CHAPTER 266

DEVELOPMENT OF UNDERWATER BEACH PROFILE BY MONOCHROMATIC AND RANDOM WAVES

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ABSTRACT: Central to all problems involving alluvial coasts is the response of the underwater profile to given wave conditions. It has been demonstrated in laboratory tests that a constant wave pattern leads to an equilibrium profile. BRUUN (1954) defined this profile by a parabolic equation and various refinements have been proposed since. Applications to field data show, however, that the fit is frequently less than satisfactory. Noteworthy is also that profiles generated in the large wave flumes tend to have significantly narrower surf zones than similar sand beaches in the nature. To answer this and other questions a series of experiments were carried out in the Large Wave Flume (LWF) in Hannover.

INTRODUCTION

The Large Wave Flume in Hannover is 324 m long, 5 m wide and has a depth of 7 m and is capable of generating waves up to 2 m height. These waves are generated by an electronically controlled hydraulic system, which drives a piston-type wave board. A wave absorption device allows the minimization of wave reflections during the tests.

The main objective in the 1993 experiments was the investigation of beach profile response under erosional and accretional wave conditions. The experiments included tests with monochromatic waves and spectral waves at constant water level and spectral waves with superimposed tidal simulation with 1m tidal range.

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EXPERIMENTAL SET-UP

The initial profile geometry consisted of a dune, a 1:30 beach slope and a 70 m long toe berm (Fig. 1). A sand volume of 1.700 m^3 was necessary to build up the initial profile. The used sand had a grain diameter of D_{50} = 330 μm with a fairly narrow grading. This is representatively for the beaches along the west coast of the high energy coast of the Island of Sylt/North Sea. Data were collected on bed profile development, water levels and waves, wave energy dissipation, velocity distributions and suspended sediment distributions, only aspects relating to profile development will be discussed here.

The experiments in the Large Wave Flume can be devided into three major parts:

- In part I monochromatic waves were used to generate an equilibrium profile under erosional conditions (Test Series 0 and 2) and accretional conditions (Test Series 1), while the water level was kept constant.
- In part II (Test series 3 and 4) random waves (TMA-Spectra) were used to investigate the profile response under erosional and accretional test conditions with a constant water level.
- In part III (Test Series 5 and 6) random waves (TMA-Spectra) were run together with water level variations in order to simulate a profile development under tidal conditions. The tide had a range of 1 m with the previous constant water depth of 4.50 m representing the high water level. The 12 hours 'sinusoidal' tide is simulated as step function in 25 cm steps of 60 minutes, except high and low water phases with 90 minutes duration.

Table 1 summarizes information on wave parameters, water level, test duration and profile response for the Test Series' 0 to 6. The final profile of each single Test Series was used as initial profile for the following series.

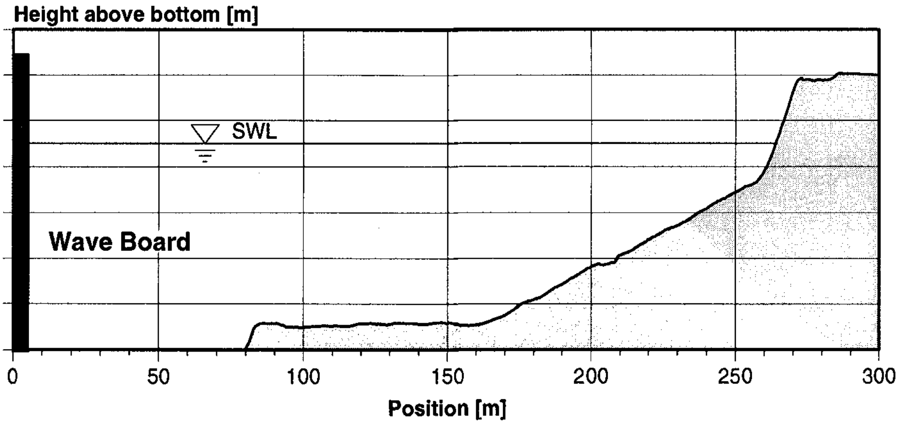


Figure 1. Initial profile built up in the Large Wave Flume in Hannover.

