MOBILE-BED TESTS. THE SANDS PROJECT

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In this work the experiments done within the SANDS project are presented. This project include the bottom evolution experiments done at three different flumes (Hannover, Barcelona and Delft) working at three different scales (prototype, 1:2 and 1:6 respectively), and the development and performance study of new measurement equipment. The obtained results of "identical" experiments performed at the three flumes show that a scaling of 1:2 leads to bottom evolution results almost identical to prototype under erosive conditions. However for smaller scales, there is transport in a larger area outside the foreshore slope and thus clearer morphodynamic differences appear with respect to prototype. The results obtained under Accretive wave conditions show bigger differences between the three scaled flumes and present a limited capacity to to promote shoreline accretion.

Introduction

The Sands Project (scaling and analysis and new instrumentation for dynamic bed tests) is a research project financed by the European Commission within the I3 project HYDRALAB III. It deals with the performance of Mobile Bed Tests looking at the flume and paddle characteristics but also at the sedimentary body behaviour and the corresponding instruments deployed in the flumes or basins. The main research topics shall try to answer the questions: Are there issues such as how to design a Mobile Bed Test or how to interpret the obtained observations.

Sands has been structured in three blocks: 1° Instrumentation, 2° Performance and 3° Morphodynamics. Within the first block we look at the instruments to recover: a) bottom dynamics, b) swash zone morphodynamic fluxes, c) sediment transport within the water column and d) fluxes through the granular medium. These measurements are obtained by means of advanced state of the art gear and also by means of newly instrumentation both of optic and acoustic type, developed within the project.

This instrumentation is tested within a series of carefully designed Mobile Bed Tests which are included in the second block of the project dedicated to

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performance. For this purpose the tests have been executed at three scales trying from the very beginning to reproduce exactly the same geometric and hydraulic conditions in all cases. These tests have been carried out at the different flumes at Hannover, Barcelona and Delft. The last block of Sands deals with the interpretation of these results and therefore the associated test morphodynamics. It includes a critical review of analysis and protocols to interpret the data including the quality control and error bounds arising from those analyses. The logic structure of the project is schematized in figure 1.

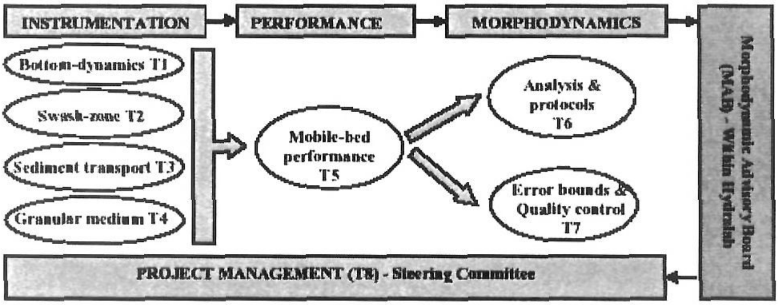


Figure 1. Schematization of relations between tasks.

Experiments and measurements.

The tests designed for analyzing the performance limits of Mobile Bed experiments were done using undistorted models and similar Froude number in the three facilities (Hugues 1993). The experiments were done in the Large Wave Channel (GWK) of the Coastal Research Centre (FZK) in Hannover, considered as prototype and with a length of 300 meters, a depth of 7 meters and a width of 5 meters. For these tests the mean diameter of the sand bed was selected as 0.28 mm. The tests in the Large Wave Flume CIEM of the Maritime Engineering Laboratory (UPC) in Barcelona, with a length of 100 meters, a depth of 5 meters and a width of 3 meters have been performed with a scale of 1:1.9 to the prototype and with a sediment median grain size of 0.25 mm. In the Scheldt flume of Deltares in Delft with a length of 50 m, a depth of 1.2 m and a width of 1 m, the tests have been performed in a scale of 1:6 related to the prototype and with a sediment grain size of 0.128 mm.

The Delft flume has performed experiments with a beach slope of 1 in 10, 1 in 15 and 1 in 20, while the flumes of Hannover and Barcelona have performed experiments of 1 in 15. This represents the normal availability of flumes for carrying out tests, in which the size plays a critical role in determining cost and therefore the number and days of experiments carried out.

