HYDRODYNAMIC AND MORPHODYNAMIC VALIDATION OF CROSS-SHORE PROFILE MODEL (CROSMOR) BASED ON LARGE SCALE FLUME TESTS (LIP-TESTS)

by

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1. Introduction

The CROSMOR-model (Van Rijn, 1997, 1998), representing wave propagation, refraction, shoaling, breaking, associated sand transport and morphology in cross-shore direction based on a probabilistic approach, has been applied to simulate the hydrodynamics and the nearshore bar behaviour for three experiments in the large-scale Delta flume of Delft Hydraulics.
The CROSMOR model has been applied with updated submodels for hydrodynamics and sand transport. The update of the submodels is related to:

- the description of the wave orbital velocity using the modified Isobe method;
- the effect of bed roughness and wave breaking on sediment mixing (diffusivity);
- the representation of the high frequency oscillatory suspended transport.

The effects of the updated models on bed morphology will be evaluated.

First, a short description of the experimental conditions is given in Section 2. Next, the input data and the results of CROSMOR simulations are described in Sections 3 and 4, respectively. Conclusions and recommendations are given in Section 5.

2. Experimental conditions

Within the framework of the European Large Installations Plan (LIP) a programme of detailed measurements of hydrodynamics, sand transport and morphology along a sloping cross-shore profile has been carried out in the large-scale Deltaflume of Delft Hydraulics (Arcilla et al, 1994; Roelvink and Reniers, 1995).

The flume has a length of 230 m, a width of 5 m and a depth of 7 m. The flume has a wave generator able to generate waves with a maximum height of 2.5 m (regular waves) or a maximum significant wave height of H_s =1.5 m for irregular waves. The wave generator can minimize wave reflection against the board.

Two test series were done:

- irregular waves over cross-shore profile without dune at the shore (Test 1A, 1B and 1C),
- irregular waves over cross-shore profile with dune at shore (Test 2A, 2B, 2E and 2C).

Herein, only test series 1A, 1B and 1C are considered. The water level was constant in these tests (4.1 m above the concrete flume bottom). The intital profile of Test 1B was the end profile of Test 1A and so on.
Tests 1A and 1B represent erosive short-period storm waves; test 1C represents accretive long-period fairweather waves:

Measured parameters are:

- wave height from pressure sensors attached to the side wall of the flume (at 10 locations),
- velocity sensors at 5 elevations above the bed from measurement carriage on top the flume (used at various positions along the flume),
- bed level soundings at regular time intervals during the tests (wave generation was stopped);
- total net sand transport derived (by integration along profile) from bed level soundings at different time intervals.

3. Boundary conditions

The boundary conditions and input data are given in Tables 3.1 and 3.2.

BOUNDARY CONDITIONS AND INPUT DATA	LIP1A	LIP1B	LIP1C
Wave height $H_{m,o}$ at x=0 (m)	0.9	1.4	0.6
Peak period T_p (s)	5	5	8
Water depth at x=0 (m)	4.1	4.1	4.1
Duration of test (hrs)	10	18	12
Number wave classes	10	9	6
Number of sand fractions	1	1	1
Sand size, d_{50} and d_{90} (m)	0.0002 and 0.0004	0.0002 and 0.0004	0.0002 and 0.0004
Factor for high freq, susp. sand transport (-)	0.2	0.2	0.2
Temperature (C)	15	15	15
Salinity (promille)	0	0	0
Porosity (-)	0.4	0.4	0.4
Bed roughness $k_{s,w}$(m)	0.01 (x<140, x>160) 0.03(145<x<155 m)	0.01 (x<135, x>160) 0.03 (142<x<155 m)	0.01 (x<138, x>160) 0.03 (139<x<155m)
Bed roughness $k_{s,c}$ (m)	same	same	same
Space step (m)	1	1	1
Minimum depth (m)	0.25	0.25	0.25
Time step (s)	2400	2400	3600

Table 3.1, *Boundary conditions and input data*

The wave spectrum measured at the entrance of the flume is schematized in classes according to Table 3.2.

LIP1A			LIP1B			LIP1C		
H (m)	T (s)	p (%)	H (m)	T (s)	p (%)	H (m)	T (s)	p (%)
0.18	2	13.3	0.3	2	14	0.12	4	23
0.37	3	15	0.55	3	13	0.27	6	25
0.49	3.5	17	0.7	3.7	13	0.39	7	20
0.61	4.2	13	0.85	4	13	0.51	8	18
0.73	4.2	16	1.0	4	14	0.63	8	12
0.85	4.5	9	1.15	4	15	0.78	8	2
0.97	4.5	9	1.3	4	8			
1.10	4.5	3	1.5	5	6			
1.24	4.5	1.5	1.9	5	4			
1.36	4.5	1.2						

Table 3.2, *Schematization of measured wave spectrum*

4. Results

4.1 LIP1A-test

Computed and measured results are given in Figure 4.1, yielding:

Wave height

- computed significant wave heights ($H_{1/3}$) are within 5% to 10% of measured values ($H_{m,o}$) in all stations.

Undertow

- computed values (depth-integrated velocity below wave trough level) show good agreement with measured values (error bars indicate variations of velocity over depth);
- computed and measured values are maximum above the developing breaker bar at x=140 m.

Peak onshore and offshore high freq. orbital velocities near bed ($U_{1/3,on}$ and $U_{1/3,off}$)

- computed peak onshore orbital velocity (modified Isobe-method, see Grasmeijer and Van Rijn, 1998) is about 10% to 20% too large compared to measured values,
- computed peak offshore orbital velocity shows good agreement with measured values.