Table 1: Test conditions for the flume experiments 1993.

Test Series	Initial Geometry	Wave Parameters			Water Level [m]	Duration [hrs]	Profile Response
		Type	H, H_{m0} [m]	T, T_p [sec]			
0	1:30 slope	M	1.20	5	4.50	17:00	Erosion
1	result of 0	M	1.20	10	4.50	15:45	Accretion
2	result of 1	M	1.20	5	4.50	07:20	Erosion
3	result of 2	S	1.20	5	4.50	15:00	Erosion
4	result of 3	S	1.20	10	4.50	10:30	Accretion
5	result of 4	S+T	1.10	5	3.5 - 4.5	45:00	Erosion
6	result of 5	S+T	1.05	10	3.5 - 4.5	39:00	Accretion

with M - monochromatic waves with H and T
S - TMA-spectrum with H_{m0} and T_p
S+T - TMA-spectrum with water level variations (tidal simulation)

RESULTS AND DISCUSSION

Profile Shape

■ In part I monochromatic waves in Test Series 0 with a height of 1.2 m and a period of 5 sec. were used to generate an equilibrium profile under erosional conditions. The initial 1:30 beach slope and the dune (Fig. 2a) were transformed during 17 hours of erosion in Test Series 1 (Fig. 2b) into a typical bar-trough-profile, which can be characterized by the relatively steep and narrow bar and the following trough. The slope of the seaward bar face had a magnitude of 1:5. Arrows in Fig. 2 indicate the direction of the bar movement.

The final profile form in Test Series 0 was stabilized under 16 hours of accretional waves with a period of 10 sec. in the following Test Series 1 (Fig. 2c), where ripple structures were formed seaward and landward of the widened bar. The surf zone has been filled with sand so that the profile level inside the surf zone raised.

Additional 7 hours of erosional wave conditions in Test Series 2 (Fig. 2d) widened the surf zone and formed a steeper bar. The inner surf zone was raised again and rebuild like a foreshore terrace, while the ripple structures at the sea floor disappeared.

