and

b) the view over the open sea.

Underwater breakwaters are not visible, but the water exchange does not increase as much as the efficiency decreases. One possibility to enhance the performance without hindering the water exchange is the use of a semi-submerged vertical wall which obstructs the energy flux near the surface. However, this leads to construction problems (destruction of the

** Senior Research Engineer
Wasserbau und Wasserwirtschaft, Bergische Universität GH Wuppertal
Pauluskirchstraße 7, 5600 Wuppertal 2, Germany

wall in large waves), and also in this case the structure is visible. The breakwater type which reduces all these secondary problems is the rigid horizontal submerged plate mentioned in this paper. The plate cannot be used to stop the wave motion in the protected area, but its efficiency is sufficient for many applications.

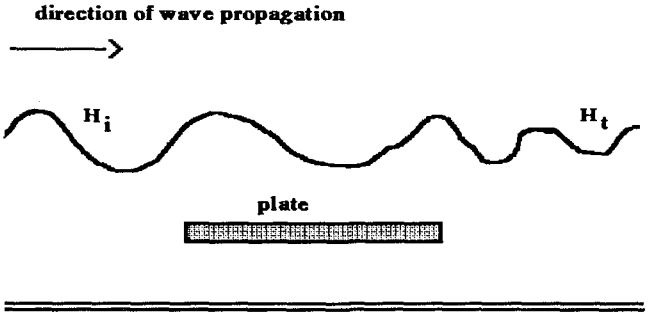

Figure 1: The submerged plate

2. THE SUBMERGED PLATE: THE WAVE FILTER

The performance of "normal" breakwaters can be explained by using the Wiegel approach. This means that the part of the wave energy in the regions covered by the structure is reflected, a very small part of the energy is dissipated at its surface and the other part passes by.

Figure 2 shows one series of the different measurements performed by Dauer [1984]. The figure shows the results for the shortest of the plates used (the length is only 1.333 times the water-depth, l/d=1.333).
The performance of the plate is not adequate in two cases:

① All long waves (L/l > 6) are not reduced sufficiently, the wave height reduction is approximately 25%.

② Furthermore it can be seen, that the plate which is submerged by more than one third (40%) of the water-depth does not really work.

All waves not longer than 3.5 times the plate length (L/l < 3.5) are reduced by more than 50%. The largest value of the wave height reduction is approximatly 80%.

The best results were obtained for the three smallest values, but one important reason for this is wave breaking above the plate, connected with large forces exerted on the plate. For a submergence depth between 20 and 30% of the water depth a sufficient wave height reduction was observed, not caused by wave breaking. These results were confirmed for

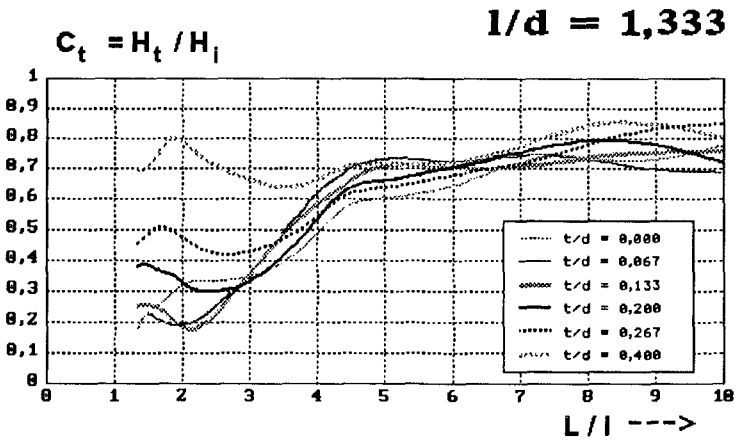

Figure 2: Wave height reduction at the plate [Dauer, 1984]

different plates longer than two times the wave length (l/d > 2). The wave height reduction is relatively constant (50 - 70%) in the wave length range between L/l = 0.4 and 4.