Bed level evolution

- bar development is reasonably well predicted, if the effective bed roughness is varied along the profile (larger bed roughnessof 0.03 m in the bar trough zone between x=145 and 155 m; roughness of 0.01 m outside the trough zone);
- constant bed roughness of 0.01 m does not result in sufficient bar development;
- application of the Bagnold sand transport formula and variable bed roughness does not result in sufficient bar development; the Bagnold sand transport formula yields onshore transport at all locations along the profile (bed and suspended load are both onshore directed); this will lead to unrealistic accretion of the upper profile on longer time scales; similar conclusions were given by Roelvink et al. (1995).

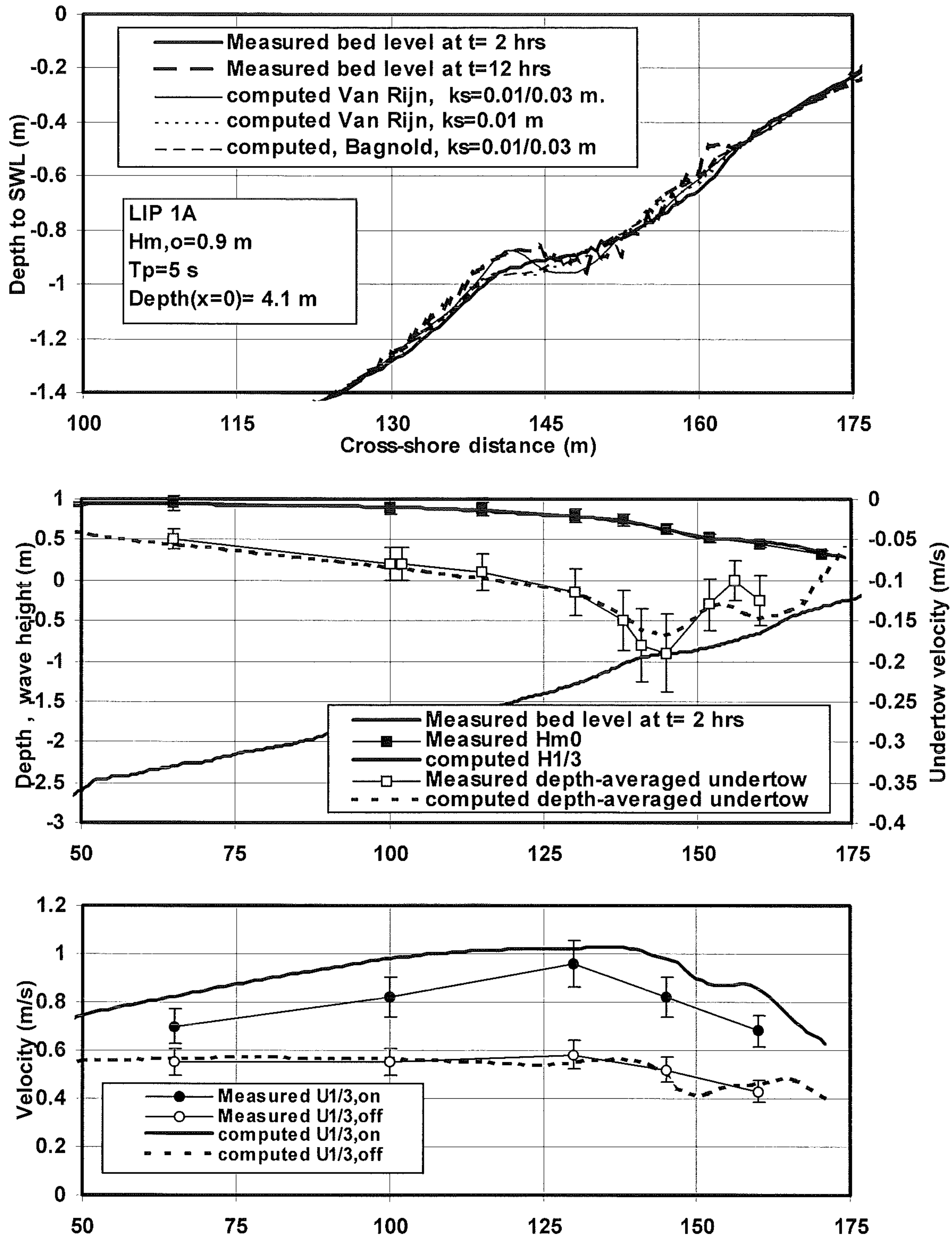

Figure 4.1 *Computed and measured results of LIP1A-test*

Top: *Bed level evolution*

Middle: *Wave height and undertow along profile*

Bottom: *Peak onshore and offshore orbital velocities (near bed)*

4.2 LIP1B-test

Computed and measured results are given in Figures 4.2 and 4.3, yielding:

Wave height
- computed significant wave heights ($H_{1/3}$) are within 5% to 10% of measured values ($H_{m,o}$) in all stations.

Undertow
- computed values (depth-integrated velocity below wave trough level) show good agreement with measured values (error bars indicate variations of velocity over depth);
- computed and measured undertow velocities are maximum above the developing breaker bar around x=135 m.

Peak onshore and offshore high freq. orbital velocities near bed ($U_{1/3,on}$ and $U_{1/3,off}$)
- computed peak onshore orbital velocity (modified Isobe-method, see Grasmeijer and Van Rijn, 1998) is about 10% to 15% too large compared to measured values, especially landward of the bar (x=135 m) where the waves are broken;
- computed peak offshore orbital velocity shows good agreement with measured values.