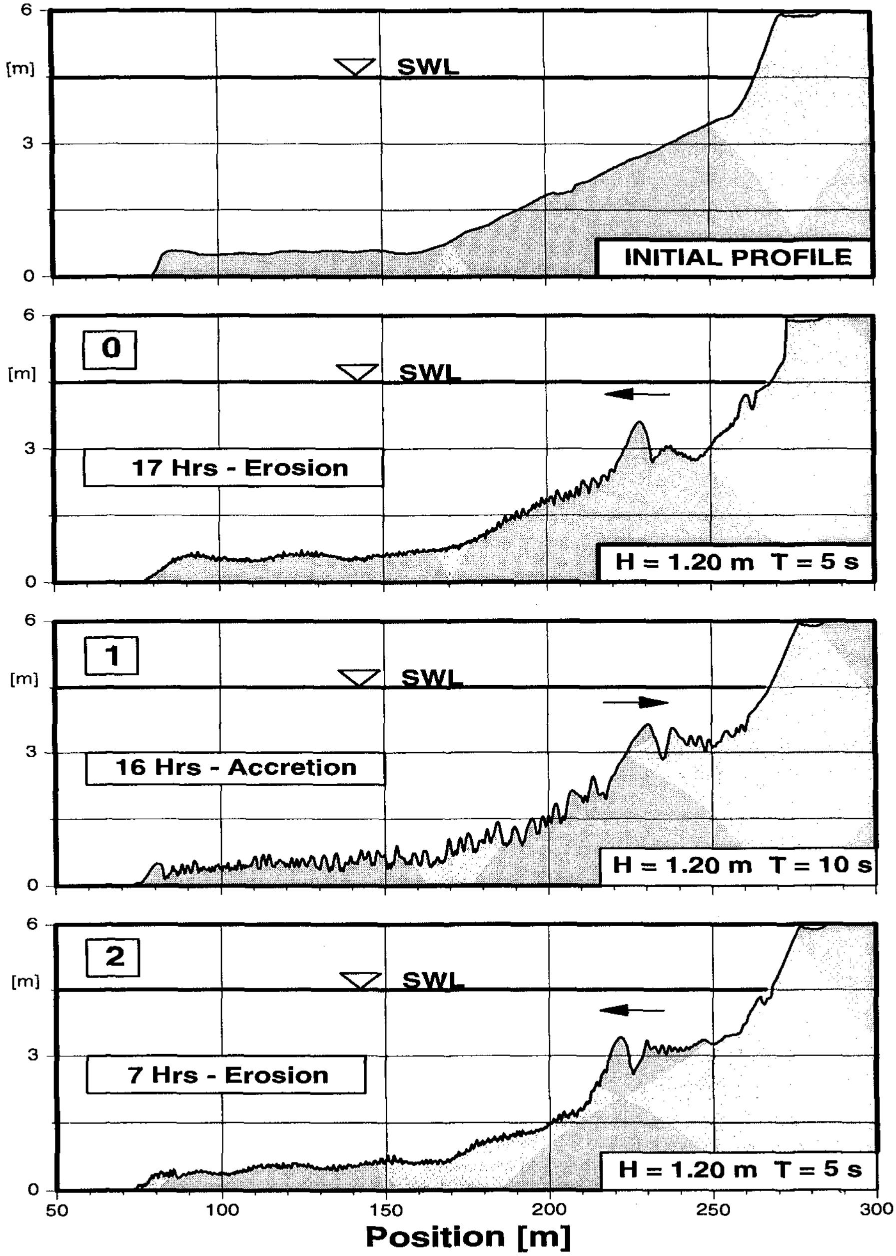


Figure 2. Initial and final beach profiles under monochromatic waves and constant water level (Test Series 0 - 2).

- In part II (Test series 3 and 4) irregular waves (TMA-Spectra) were used in order to investigate the profile response under erosional and accretional waves. In 15 hours of erosion the profile has smoothed inside and outside the surf zone and the seaward slope of the foreshore terrace has moved further offshore (Fig. 3a).

  11 hours of accretional wave conditions formed ripple structures at the profile bottom (compare with Test Series 1) and rounded the foreshore terrace (Fig. 3b). In comparison to the monochromatic case the bar is much lower and broader.

- In part III (Test Series 5 and 6) random waves (TMA-Spectra) were run together with water level variations in order to simulate the profile development under tidal conditions. Caused by different water levels and spatially moving zones of energy dissipation an equilibrium profile developed in the surf zone area. The final profile of Test Series 5 (Fig. 3c) shows how the inner surf zone has been smoothed, while the seaward front face of the surf zone moved further offshore indicated by an arrow.

  39 hours of accretional wave conditions in Test Series 6 flattened the bar profile in the surf zone area and a short terrace could develop (Fig. 3d). The wet beach remained the original shape over the whole Test Series' 5 and 6.

2D/3D Profile Development

In order to illustrate the morphological processes caused by the spectral waves and superimposed tidal simulation more in detail the single profiles of Test Series 5 have been joint together into time-dependent profile evolution diagrams. The upper diagram in Fig. 4 shows the profile evolution under erosional wave conditions over the time of 3½ tidal cycles. Two arrows indicate the starting and the final position of the bar crest. In the lower graph (Fig. 4), which shows the top view of the profile evolution, the phases after low and high water level conditions are marked.

It is significant to see in both graphs how the bar profile changed into a smoothed foreshore terrace, while the seaward face of the terrace moved in rhythmic manner further offshore. The offshore movement of the bar, which is caused by erosional wave conditions, is overlapped by the rhythmic bar movement over the tidal cycles. This morphological rhythm, which can be observed between position 200 m and 220 m in the upper diagram with the help of the contour lines, shows the profile response on the tidal simulation.

At low water level zones of energy dissipation are spatially placed further offshore, which results in a higher erosion potential because the profile in that tidal phase is not in equilibrium with the incoming waves. At high water level the zones of energy dissipation are shifted further onshore and the waves do not break at the front face of the forshore terrace as at low water levels. The front face of the foreshore terrace moves onshore, by which means the crest height of the bar is increased.

