CHAPTER 142

Stable Profiles of Reshaping Breakwaters with a Berm Below the Water Level

C.I.Moutzouris[1]

Abstract

An experimental study of breakwaters with an initially horizontal berm below the SWL was conducted in a wave flume. The study aimed at defining the shape and geometrical features of the adjusted stable profiles and at confirming the existence of a zone of non-significant profile adjustment below the initially flat and horizontal slope.

Indroduction

Berm breakwaters are increasingly recieving attention from researchers and practicing engineers (see f.i.van der Meer, 1988, Hall & Kao 1991, Tomasicchio et al., 1994, etc.), because they are considered to be economically attractive, to minimise rock movement and to reduce the time required for natural stability to be obtained. The concept of the berm is to pre-break incident waves further out and the stability is greatly enchanced due to waves breaking on a level surface instead of on a slope. As an almost general rule, the berm is placed slightly above the still water level(SWL), as it can be seen in Fig. 1.

Although the existence of a berm above the SWL facilitates the position of construction equipment

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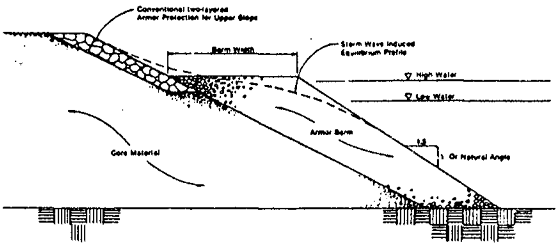
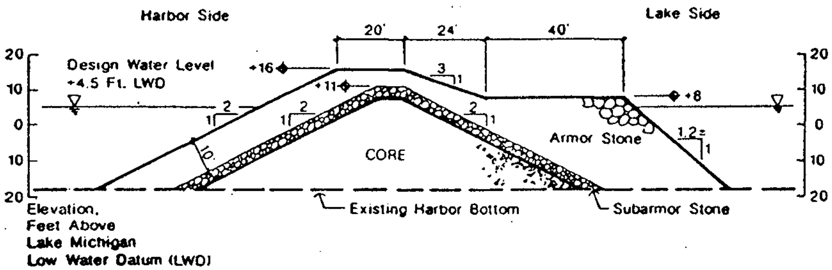
[1] Professor, Laboratory of Harbour Works, Civil Engineering Department, National Technical University of Athens (NTUA), 5 Iroon Polytechniou Str., Zografou, 15773 Athens, Greece



from Rauw, 1988



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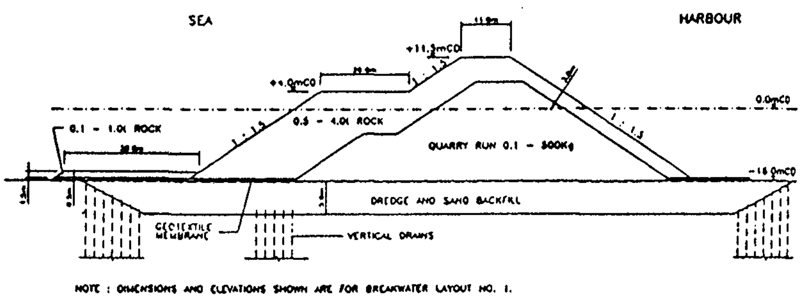


from Lingteringen et al., 1992

Figure 1. Typical breakwaters with a berm above the SWL

physical evidence seems to indicate that in reshaping (or dynamically stable) breakwaters flat slopes form below the SWL. The model tests reported by Foster and Hall show that flatter slopes tend to develop in the area below the SWL, but above the level of the lowest wave rundown, which is an area of maximum hydrodynamic forces. It is, therefore, surprising that very little data exist on the response of profiles with a berm built below the SWL.

An experimental study of breakwaters with an initially horizontal berm below the SWL was conducted in a wave flume of the Laboratory of Harbour Works, NTUA. The study aimed at defining the shape and geometrical features of the adjusted stable profiles and at confirming the existence of a zone of non-significant profile adjustment below the initially flat and horizontal slope.

Experimental Conditions and Procedure

The wave flume was 25m long and 0.6m wide. The wave generator was placed at one end of the flume and generated regular waves. Crushed stones with a density of $\rho_s = 2.6 t/m^3$ were used for the armour layer of the breakwaters. Nominal armour diameter D_{n50} defined as $(W_{50}/\rho_s)^{1/3}$, where W_{50} is the 50% value of armour mass distribution, was equal to 3.5cm.