Sand transport
- measured sand transport has been derived by integration of the bed levels at t=0 and t=18 hours (Fig. 4.2Bottom) and thus represents the time-averaged value over the considered time interval;
- computed sand transport rates (including oscillatory high frequency suspended transport) at t=0 and t=18 hours based on variable bed roughness are shown (Fig. 4.2Bottom); the computed transport is onshore-directed just seaward of the bar and offshore-directed in the bar crest-trough zone and again onshore-directed just landward of the trough zone; the computed transport rates are of the right magnitude, but the computed transport rate distribution at the bar crest is too peaked and somewhat shifted in seaward direction at the end of the test (t=18 hours); the effect of the oscillatory high frequency suspended transport is shown in Figure 4.3Top; this effect yields onshore transport rates of about 0.03 to 0.05 kg/s/m between x=50 m and 140 m and should be included to obtain realistic transport rates in agreement with measured values; the gradients of the cross-shore transport rate are not much affected by the oscillatory suspended transport;
- computed transport according to the Bagnold formula at t=0 hrs is also shown in Fig. 4.2Bottom; the sand transport is onshore-directed at all locations and differs significantly from measured values.

Bed level evolution
- bar development is reasonably well simulated, if the effective bed roughness is varied along the profile (larger bed roughness of 0.03 m in the bar trough zone between x=142 and 155 m, roughness of 0.01 m outside this zone); the computed trough erosion is somewhat larger and is shifted somewhat more seaward compared to measured trough erosion;
- simulated bar development is not sufficient for constant bed roughness of 0.01 m (not shown);
- simulated bar development is slightly more seaward, if oscillatory high frequency suspended transport is neglected (Fig. 4.3Bottom); the effect of the oscillatory suspended transport on the short term bed evolution is not very substantial, because the transport gradients are not very much affected by this transport component; the effect on long term bed evolution will however be more significant because the absolute value of the incoming transport (at x=0) is modified by including the oscillatory suspended transport (additional onshore transport component);

- application of the Bagnold sand transport formula and variable bed roughness does not result in sufficient bar development, because this formula does not give offshore-directed sand transport.

Figure 4.2	*Computed and measured results of LIP1B-test*	
	Top:	*Bed level evolution*
	Middle 1:	*Wave height and undertow along profile*
	Middle 2:	*Peak onshore and offshore orbital velocities (near bed)*
	Bottom:	*Sand transport along profile*