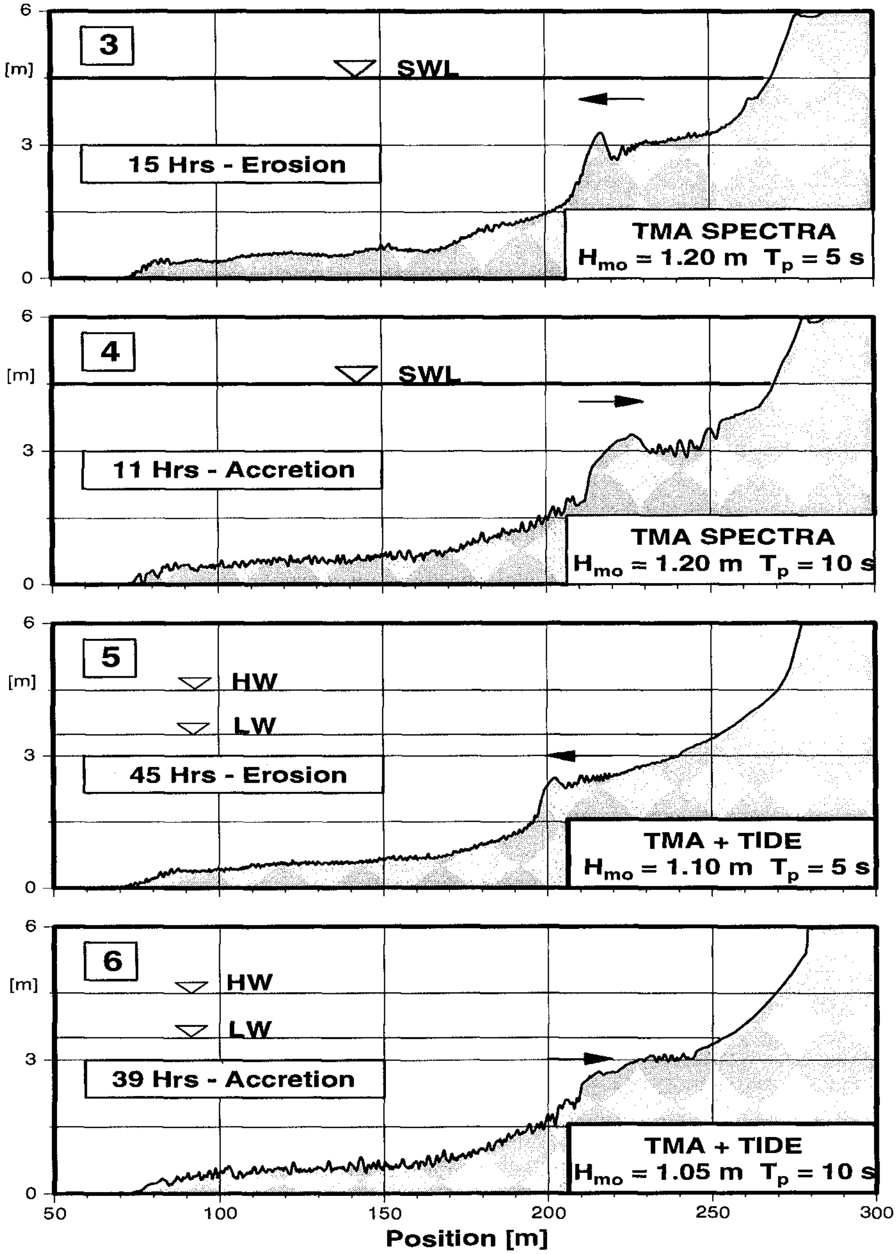


Figure 3. Initial and final beach profiles under spectral waves with constant water level (Test Series 3 and 4) and spectral waves with superimposed tidal simulation (Test Series 5 and 6)