A total of 258 experiments were carried out. The seaward slope underwent reshaping under the wave action until a stable (or final) profile developed. The influence of numerous initial conditions were examined, namely (see Fig.2 and Table 1): initial berm height d_a and width b, water depth d, wave height and length H and L, respectively, initial slope of the armour layers in the upper and lower parts 1:n and 1:m, respectively. For comparison reasons numerous experiments with b = 0 (conventional breakwater or no berm conditions) were carried out. Some experiments with a berm built above the SWL ($d_a > d$) were also performed. Finally, a number of experiments with an initially sloping berm (1:k) were executed.

The stability (or mobility) number N_s defined as $H/\Delta D_{n50}$ ranged in all cases examined from 2 to 3.5, which indicates a conservative design of the initial profile. Δ is the boyant mass density. The ratio h/d ranged from 0.2 to 0.35 indicating rather shallow water conditions.

The following geometrical features of the final profiles were measured (see Fig.3): slopes of the fronts and the berm, the final berm height d_b, the height h_c of the adjusted profile above the SWL, the length l_c of the adjusted profile above the SWL and the height of the zone of non-significant profile

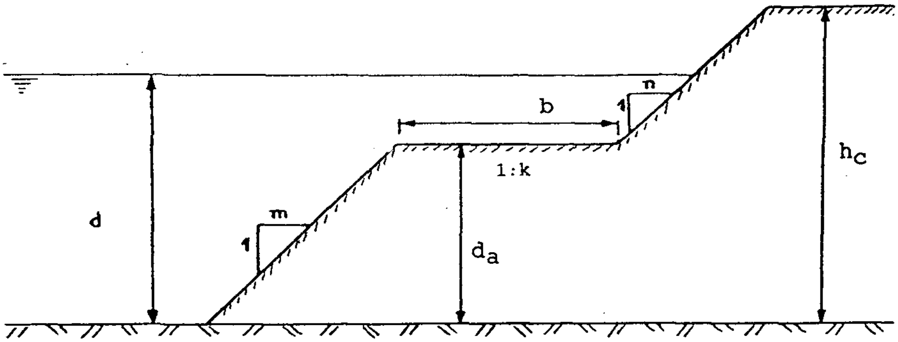
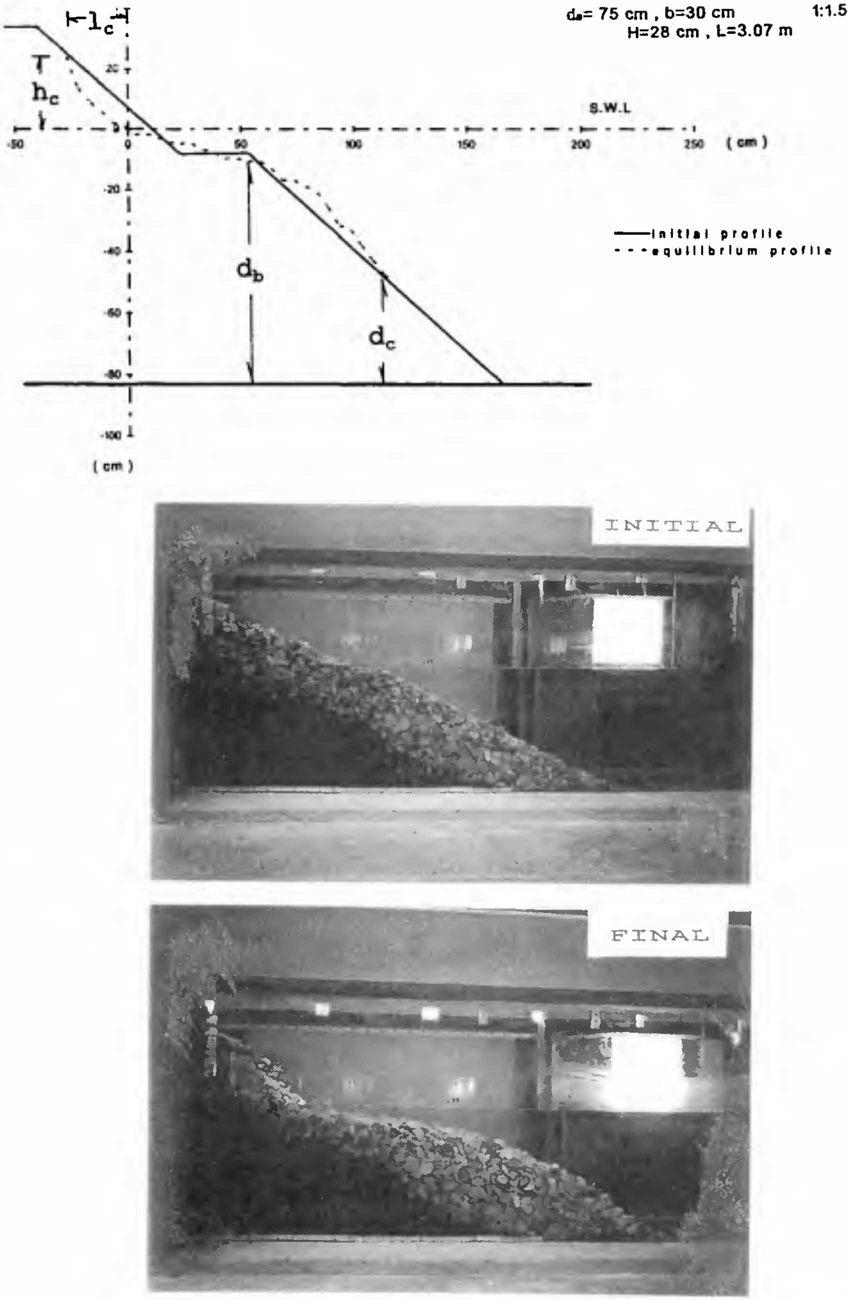