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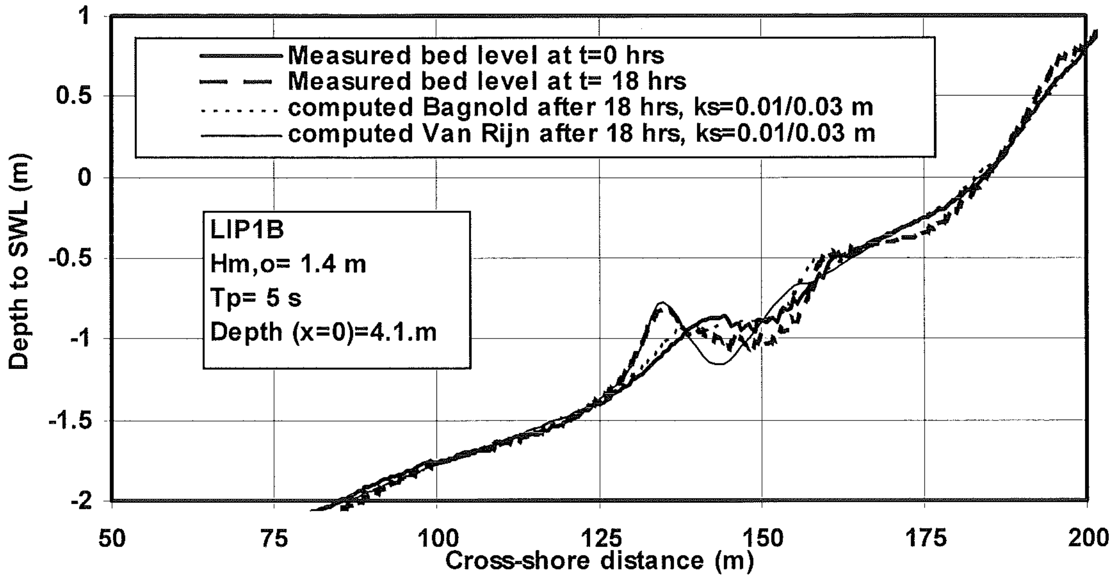
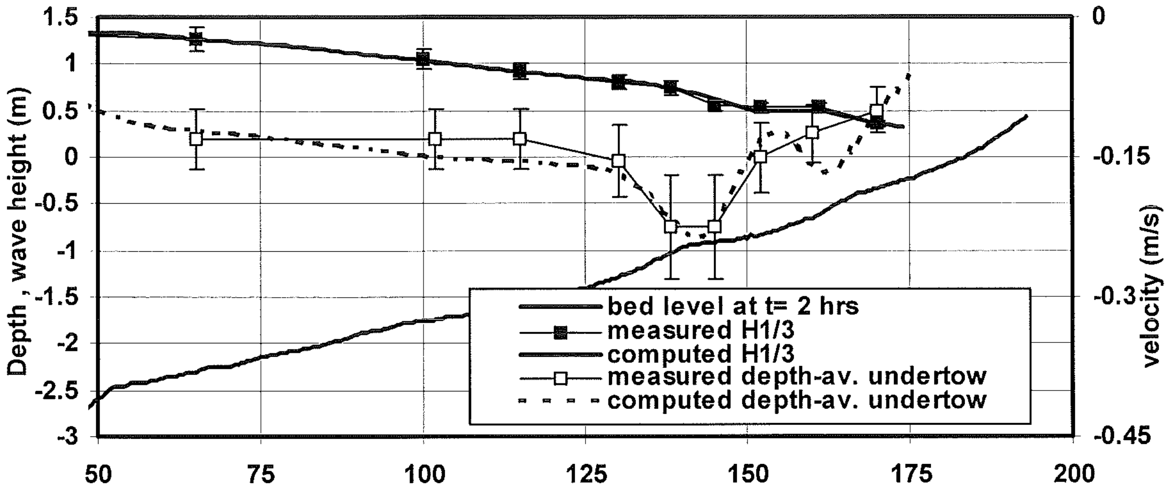