The wave conditions being tested reproduce erosive (H_s 1 m and T_p of 5.7 s at prototype scale) and accretive (H_s 0.6 m and T_p of 7.5 s also at prototype scale) wave conditions. The wave time series of the three facilities have been generated by scaling down the prototype time series by Froude law scaling (scaling also the generation frequency). The time series reproduce a Jonswap spectrum (gamma 3.3). To avoid uncertainties with second order generation and absorption, which depend of the kind of paddle, the time series have been generated using 1st order approximation. Every time series has 500 waves.

First the erosive conditions were investigated and without reshaping the beach slope this were followed by the accretive wave conditions. The duration of tests for the 1:15 slope are summarized in Table 1. It should be mentioned that the duration of erosive tests for the Delft case is longer than what would correspond to a Froude scaling of the duration. This is because we decided to carry on with the tests for a "very long" comparatively time interval to analyze the corresponding profile evolution.

Table 1. Tests sequences and durations in "clock" hours (Froude-scaled).

Delft	Barcelona	Hannover
	0,49	0,7
1	1,47	2,1
	2,44	3,5
	3,42	4,9
	4,40	6,3
3	5,86	8,4
	7,33	10,5
	8,80	12,6
	10,21	14,63
	12,17	17,43
8	14,12	20,23
	17,05	24,43
	19,99	28,63
	22,92	32,83
16		
24		
48		

An illustrative sketch of the Barcelona flume layout for such experiments appears in figure 2. In these particular tests the emphasis was on swash zone processes and that is why the density of equipment is higher in that area.

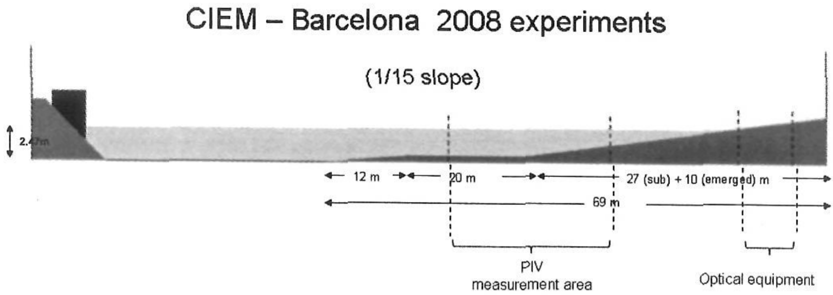


Figure 2. Flume layout for the Barcelona CIEM experiments at scale 1/1.9 related to prototype (Hannover).

Erosive conditions.

The more representative morphodynamic parameters have been evaluated for every profile from each of the 3 flumes. These parameters have included the slopes of the bar (offshore slope) and the foreshore (including also the berm or swash bar part), the horizontal position and height of the bar coast with respect to the original sloping profile, the through position and height (again with respect to the original sloping profile), the sediment balance for different areas along the profile and for the whole profile, and the sediment concentration in different vertical profiles. This has been done by means of specific processing software developed for this purpose and also checked visually for some of the profiles. This has allowed removing some of the uncertainties associated to the definition of such morphodynamic variables. The end result of these exercises is to evaluate the sediment transport and bottom evolution along the profile for the different wave conditions tested.

Using conventional Froude scaling for the time, the profile evolution in the three flumes is represented in figure 3. Figure 3 a) shows the profiles from the Barcelona (CIEM flume), the Hannover (GWK flume) and the Delft (Scheldt flume) tests after 2,1 hours of testing. This number has been selected so that there were bed profile measurements in the three flumes and they corresponded to the precise time point after scaling. It is apparent that a very similar bar is developing for the Barcelona and Hannover flumes. After 8,4 hours (figure 3 b) the main features of the Barcelona and Hannover flumes remain comparable, with the development of a secondary bar and some large scale bed forms offshore of the main bar. However the shore line position appears to be more eroded for the Hannover flume than for the Barcelona case, with the Delft results falling in between the two. Although the Delft tests correspond to a scale of one in six and therefore the distortion should be larger it is interesting to notice that there is more erosion in Hannover than in Barcelona. This could be attributed to the fact that in Hannover natural sand has been used with a granulometric distribution wider than that of Barcelona which used quarry stone sand with a very narrow granulometric distribution. This was selected explicitly so as to reduce the concentration of fine sediments in the water column (and thus facilitate optic measurements) but it resulted in a more permeable upper foreshore, which enhanced percolation and seepage which, in turn, reduces rundown and therefore erosion.