Figure 2. Definitions

water depth at the structure toe d	83 cm
water depth at the orizontal berm (or berm height) da	73, 83 and 91 cm
berm width b	0, 15, 30, 50 and 70cm
initial slope of the armour layer UPPER PART 1: n	1 : 1.5 and 1 : 2
initial slope of the armour layer LOWER PART 1: m	1 : 5 and 1 : 8
offshore wave length L	231 and 307 cm
H / L	0.05 to 0.12
b / L	0 to 0.30
wave height to water depth H / d	0.20 to 0.35 (Greek conditions)
H / D_{n50}	3.0 to 5.6
stability number $N_s = H / \Delta * D_{n50}$	2 to 3.5 (conservative design)

Table 1. Initial conditions in the experiments

adjustment d_c. Finally, the shape of the adjusted seaward profile above and below the SWL were studied.



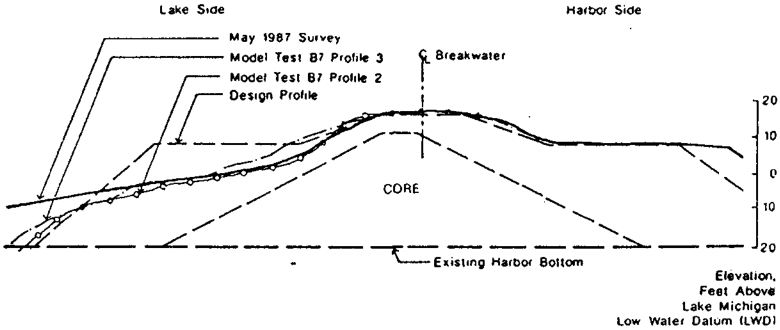
b=15cm da=83cm L=3.07m H=28cm

Figure 3. Initial and final profiles

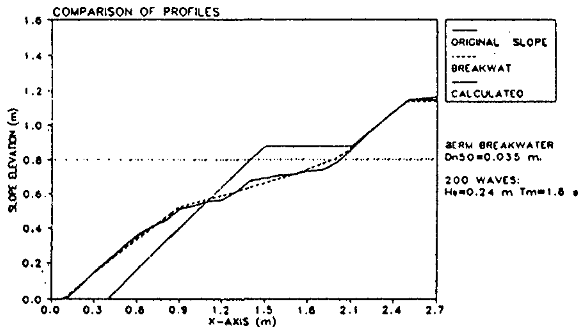
Results

In the paper results from the experiments are presented on the following features of the reshaped and finally stable profile of the breakwaters: final slope of the initially horizontal berm, non-dimensional height of the zone of non-significant profile adjustment, non- dimensional height and length of the adjusted profile above and below the SWL, final berm height and finally shape of the profile above and below the SWL.