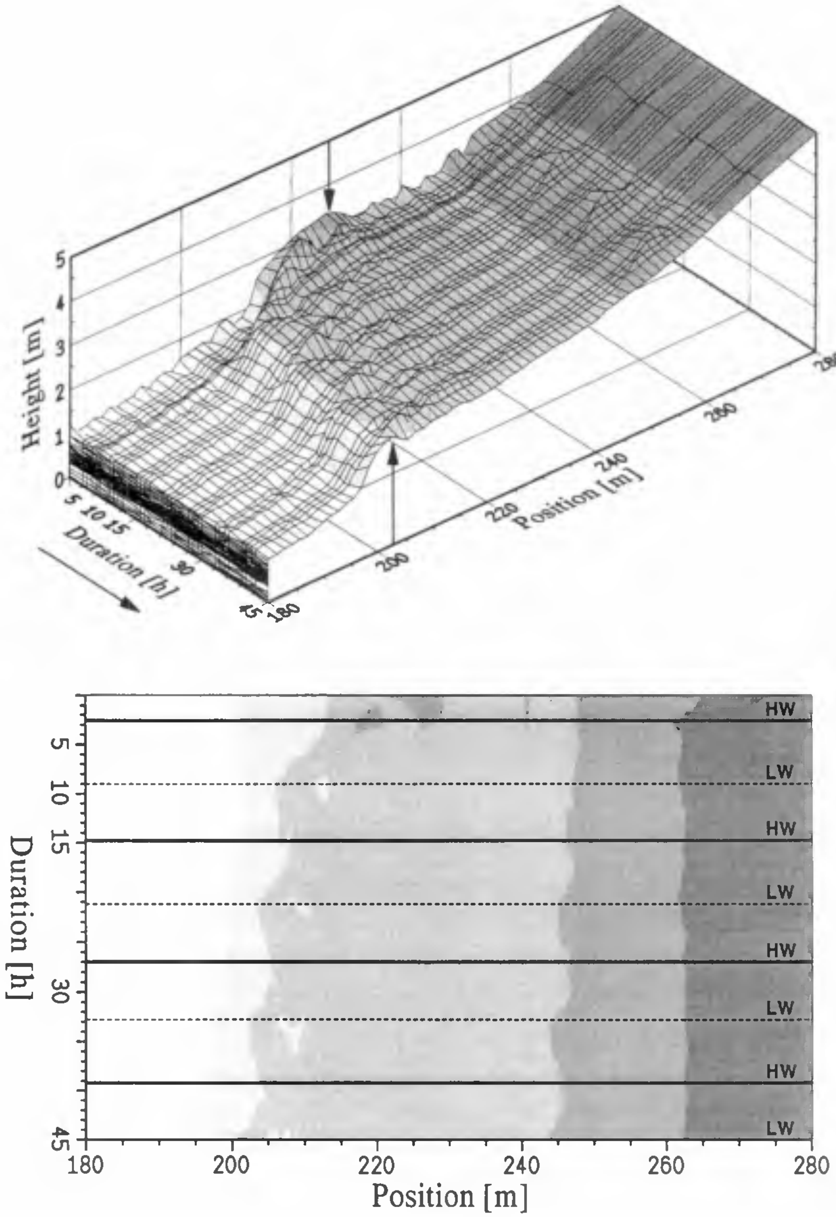


Figure 4. Profile evolution under erosional wave conditions (TMA spectra) with superimposed tide as a 3D-diagram (above) and as a top view (2D diagram below).

By tidal simulation the bar movement has been intensified. This was also observed for Test Series 6 (not illustrated here) under accretional wave conditions, where the rhythmic bar movement caused by the tide overlapped the onshore movement of the bar system.