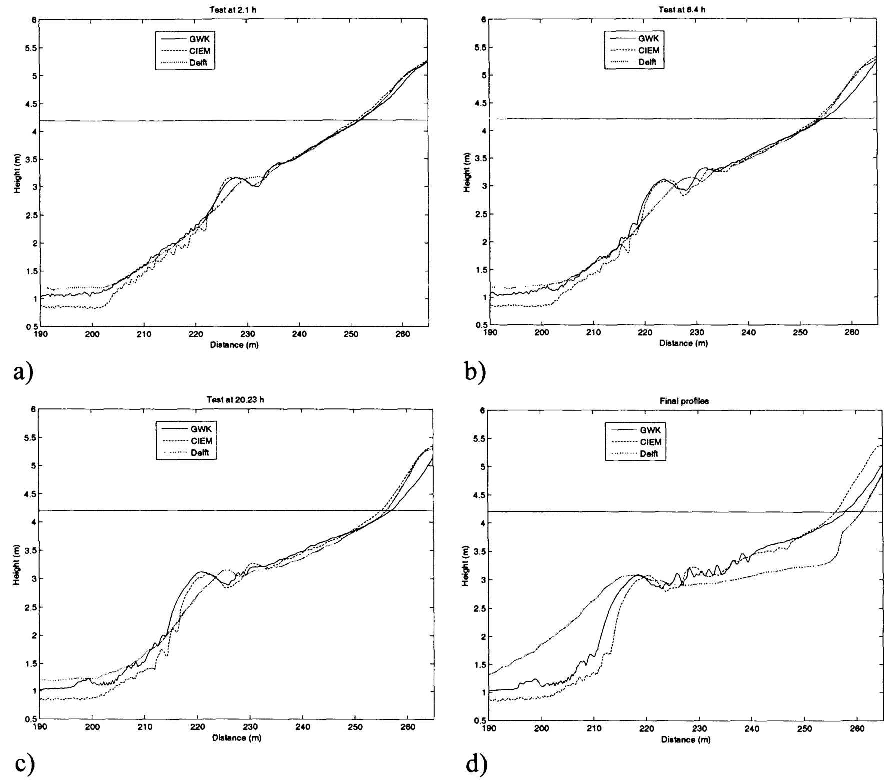
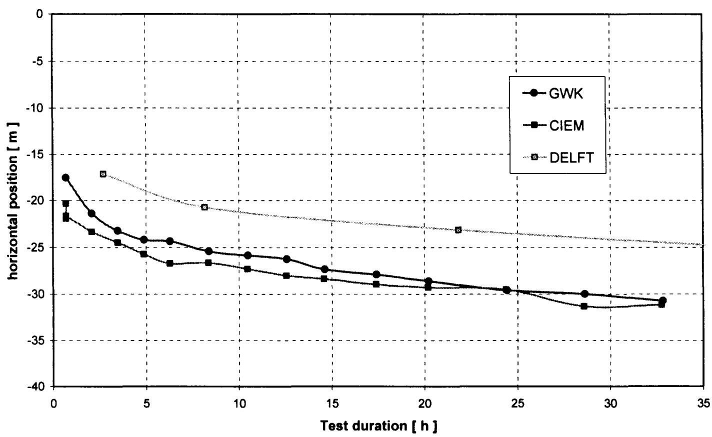


Figure 3. Bed profile evolution in the three flumes under Erosive wave conditions.

A similar development is observed at the end of the tested interval. This corresponds to 20,23 hours (figure 3 c) and it shows that the main bar is very similar for Barcelona and Hannover. The secondary bar is clearer now for the Barcelona flume and there keeps on being higher shoreline erosion for the Hannover flume than for the Barcelona one. The Delft profile shows bigger discrepancies in the bar (height and position), but has a shoreline erosion that lies in between the results of the other two flumes.