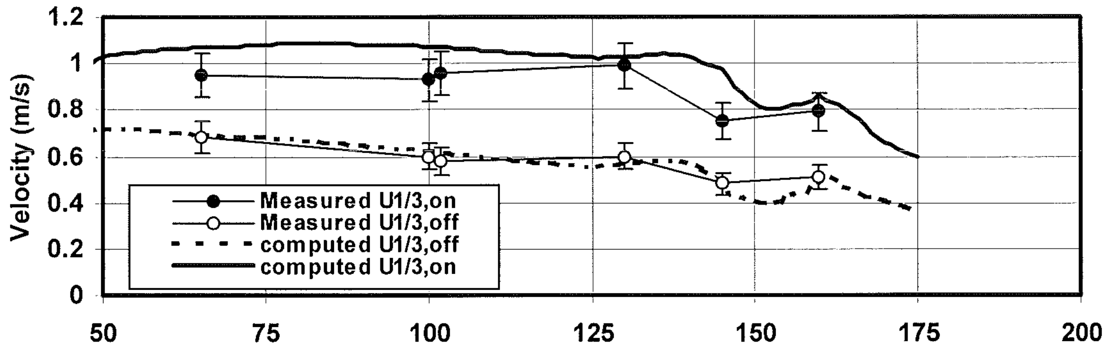
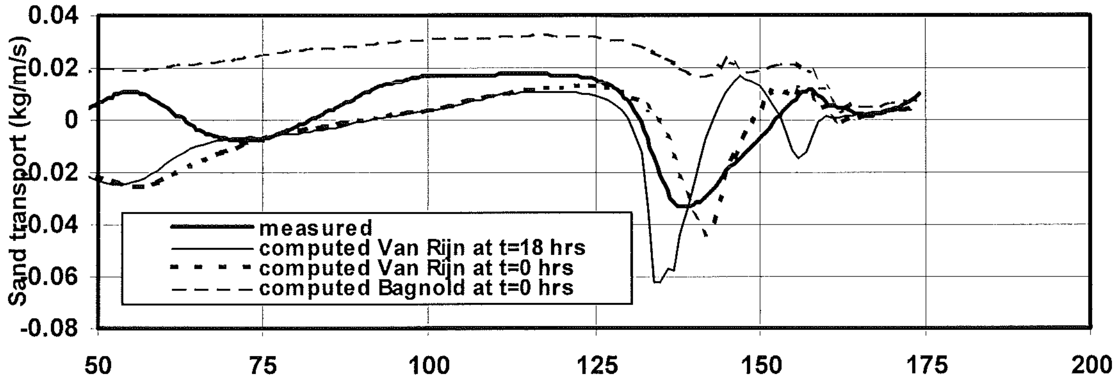
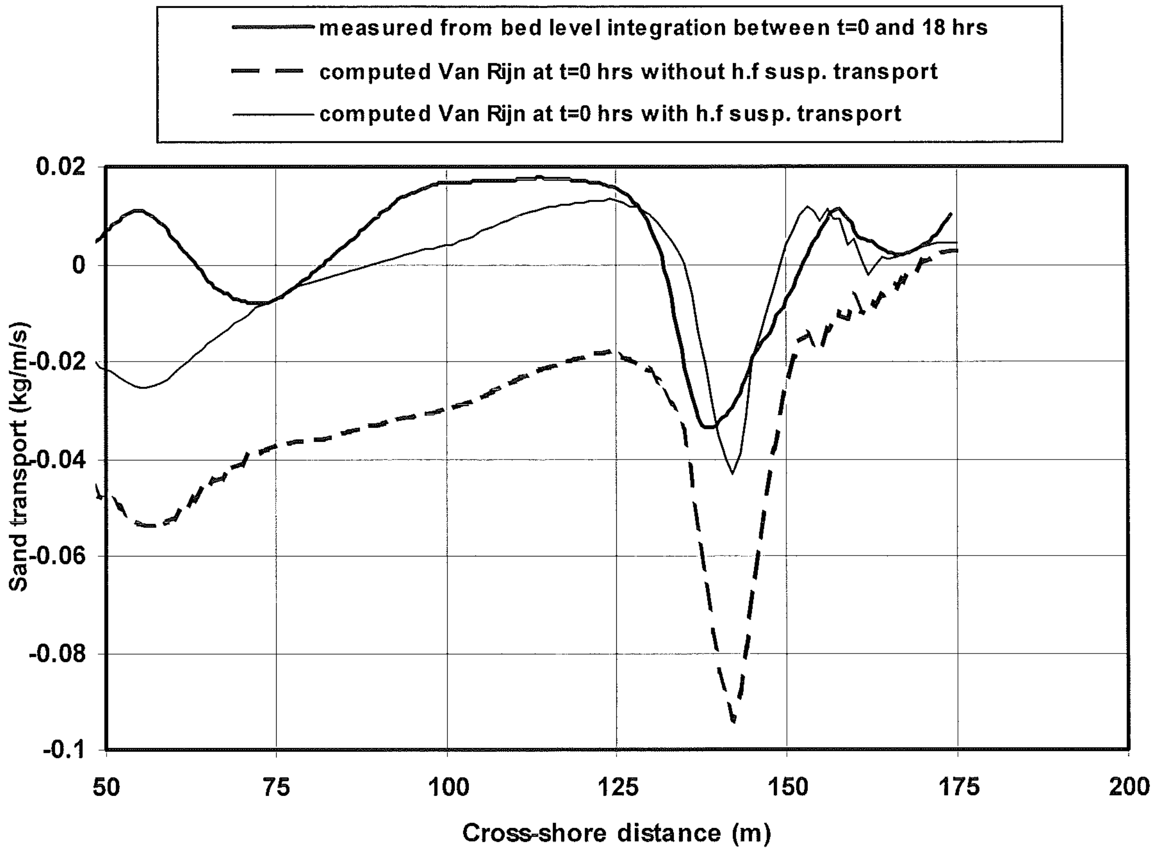