Berms initially built horizontal tend to become sloping as a result of wave action, as it can be seen in Fig.4. In the present experiments it was found that



from Montgomery et al., 1988



from van Gent, 1995

Figure 4. Sloping final berm

always the final (or stable) berm was curvilinear with a central part nearaly rectilinear. This central part was found to be almost always sloping with slopes ranging from 1:8 to 1:1 (vertical : horizontal). Most frequent final slopes were from 1:6 to 1:3. Slopes as steep as 1:2 or 1:1 were rare. No influence of the initial berm slope was detected (see Fig. 5).

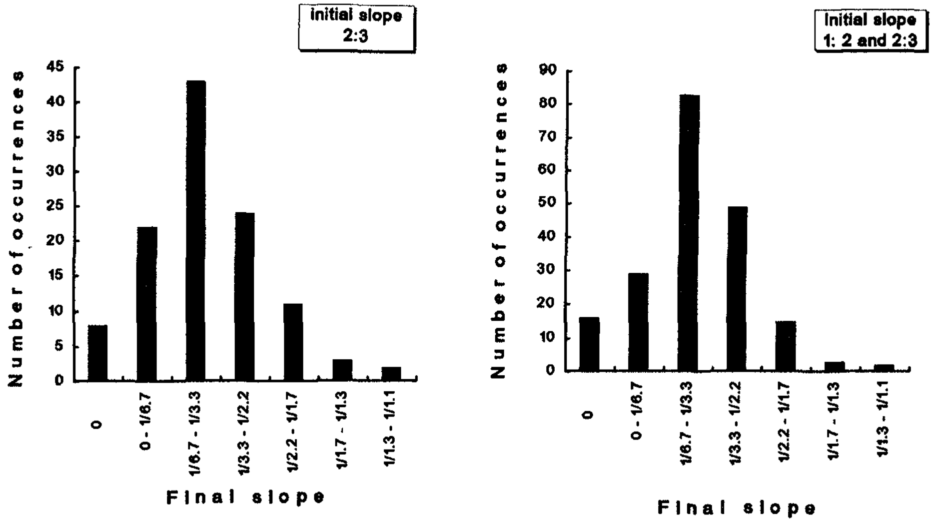


Figure 5. Slopes of the final berm

A considerable part of the profile remained always as it was built and did not deform under the wave action. The so- called "zone of non - significant profile adjustment" is the lower part of the seaward profile with a height above the flume bed equal to d_c. The values of d_c/d were found to range between 0.4 and 0.6 (see Fig.6). d_c/d was increasing when the initial slope was decreasing and this could be explained as follows: Changes in the breakwater profile are mainly due to wave breaking. As it is known, steeper breakwater slopes lead to a higher degree of wave reflection and to less pronounced wave breaking, which explains the experimental result. The initial height of the berm d_a was not found to influence the ratio d_c/d.

The conclusion that at least 40% of the height of the initial profile remains always stable and does not change is rather interesting.