Examining a normal solitary breakwater, this principle is correct; looking at the semi-submerged vertical wall, it does not cover the whole problem but it is a good approximation. The horizontal submerged plate which hardly obstructs the cross-section of the flow cannot be explained by the Wiegel approach at all. For this reason, and as it performs well only in a particular region of the wave spectrum, it shall be called a wave filter from now on.

3. THE PULSATING FLOW

Dick [1968] noticed a flow around a horizontal plate submerged beneath waves, but he did not give any explanation for it. Analyses of the flow behaviour, based on flow visualization experiments [Graw, 1988; Graw, Kaldenhoff, Stieglmeier, 1989], and measurements of the wave height were presented by Hoeborn [1986]. She first gave an explanation based on a resonant flow behaviour. Continual experiments have shown that the dissipation of energy at the plate is caused in the wake behind the plate [Fischer, 1990; Fischer, Jirka, Kaldenhoff, 1991]. A finite element model gave us the possibility of calculating the energy equilibrium at the plate quite well, but the forecast of the flow was still uncertain. New velocity measurements, carried out with an ultrasonic 3D-probe in the region below the plate, make it now possible to explain the principle much more in detail. They show that the flow phenomenon at the plate is very stable, the flow is nearly as strong if the region below the plate is partly closed.

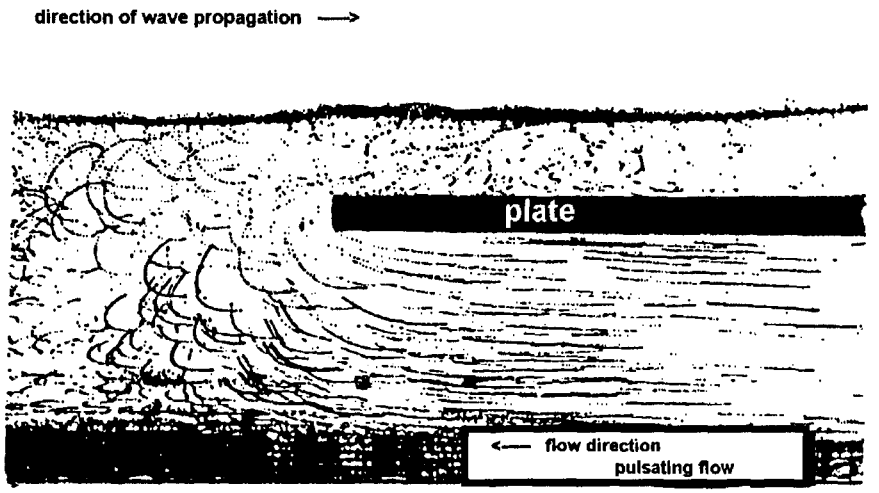

Figure 3 a: Pulsating flow beneath the plate

The physical principle of the plate as a wave filter can be explained as follows:

❶ The propagating water wave reaching the horizontal plate is divided into two parts: the energy flux above the plate is transformed into a new - shorter - gravity wave determined by the reduced water depth in this region, the one below the plate is a propagating pressure distortion travelling slowlier than the wave above.

❷ As soon as the first short gravity wave overflowing the plate reaches the region behind the plate, once more a new wave is formed, which travels away and has the same wave-length as the original wave, but less energy. Furthermore a part of the energy of the wave overtopping the plate also propagates into the region below the plate (backwards!).

❸ If the length of the plate is such that at the same time there are a wave trough at the front edge and a wave crest at the end of the plate (resonance), and if the amount of this energy is relatively large compared to that travelling forward (no shallow water waves), a strong pulsating flow opposite to the direction of the wave propagation originates (figure 3).

❹ The energy transferred back by this flow to the region before the plate makes it impossible for the pressure distortion caused by following waves to propagate into the region below the plate, the flow grows stronger. Thus a part of the energy is reflected by the structure. Figure 4 shows the particle orbits in front of the plate. It can be seen that the region below the plate is closed for the wave energy of the incoming wave.