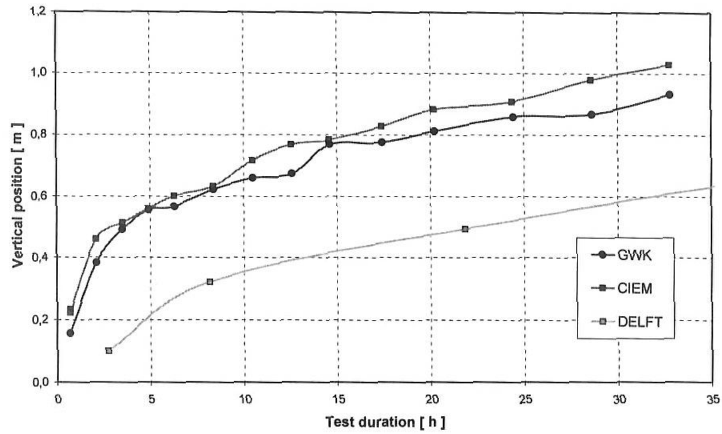
A comparison of the final obtained profiles appears in figure 3 d. This should be interpreted with care since both Hannover and Barcelona correspond to 32,8 and 32,7 hours (after time scaling) while the Delft results correspond to 131 hours after time scaling. Therefore the more mature Delft profile shows a different shape, also reflecting the fact that the sediment in Delft was much finer than that of Hannover and Barcelona and therefore suspended transport was more clearly dominant for the Delft case.

The horizontal position of the bar with respect to the original shoreline appears in figure 4 a). Here it is apparent that the Barcelona (CIEM) and Hannover (GWK) evolutions are very comparable while the Delft bar remains from the beginning closer to the original shoreline. The same behavior is observed for the bar crest vertical position with respect to the original beach profile (figure 4 b) which for the case of Barcelona and Hannover show a comparable evolution although with a slightly higher crest for Barcelona which could be attributed to a more stable uniform sediment for this case. Again here the Delft bar crest is below the other two corresponding to a smaller bar and closer to the shore, as shown in the previous figure. The volume eroded in the trough and deposited in the bar appears in figure 5 for the three flumes. The correspondence is quite close showing there was no loss of sediment towards the offshore area. Also it is apparent that the Hannover and Barcelona results are quite similar while the mobilized volume for the Delft case is smaller, as expected from the previous figures. It is also interesting to note that the volumes keep on growing with time without showing any asymptotic trend.



a)

Figure 4. Horizontal bar position (a) and Crest above the original beach profile (b).



b)

Figure 4 (*Continued*)

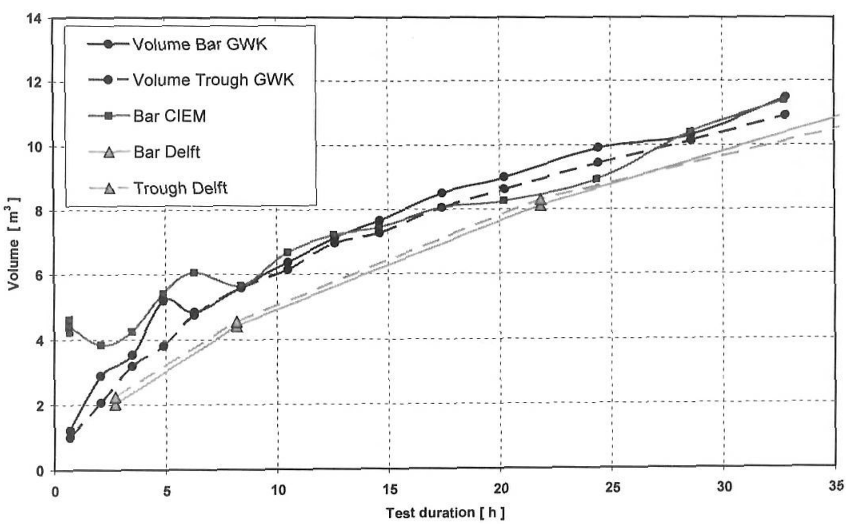


Figure 5. Bar and trough sand volume evolution along the time experiment.