Bar Position and Bar Height

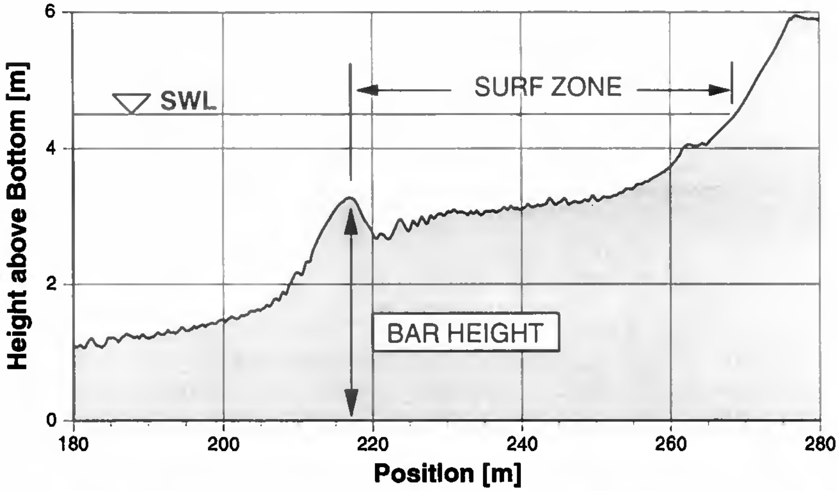
All profile data for each wave condition can be analysed as a time history over the whole test duration. In the upper graph of Fig. 5 the definitions of the bar height, the bar position and the surf zone width are shown. The bar crest in this case is defined as crest height of the seaward shore face.

In the lower graph of Fig. 5 the surf zone and the enclosed beach with the adjacent shoreline is shown as a top view and the bar height with the corressponding water level as a side view. It can be seen how the bar position at the seaward end of the surf zone developed, and how the crest height of the bar corresponds to this. Additionally the water level is indicated. For Test Series 5 and 6 the manner of tidal simulation is illustrated.

For the Test Series' 1 to 6 it can be summarized that erosional wave conditions (marked with 'E' in the graph) widen the surf zone and lower the crest of the bar, while accretional wave conditions (marked with 'A' in the graph) cause a reduction of the surf zone width and connected with an increase of the bar crest level. The superimposed tide and the tidal range intensify the bar movement, compared to the Test Series with constant water level. These two components, the bar movement at a constant water level and the tidal cycles itself, lead to a rhythmic bar movement. After 2-3 tides the morphological changes during each tide became stable, which means that the morphological changes on the profile over one tidal cycle reached already a minimum.

Ripple Structures

Accretional monochromatic waves (see Test Series 1) have caused large bed forms at the profile bottom. This is demonstrated in Fig. 3b. As a time history the plotted profiles in Fig. 6 show a considerable ripple movement seaward of the bar. Starting with the initial profile at the bottom the intermediate profiles are plotted above in temporal order. It can be seen how the bed forms grow and develop at the seafloor and how they propagate in landward direction until they reach the toe of the bar. The bed forms were not able to propagate into the surf zone, so that they stopped at the toe of the bar and increased the width of the bar. Because the bar crest remained nearly at its position the seaward slope of the bar became flatter.



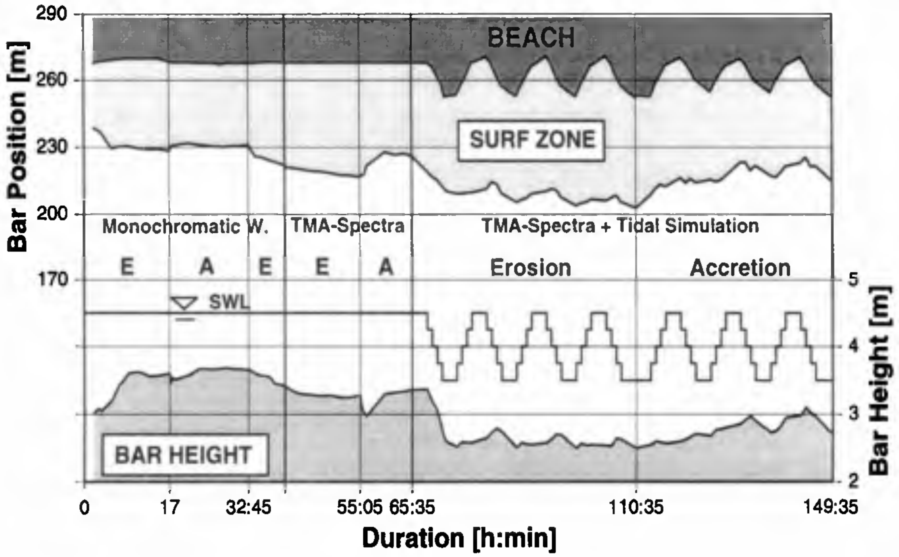


Figure 5. Definition of the surf zone (above) and position and height of bar over all Test Series' (below)