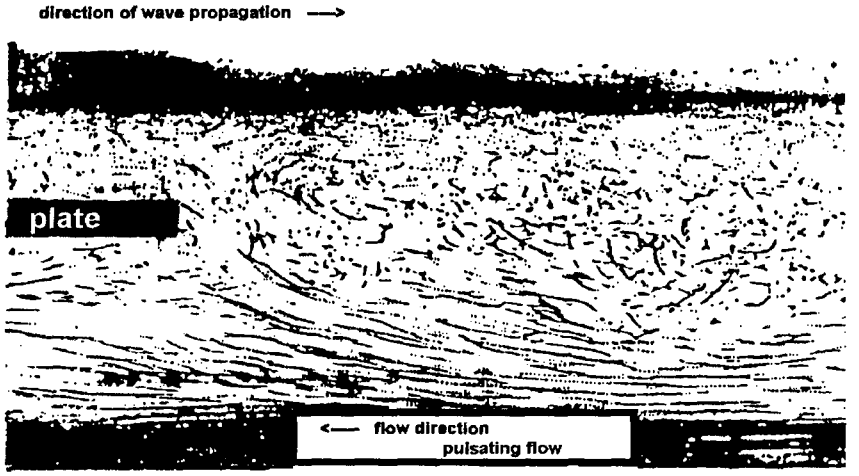

Figure 3 b: Pulsating flow beneath the plate

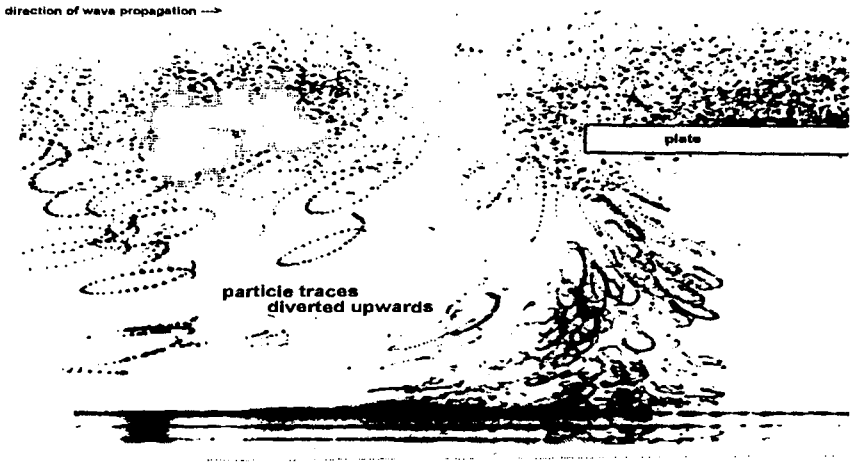

Figure 4: Diverted particle orbits in front of the plate

Figure 5 shows how the flow grows as the waves are passing by (in comparison with the undisturbed orbital motion). This flow is the physical reason why energy is reflected by this structure. As it depends on the energy equilibrium between the front and the rear below the plate, the plate acts as a wave filter. The mean parameters for the description of the performance are the ratio of wave-length (L) to length of the plate (l) and the relative immersion of the plate.