Measured bed level at t=0 hrs
Measured bed level at t= 18 hrs
computed Bagnold after 18 hrs, ks=0.01/0.03 m
computed Van Rijn after 18 hrs, ks=0.01/0.03 m
LIP1B
Hm,o= 1.4 m
Tp= 5 s
Depth (x=0)=4.1.m
Depth to SWL (m)
Cross-shore distance (m)
1
0.5
0
-0.5
-1
-1.5
-2
50
75
100
125
150
175
200


bed level at t= 2 hrs
measured H1/3
computed H1/3
measured depth-av. undertow
computed depth-av. undertow
Depth , wave height (m)
velocity (m/s)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
-0.15
-0.3
-0.45
50
75
100
125
150
175
200


Measured U1/3,on
Measured U1/3,off
computed U1/3,off
computed U1/3,on
Velocity (m/s)
1.2
1
0.8
0.6
0.4
0.2
0
50
75
100
125
150
175
200


measured
computed Van Rijn at t=18 hrs
computed Van Rijn at t=0 hrs
computed Bagnold at t=0 hrs
Sand transport (kg/m/s)
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
50
75
100
125
150
175
200



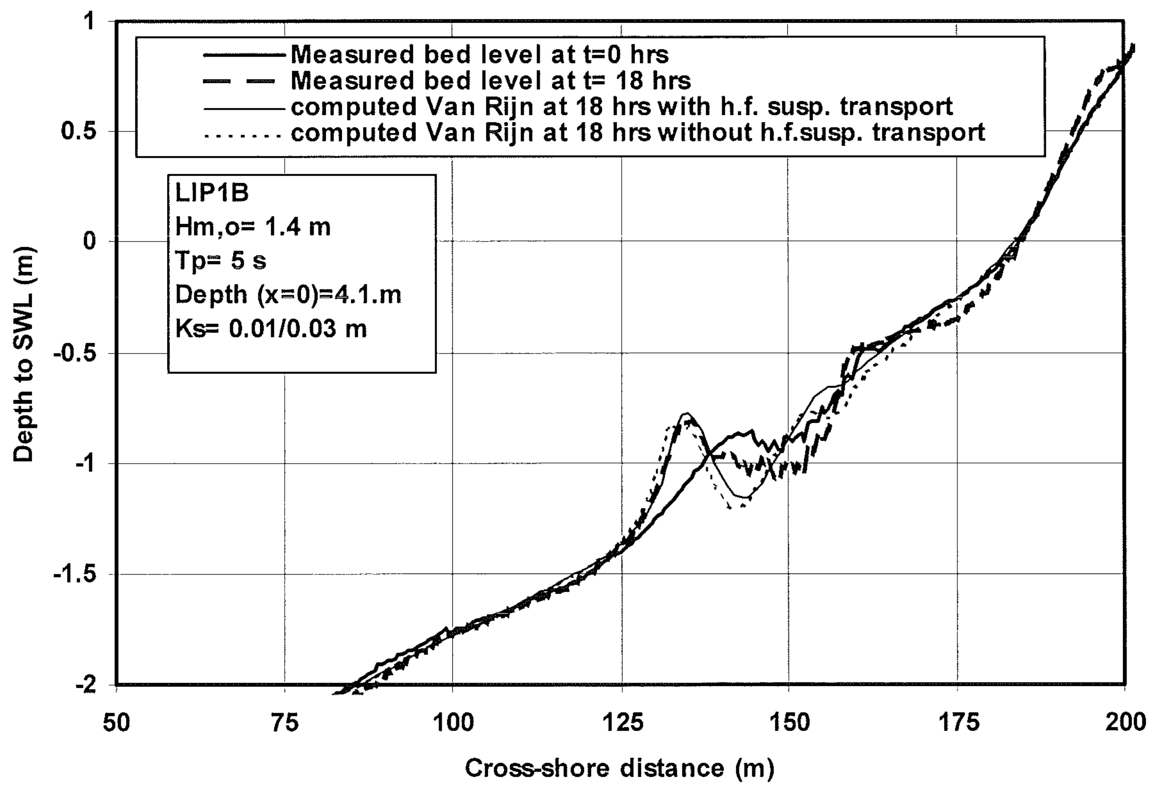


Figure 4.3 *Computed and measured results of LIP1B-test*
Top: Sand transport along profile with and without oscillatory susp. tr.
Bottom: Bed level evolution with and without oscillatory suspended transport

4.3 LIP1C-test

Computed and measured results are given in Figures 4.4 and 4.5, yielding:

Wave height

- computed significant wave heights ($H_{1/3}$) are somewhat too large in the shoaling zone (5% to 10%).

Undertow

- computed values (depth-integrated velocity below wave trough level) show good agreement with measured values in trough zone, but computed values are too large (factor 2) seaward of the bar.

Peak onshore and offshore high freq. orbital velocities near bed ($U_{1/3,on}$ and $U_{1/3,off}$)

- computed peak onshore orbital velocity (modified Isobe-method, see Grasmeijer and Van Rijn, 1998) is about 10% to 15% too large compared to measured values, especially landward of the bar (x=145 m) where the waves are broken;
- computed peak offshore orbital velocity are substantially too large (30%) in the bar crest zone.