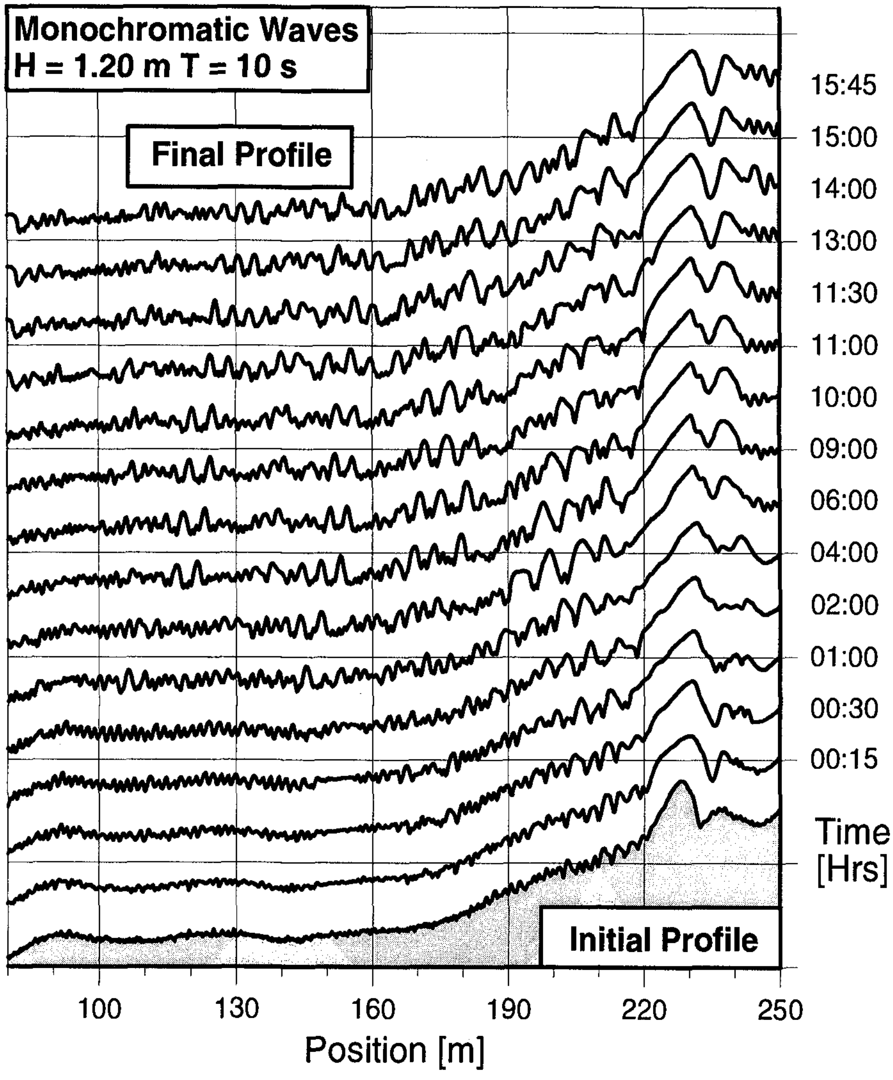


Figure 6. Development of bed forms during accretional wave conditions (Test Series 1).

CONCLUSIONS

The flume experiments in 1996 showed that beach profiles reached their equilibrium state under erosional and accretional wave conditions in small timescales. For a constant water level the profiles have been transformed into quasi-equilibrium profiles after 10 to 15 hours of test duration. In the case of a varying water level 2-3 tidal cycles were only necessary to develop a state, where the profile changes during one tidal cycle reached a minimum.

The experiments for accretional conditions were affected by a steep seaward slope, what is not naturelike. Further tests are necessary to investigate this question.

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