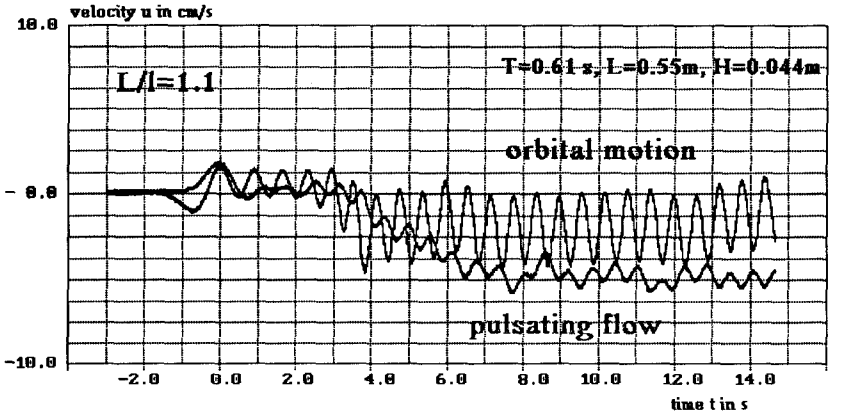

Figure 5: Development of the pulsating flow

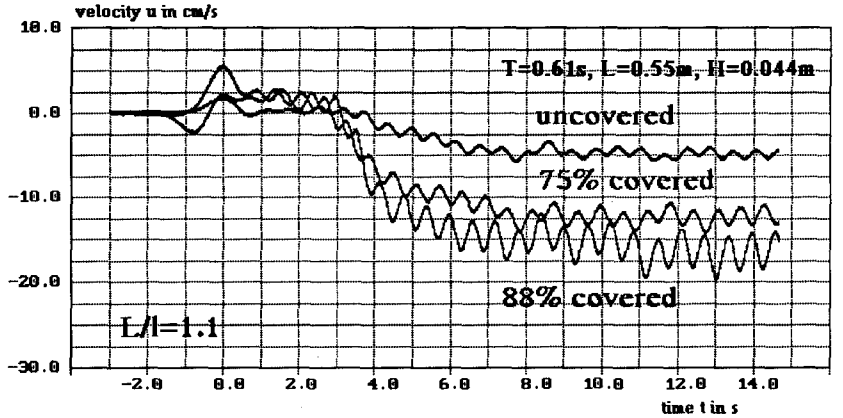

Figure 6: Pulsating flow with obstruction below the plate

In order to construct this wave filter it is necessary to build a connection between the plate and the bottom of the sea. The possibility of a durable realization increases if it is possible to build a very solid connection. The answer to the question if it is possible to partially obstruct the region below the plate without destroying the pulsating flow is given in figure 6. The kinetic energy of the three pulsating flows shown here is nearly the same.

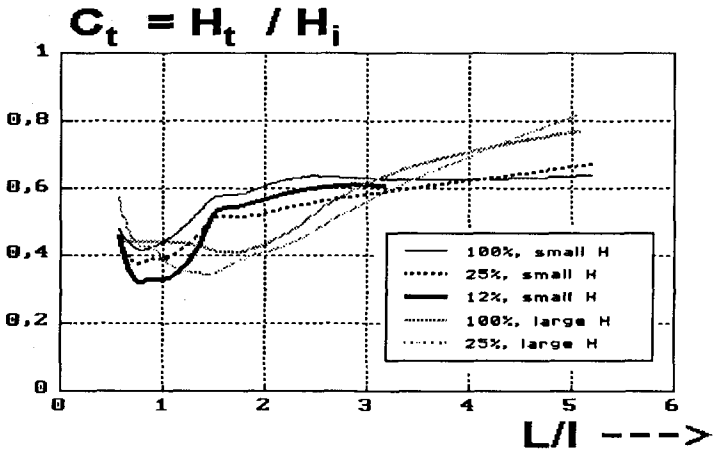

Figure 7: Performance of the breakwater

The phenomenon of the pulsating flow is not disturbed by the blockage and, connected with that, the performance of the wave filter is not reduced. Figure 7 shows the wave height reduction observed during the present experiments. The two measurements series shown were not performed with constant values of the wave height, accordingly they are named small and large waves. It is clearly visible that the wave height reduction also depends on the height of the incoming waves (and therefore on the depth distribution of the kinetic energy of the waves).

4. CONCLUSIONS AND OUTLOOK

The experiments - that are presented here very briefly - show that the performance of the "plate as a wave filter" is a phenomenon which is stable even if the region below the plate is partly blocked up. This is a necessity because the plate has to be fastened to the ground of the sea somehow. As it is possible to build a solid construction, this way it seems possible to construct an economic, durable and strong breakwater.

The submerged plate as a wave filter is the only construction which allows to reduce the wave height without obstructing the flow region with the largest energy flux - the surface region - because a large amount of the wave energy is diverted into the deeper regions. This means that problems with the construction of common wave breakers as the destruction by very large waves, corrosion problems, etc, are reduced.

The diversion of energy also introduces a new principle for the construction of a wave energy converter. Today all known devices are placed somehow near the surface of the sea, including again all the problems mentioned above. The possibility of such a new wave energy device is being investigated at our institute at the moment.

5. LITERATURE

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