Sand transport

- measured sand transport has been derived by integration of the bed levels at t=0 and t=13 hours and thus represents the time-averaged value over the considered time interval;
- computed sand transport rates at t=0 and t=13 hours (based on variable bed roughness) are shown; the onshore-directed transport rates are quite well represented seaward of the bar crest; at the bar crest the sand transport is much too small, which may be caused by the overestimation of the offshore orbital velocity by the model; another cause may be the overestimation of the undertow by the model just seaward of the bar; the offshore-directed sand transport just landward of the bar crest is reasonably well represented; the effect of the oscillatory high frequency suspended transport is shown in Figure 4.5Top; this effect yields a maximum difference of about 0.02 kg/s/m (onshore directed) at about x=140 m and should be included to obtain more realistic transport rates;
- the transport according to the Bagnold formula is also shown in Fig. 4.4Bottom; the transport gradients are not large enough to give sufficient bar development (not shown).

Bed level evolution

- bar growth can only be computed by introducing a sudden change of bed roughness from $k_{s,w}$=0.01 to 0.05 m over a distance of about 1 m to simulate the generation of ripples landward of the bar crest;
- computed bar development is much too small compared to the measured bar development;
- increase (20%) of the onshore peak orbital velocity at all locations along the profile did not result in sufficient bar growth (see Fig. 4.4Top);
- comparison of computed and measured transport rates shows that the peak of the transport distribution is not represented by the model; this can only be improved by a local (at the bar crest) increase of the onshore orbital velocity or by a local decrease of the offshore orbital velocity; the measured and computed data suggest that the offshore orbital velocities are overestimated by the model (Fig. 4.4);
- simulated bar height is slightly better, if the oscillatory high frequency suspended transport is neglected (Fig. 4.5Bottom); the transport gradient at the bar is larger without the effect of the oscillatory suspended transport resulting in a slightly larger bar height; the computed trough is slightly deeper; the seaward bar flank is shifted slightly more seaward;
- simulated bar development is almost perfect if the high frequency suspended transport is taken into account and the onshore-directed orbital velocity near the bed is increased with 20% along that part

of the profile where the slope is larger than 0.04 (1 to 25); based on this it is recommended to better study the effect of bar slope on the near bed orbital velocities (non linear shoaling).

Figure 4.4 *Computed and measured results of LIP1C-test*
Top: *Bed level evolution*
Middle 1: *Wave height and undertow along profile*
Middle 2: *Peak onshore and offshore orbital velocities (near bed)*
Bottom: *Sand transport along profile*

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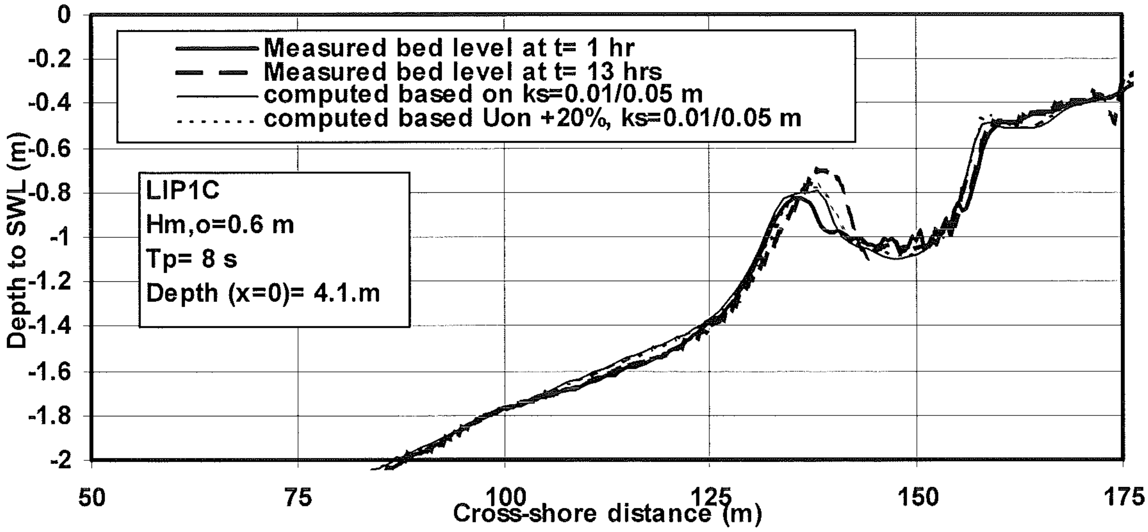
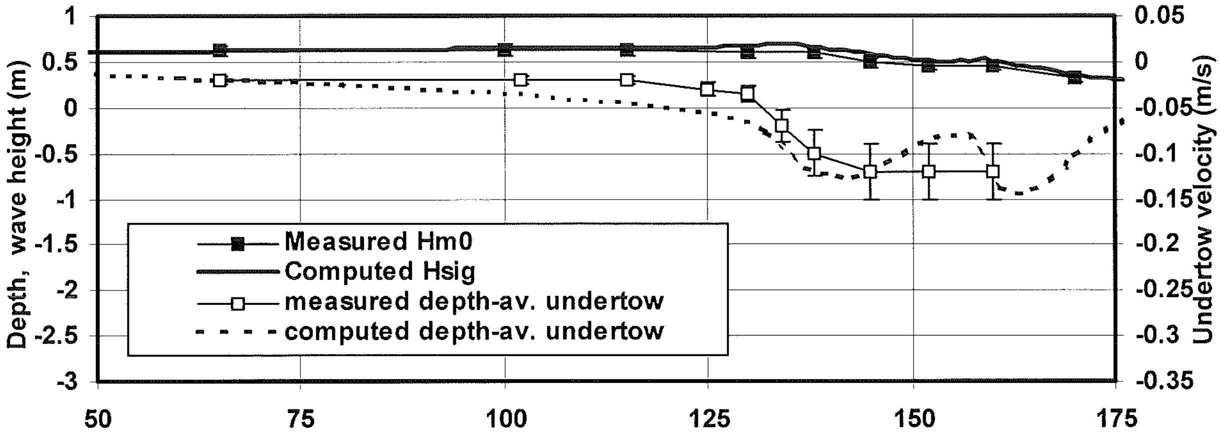
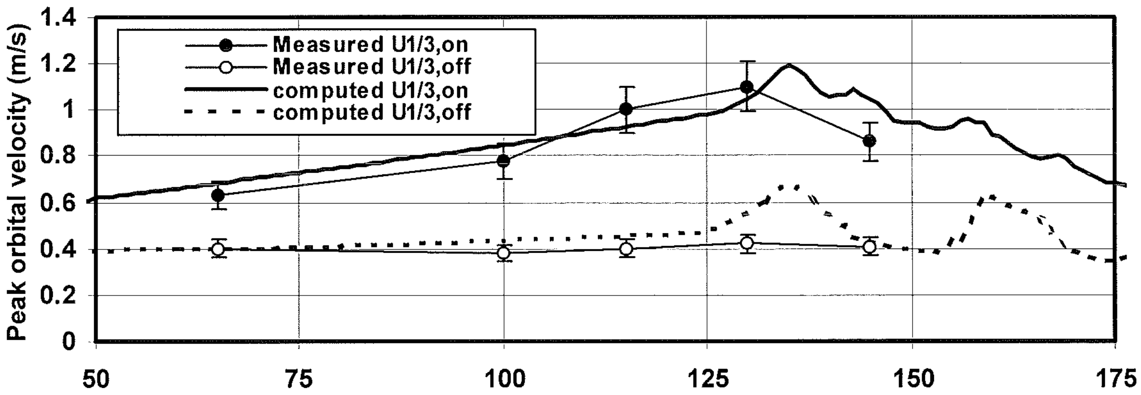
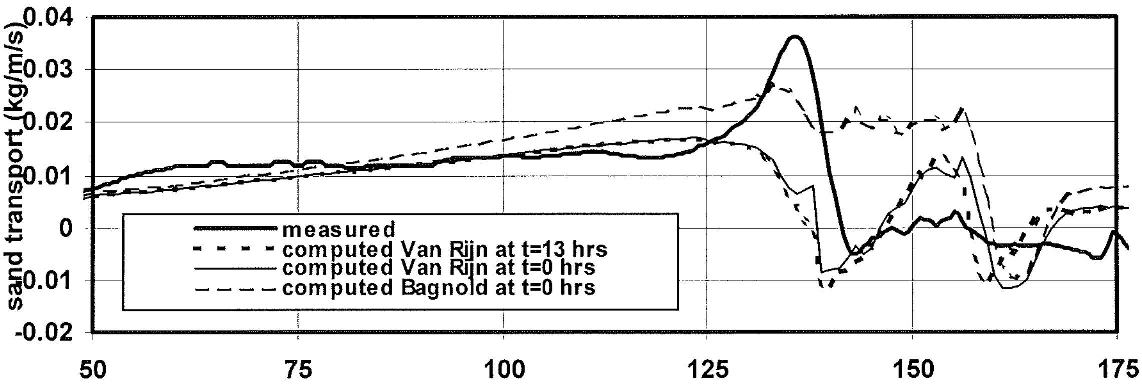