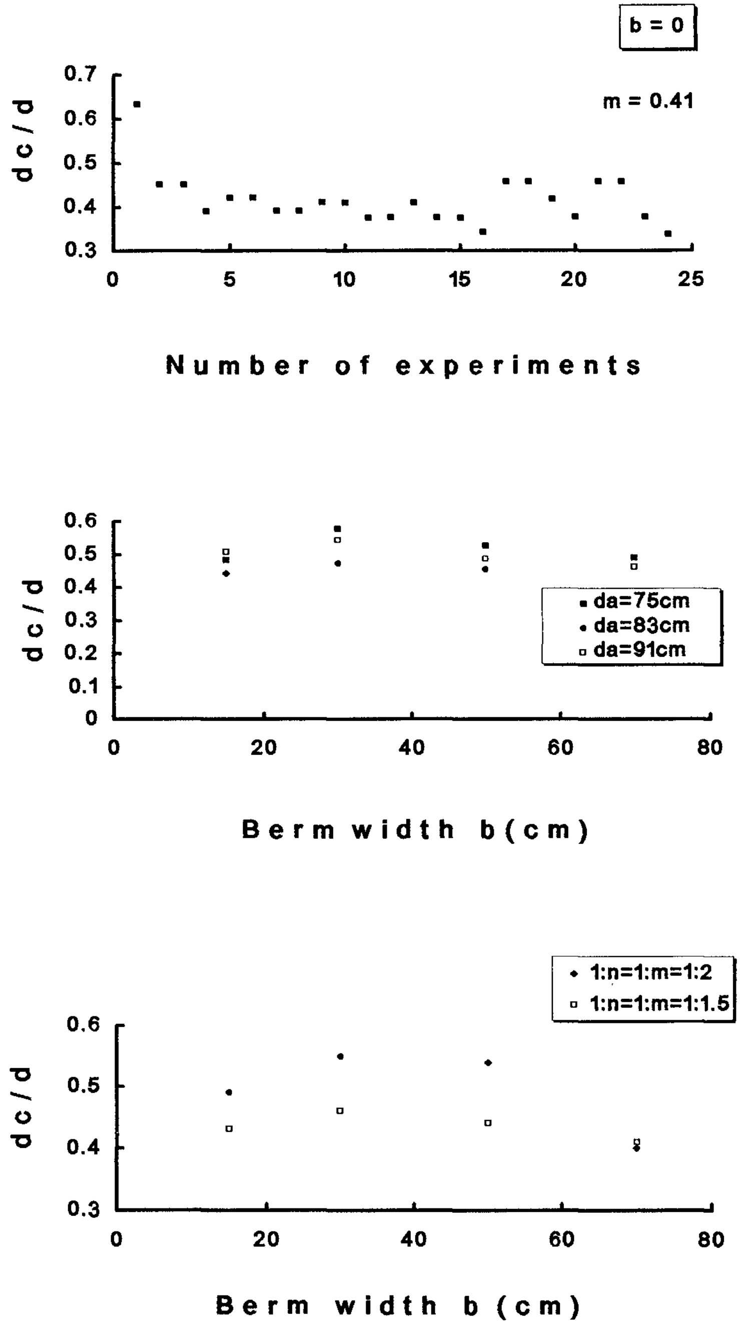


Figure 6. Height of the zone of non-significant profile adjustment

The height of the adjusted profile above the SWL was found to be strongly influenced by the width of the berm (see Fig. 7). In the case of a conventional breakwater (no berm) h_c was of the order of the deforming wave height (0.7 to 1.2 H). When a berm 70cm wide was present, h_c decreased to less than half the wave height. This could be explained as follows: Waves break directly on the slope of a conventional breakwater and cause extensive deformation of the profile. A wide berm forces the waves to break further offshore and, therefore, the zone of deformation becomes smaller.

Similar conclusions were drawn from the experimental results on the length l_c of the adjusted profile above the SWL. l_c was decreasing as the berm width was increasing. The wave length was in most cases in the order of 10 to 20 times the length of the adjusted profile (see Fig.8). Van der Meer (1988) proposed an empirical expression for l_c. The present results concerning l_c were not always in good agreement with van der Meer's $l_{c,vM}$.

The seaward profile of a berm breakwater is often predicted by simple models (f.i. van der Meer, 1988) based on physical model tests of the following type:

$$y = ax^b \qquad (1)$$

where a and b are empirical coefficients. The present experiments showed that both the sections below and above the SWL of the deformed profile could be represented by an equation of the same type as equ.(1), namely:

$$y = a_1 x^{b_1} \quad \text{for the section below the SWL}$$

and

$$y = a_2 (-x)^{b_2} \quad \text{for the section above the SWL}$$

The range of values of b_1 and b_2 were as follows:

$$b_1 = 0.70 \text{ to } 1.15$$

$$b_2 = 0.98 \text{ to } 1.12$$

Table 2 contains the values of b_1 and b_2 as found in the present experiments and as proposed by various authors. According to a PIANC report, for values of N_s lower than about 10 to 15 the prediction model of van der Meer seems to be less reliable than for larger values of N_s.