Accretive conditions.

For these test sequences all flumes started from the profile obtained after the erosive waves. Therefore it should be remembered that the initial profile shape is different for the three cases (figure 6 a). After nine scaled hours the profiles (figure 6 b) show a transformation of the main bar into a considerable number of large scale bed forms which tend to migrate slowly towards the shore. The offshore bar slope however remains rather similar to what was "left" from the erosive sequence, showing a tendency to become milder with time. The shoreline position in the Barcelona flume remains in front of the shoreline in Hannover, probably due again to the different granulometric distributions in the two flumes.

After 31,75 hours the three profiles (figure 6 c) keep on showing the same overall features. The Barcelona flume shoreline remains in front of the Hannover one and the Delft shoreline is the more receded one. The profiles show also a trend to generate a large welding bar moving towards the shore. However all tests show very little shoreline recovery in the sense that the corresponding position did not show a clear accretion. This "inability" of the mobile bed tests to promote shoreline accretion remains under further analysis.

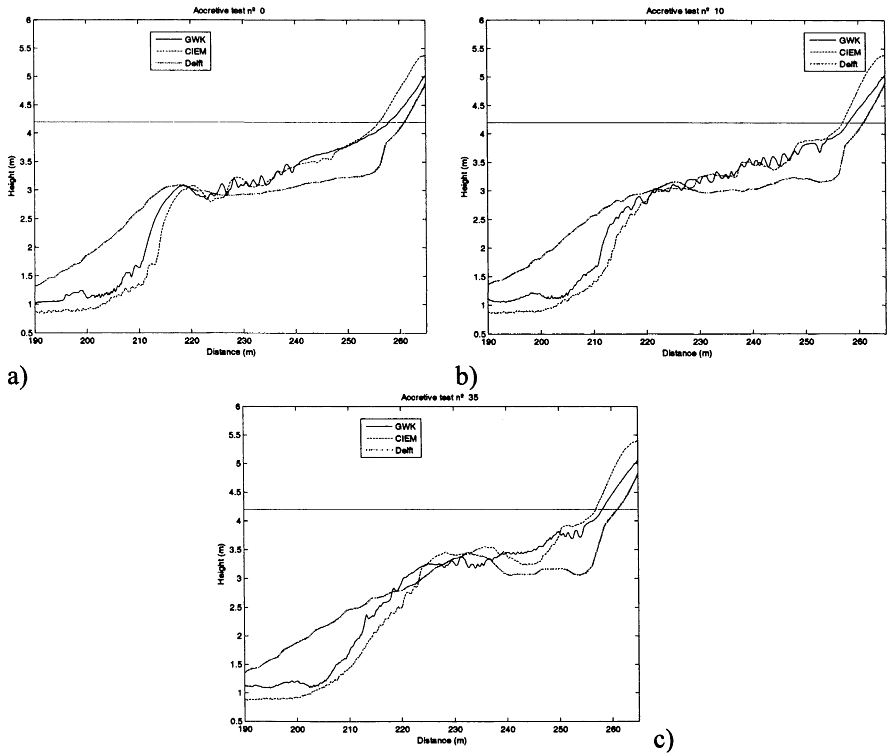
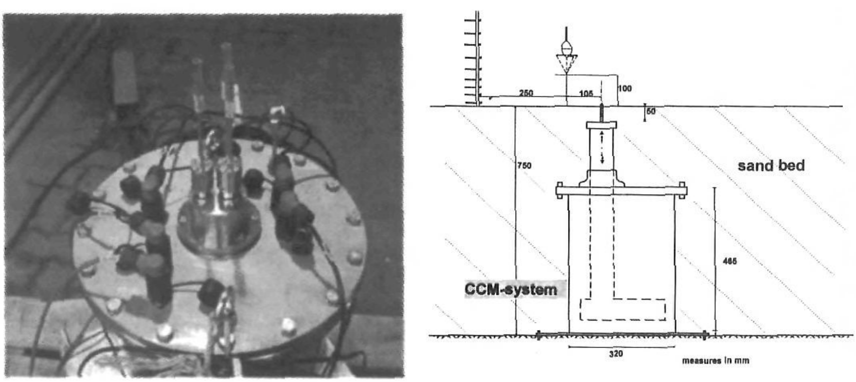


Figure 6. Bed profile evolution in the three flumes under Accretive wave conditions

Observational equipment.