Measured bed level at t= 1 hr
Measured bed level at t= 13 hrs
computed based on ks=0.01/0.05 m
computed based Uon +20%, ks=0.01/0.05 m
LIP1C
Hm,o=0.6 m
Tp= 8 s
Depth (x=0)= 4.1.m
Depth to SWL (m)
Cross-shore distance (m)


Measured Hm0
Computed Hsig
measured depth-av. undertow
computed depth-av. undertow
Depth, wave height (m)
Undertow velocity (m/s)


Measured U1/3,on
Measured U1/3,off
computed U1/3,on
computed U1/3,off
Peak orbital velocity (m/s)


measured
computed Van Rijn at t=13 hrs
computed Van Rijn at t=0 hrs
computed Bagnold at t=0 hrs
sand transport (kg/m/s)

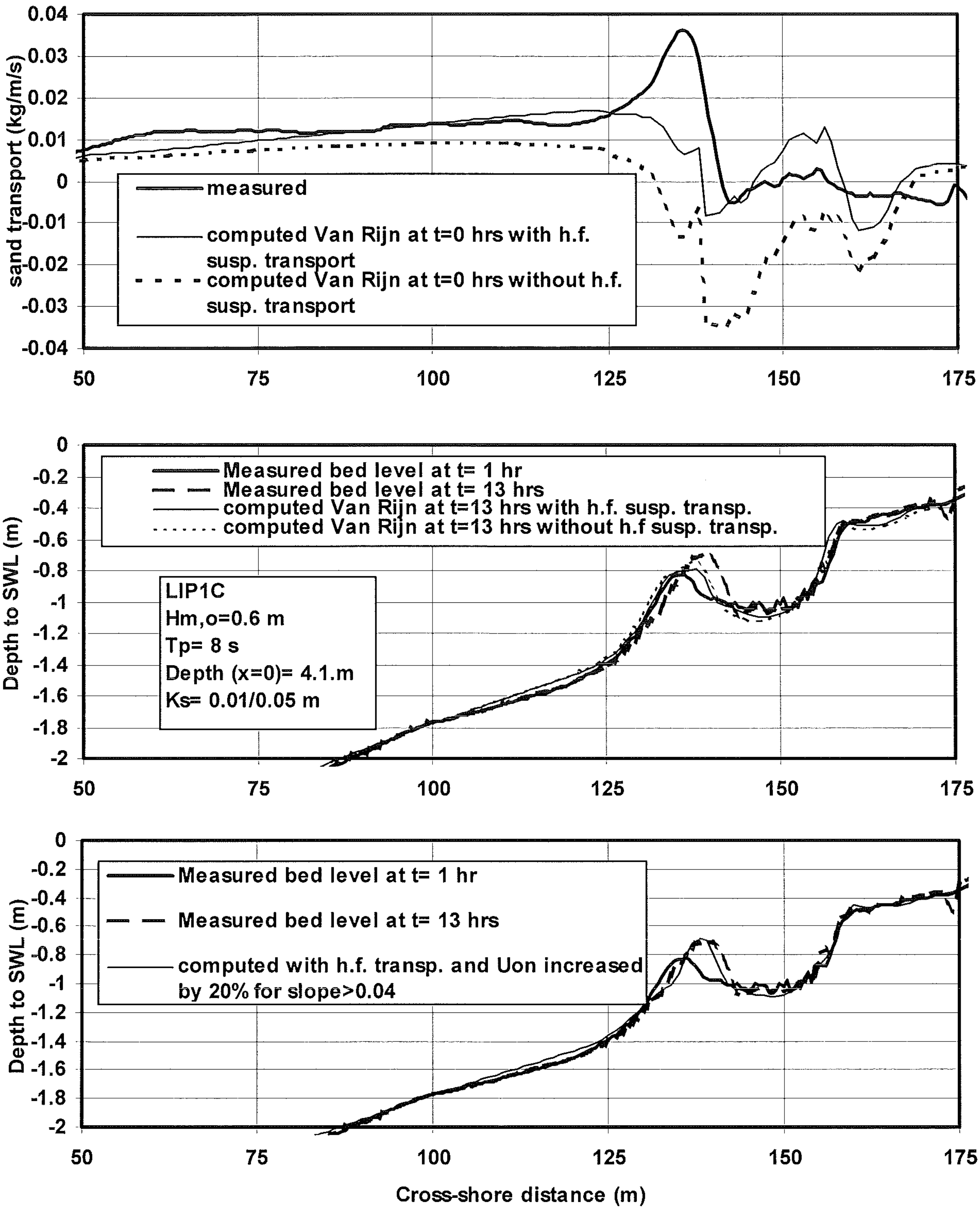


Figure 4.5 *Computed and measured results of LIP1C-test*

Top: *Sand transport along profile with and without oscillatory susp. tr.*
Middle: *Bed level evolution with and without oscillatory susp. transport*
Bottom: *Bed level evolution with oscillatory susp. transport and increased onshore orbital velocity if local slope is larger than 0.04*

5. Conclusions and recommendations

5.1 Conclusions

The following conclusions are given for tests 1A and 1B (erosive short-period storm waves) and test 1C (accretive long-period fairweather waves):

Wave height
- simulation of wave height is almost perfect for tests 1A and 1B; the shoaling wave height in test 1C is slightly too large;

Undertow
- simulation of the undertow shows reasonable results (within 30% error) for test 1A and 1B;
- computed values in test 1C show good agreement with measured values in the trough zone, but computed values are too large (factor 2) seaward of the bar;

Peak orbital velocity
- computed onshore-directed values are systematically too large (about 10% to 20%) in test 1A and 1B, especially just landward of the bar crest where the waves are broken;
- computed peak offshore orbital velocity are in good agreement with measured values in test 1A and 1B, but substantially too large (30%) in the bar crest zone of test 1C;

Sand transport
- in test 1B the computed transport rate based on variable bed roughness is onshore-directed just seaward of the bar and offshore-directed in the bar crest-trough zone and again onshore-directed just landward of the trough zone; the computed transport rates are of the right magnitude, but the computed transport rate distribution at the bar crest is too peaked and somewhat shifted in seaward direction at the end of the test; the computed sand transport is less realistic if the effect of the oscillatory suspended transport component is neglected;
- in test 1C the onshore-directed transport rates based on variable bed roughness are quite well represented seaward of the bar crest; at the bar crest the sand transport is much too small; the offshore-directed sand transport just landward of the bar crest is reasonably well represented;
  the computed sand transport is less realistic if the effect of the oscillatory suspended transport component is neglected;
  the computed sand transport can be improved substantially by increasing the local onshore-directed near-bed orbital velocities with 20% (local slope larger than 0.04) based on results of sensitivity computation;
- the Bagnold sand transport formula yields onshore-directed transport rates at all locations and the computed transport rates differ significantly from measured values.

Bed evolution
- realistic simulation of bar development in all three tests requires the simulation of variable bed roughness along the profile; pronounced ripples are present in the trough of the bar and the effective roughness of these ripples should be taken into account by using a larger roughness value in the bar trough zone;
- the effect of the oscillatory suspended transport on the short term bed evolution is not very substantial, because the transport gradients are not very much affected by this transport component; the effect on long term bed evolution will however be more significant because the absolute value

of the incoming transport (at x=0) is modified by including the oscillatory suspended transport (additional onshore transport component);
- the simulated bar development is almost perfect if the onshore-directed near-bed orbital velocity is increased with 20% at that part of the profile where the local slope is larger than 0.04 (1 to 25); this results in a local increase of the asymmetry-related bed and suspended transport;
- application of the Bagnold sand transport formula does not result in sufficient bar development, because the offshore-directed sand transport component is not accurately modelled.

5.2 Recommendations

The following recommendations are given:
- the modified Isobe-method is relatively simple and works reasonably well; the onshore orbital velocities are about 10% to 20% too large for storm waves; the offshore orbital velocities are about 30% too large (at the bar crest) for long-period fairweather waves; the effect of wave period and bed slope on the orbital velocity should be better studied;
- the bed form dimensions and associated bed roughness are variable along the profile (relatively large values in trough zone); these effects should be better modelled, because they are of crucial importance for bar development;
- measurements of the high frequency oscillatory suspended transport rates are required to better evaluate this transport component; it is of crucial importance for long term profile development.

6. References

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