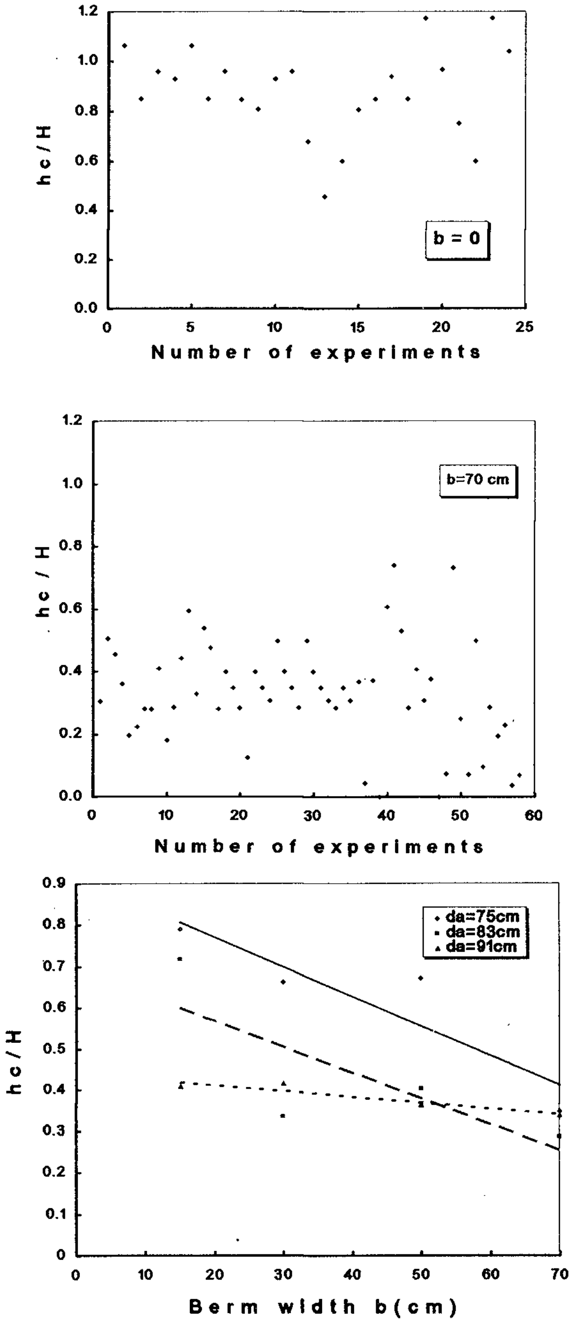
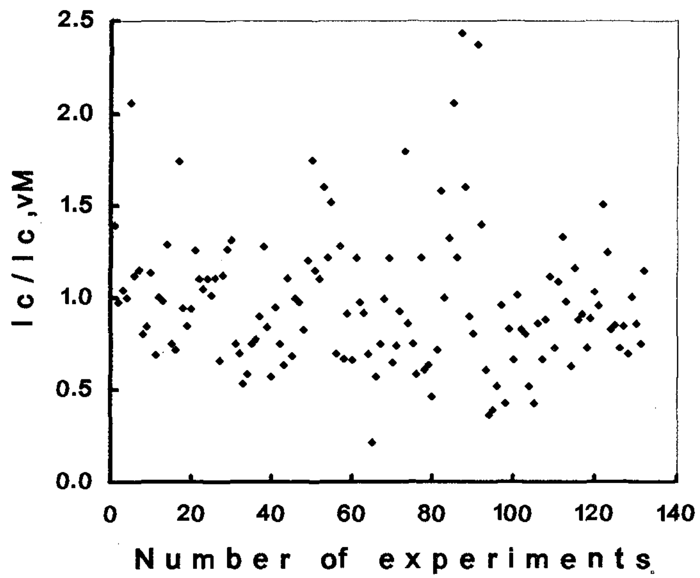