The three flumes have been heavily instrumented to obtain redundant information about water motion, sediment motion and the corresponding bed evolution. The state of the art equipment has included optic and acoustic back-scatter sensors, electromagnetic current meters, acoustic doppler velocimeters and various types of wave gauges and digital video recordings.

The advanced instruments which were deployed in the three wave flumes feature a number of unique equipment being tested to asses its performance limits and to suggest protocols for best use. This includes the CCM tank equipment of the Twente University which (figure 7), consisting of a series small electro-resistance probes (CCM = Conduction Concentration Meter) for the measurement of sediment concentrations, sediment velocities in the wave boundary layer and for bed-level tracking during the wave motion. The tank is buried below the sand bed and the CCM probes are positioned from below with sub-millimeter accuracy in the granular flow near the bed surface using remote control.



a) b)

Figure 7 a) Top view of the CCM tank (University of Twente) with the three electro-resistance probes for granular flow measurements and b) schematic plot of the tank set-up in the flume.

The new optic equipment being developed can be illustrated by the advanced probe for bed shape mapping, using a non-structured light approach. This equipment, developed by the CNRS-Toulouse partner, provides an optical grid to map the 3D bed evolution with millimetre accuracy. This allows obtaining the details of, for instance, swash zone evolution and also to check any cross flume discrepancies. When applied to the Barcelona CIEM flume the differences between the two sides of the flume were below 3 centimetres, which shows the essentially 2DV character of the performed tests.

Ongoing discussion and conclusions.

The performed experimental work is a first attempt to homogenize the protocols and generate best practice criteria for mobile bed tests, covering from the initial morphodynamic test design to the deployment of instruments and the corresponding analysis of obtained data. The work is very much ongoing and it shows the difficulties in performing exactly reproducible tests at three different scales.

The tests were designed looking for geometrical scaling and using a common time series for the wave driving so as to avoid the differences in random phase generation from a prescribed spectral function. In spite of these efforts to achieve consistency the recorded water velocities and free surfaces elevations along the flume still showed some subtle differences imposed by the different flume characteristics.

Moreover, the tests showed the importance of secondary effects such as porosity which, because of the different widths in granulometric distributions of the three flumes, resulted in different up-rush/down-rush balances for the three cases. This led to different foreshore slopes, with less erosion for the more permeable cases.

The time evolution of erosive wave sequences showed an initial evolution towards an erosive profile with one, or in some cases, two main bars. However the accretive sequences took much longer than expected to start forming a "welding" bar moving towards the shore. This happened through the formation of a number of large scale bed forms, which eventually originated that onshore migration. In all cases the shoreline recovery was much less than expected and the main morphodynamic parameters featured a lack of asymptotic steadiness.

The role of the new optic and acoustic instrumentation being used in these tests is considered to be essential in interpreting all these features, particularly for defining "elusive" variables such as bed level or boundary layer characteristics.

The high quality and resolution optic data obtained, which show the cross flume and intra wave variability, should be processed and supported by powerful software packages since otherwise the benefit of such high quality information will be limited by its volume, in terms of storage and processing capabilities.

The obtained morphodynamic results show that a scaling of 1:2 leads to results almost identical to prototype under erosive conditions. This is due to a dominance of bed load in both cases (prototype and 1:2 scale model) and a relatively small distortion due to the limited scale reduction. However for smaller scales, such as one in six, there is transport in a larger area outside the foreshore slope and thus clearer morphodynamic differences appear with respect to prototype. This is due to the comparable importance of suspended and bed loads in this case.

All these issues illustrate the importance of carefully designing the tests, using different scaling laws at different zones along the profile, always considering the dominant process in each area. This may result in an along-flume distortion which may also vary from erosive to accretive sequences or far different wave types. Likewise the protocols to deploy, record and process the observed time series may vary from zone to zone depending on the dominant process in each case. This explains the limited repeatability of mobile bed tests in the present state of art.

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