Figure 7. Height of the adjusted profile above the SWL



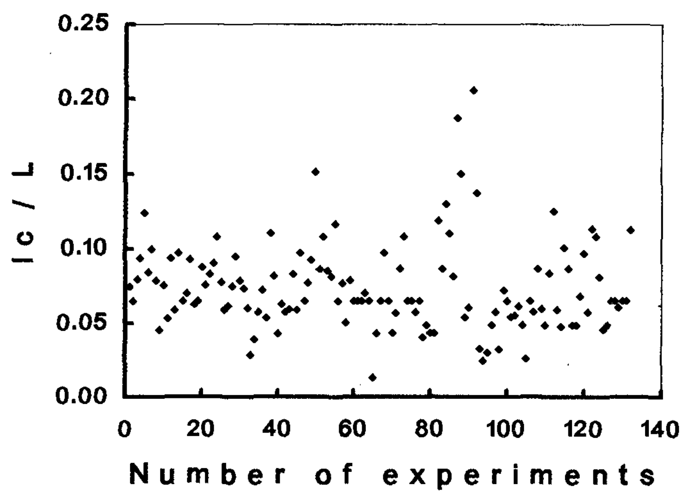


Figure 8. Length of the adjusted profile above the SWL

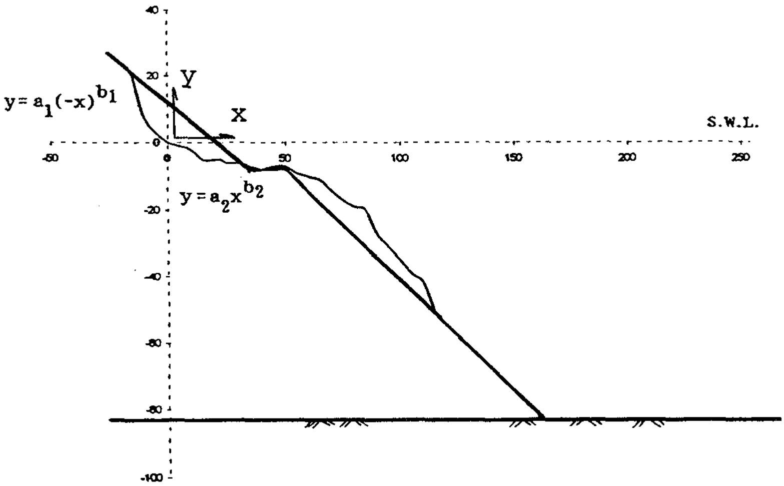


Figure 9. Final profile above and below the SWL

Researcher	b_1	b_2
Dean (1977)	-	0.67
Vellinga (1986)	-	0.78
Van der Meer (1988)	1.15	0.83
Present experiments		
(a)1:n=1:m=1.5 and 1:2,		
1:k=0 (250 exper.)	1.09	0.98
(b)1:n=1:2, 1:m=1:1.5,		1.12
1:k=0 (8 exper.)	1.00	
(c)1:n=1.5, 1:m=1:2,		
1:k=0 (21exper.)	1.13	1.03
(d)1:n=1:m=1:2,		
1:k=0 (84 exper.)	0.99	1.05
(e)1:n=1:m=1:1.5,		
1:k=0 (112 exper.)	1.02	1.10
(f)1:n=1:1.5, 1:m=1:2,		
1:k=1:5 and 1:8 (8exper.)	0.74	-

Table 2. Values of b1 and b2

The range of values of a_1 and a_2 was rather broad. No conclusion could be drawn.

The final height of the berm d_b is defined as the height above the flume bed of the center of the rectilinear part of the final sloping berm. d_b was always found to be in the order of 80% to 100% of the initial berm height d_a (see Fig.10). In many cases d_b was almost equal to d_a, which means that the final position of the berm did not change considerably in its central part.

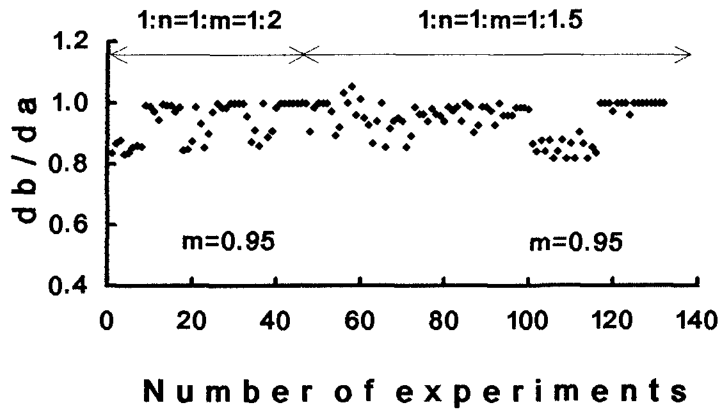


Figure 10. Final berm height

Conclusions

Some rather interesting conclusions are drawn from the results. The adjusted berm height was found to be in the order of 80% to 100% of the initial height. The height of the zone of non-significant profile adjustment was in all cases in the order of 40% to 50% of the water height.

Appendix: References

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