HYDRODYNAMIC AND MORPHODYNAMIC BEHAVIOUR OF THE STRAIGHT COAST OF EGMOND ON THE TIME SCALE OF A STORM MONTH

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1. INTRODUCTION.

Field measurements of hydrodynamic and morphodynamic parameters have been carried out in the tidal surf zone of Egmond beach (The Netherlands) during the periods April-May 1998 (Egmond-Pilot campaign) and October-November 1998 (Egmond-Main campaign) within the European COAST3D project. Herein, the most important results are summarised (see also Van Rijn, 2000).

2. WATER LEVELS AND WAVES

The water level setup values depend on the offshore wind and wave conditions (magnitude and directions) and the duration of these conditions. Approximate values for the water level setup during the main experiment are: η_{setup}= 1.5 m for $H_{s,o}$= 5 m; η_{setup}= 1.0 m for $H_{s,o}$= 3.5 m and η_{setup}= 0.5 m for $H_{s,o}$= 2 m.

During major storm events the nearshore significant wave height (at crest of inner bar; crest level at about -1.5 m) is about 50% of the offshore significant wave height due to refraction, bottom friction and wave breaking.

The maximum relative wave heights H_s/h values vary between 0.4 and 0.8 for local wave steepness values (H_s/L) in range 0.02 to 0.05. The maximum of H_s/h is about 0.8 at the crest zone of the outer and inner bars and is almost independent of the tide level. The values of H_s/h in the landward trough zone of the inner bar do not become larger than about 0.4 to 0.5. Generally, the offshore wave height ($H_{s,o}$) has to be larger than 3 m to produce the maximum H_s/h value on the outer bar and $H_{s,o}$ has to be larger than about 1.5 m for the inner bar.

Low frequency waves are relatively small; the maximum value of $H_{s,l.f.}/h$ on the outer and inner bars is about 0.1 for minor storms ($H_{s,offshore}$<2 m) and about 0.15 for major storms ($H_{s,offshore}$>2 m).

The asymmetry of the significant value of the peak orbital velocity (defined by $U_{s,on}/U_{s,off}$ with $U_{s,on}$= significant value of onshore peak orbital velocity), which is important for the onshore-directed sand transport, is maximum about 1.35 at the outer bar crest for H_s/h=0.7. The asymmetry increases markedly in onshore direction and is maximum 1.5 around the crest of the inner bar for a relative wave height of about 0.3. Larger breaking waves in shallow water (H_s/h>0.3) do not produce larger asymmetry values. This means that onshore transport of sand is maximum under shoaling waves during minor storm events and fair weather conditions. These are the most favourable conditions for onshore sand transport.

3. LONGSHORE CURRENTS

The nearshore current velocity field is strongly affected by tide, wind and wave-driven processes.

The maximum **tidal** longshore current-velocities near the bed in the surf zone vary in the range 0.3 to 0.5 m/s. These values occur during calm weather conditions with significant offshore wave heights up to about 1 m. Storms from the southwest strongly enhance the flood currents to the north, but reduce the ebb currents to the south.

The longshore velocity shows maximum values up to about 2 m/s on the seaward flank of the outer breaker bar during a major storm event with wind velocities of about 20 m/s from southwest. The maximum values in the crest zone of the inner bar are about 1.3 m/s under these conditions.

The longshore current velocities (average value over 10 minutes) in the surf zone show low-frequency oscillations on the time scale of minutes (infragravity time scale), which can be considered as a meandering behaviour of the longshore current. These oscillations range between 25% (in surf zone) up to 50% (in beach zone) of the mean current velocities.

The tidal flood current in deeper water (offshore) is strongly enhanced (up to factor 2) by wind-induced forces up to a velocity of about 1.3 m/s for a wind velocity of about 20 m/s from southwest.

4. CROSS-SHORE CURRENTS

The cross-shore velocities (average value over 10 minutes) at the inner bar strongly depend on the local wave height, local mean water depth, tide level and the presence (position) of a rip channel (depression) in the bar crest.

The largest cross-shore current velocities (up to -0.65 m/s offshore-directed) have been measured on the seaward flank of the outer bar during storm conditions with an offshore significant wave height of about 4.5 m (storm waves from southwest with angle of 20 to 30 degrees to shore normal). Similar values have been measured at the crest of the inner bar inside a rip channel (local depression) during major storm events. Offshore-directed currents are almost absent in the outer bar zone during minor storm events with significant offshore wave heights smaller than 3 m ($H_{s,o}$<3 m). Figure 1 shows class-averaged cross-shore current velocities during flood tide for 4 wave height classes related to storms from sw and nw.

The cross-shore current during major storm events has a pulsating character at the inner bar with large and small velocity fluctuations between -0.2 and -0.5 m/s due to tide level variations.

The cross-shore current at the inner bar during low wave conditions also exhibits a pulsating behaviour related to low and high tide levels; offshore current velocities can be as large as -0.6 m/s for fairweather conditions (local waves of 0.5 to 1 m) at low tide. These conditions may easily occur during normal summer conditions.

5. BED FORMS AND SAND TRANSPORT

Bed form activity is most pronounced on the seaward flanks of the outer and inner bars, where wave breaking is the dominant process. Three-dimensional lunate type mega-ripples with length scales of 1 to 5 m are generated in the breaker zone with strong wave motion (due to spilling and plunging waves) and wave-induced undertow in depths of 2 to 4 m.

The cross-shore transport rates are dominated by the current-related suspended transport processes, except for low wave conditions. The cross-shore current-related suspended transport (between -5 and -25 m^3 per m width per day) is dominantly in offshore direction due to the presence of undertow and rip currents, carrying sand from the beach zone to the trough zones between the bars during minor and major storm events. The bed-load transport is negligibly small compared to the suspended transport during storm events.

During conditions with low waves all cross-shore transport components are equally important and sand may be carried in onshore direction (maximum 0.5 to 1 m^3/m/day).

The total longshore transport is maximum of the order of 30,000 m^3 per day to the north for a major storm event from southwest.

6. BAR MORPHOLOGY

On large alongshore scale (10 km) and on long term (years), the behaviour of the outer and inner bars at Egmond is 2-dimensional in the sense that the bars are continuous and of the same form in alongshore direction and show the same overall migrational pattern (onshore and offshore migration). On small scale (1 km) and on the short time scale of a storm month, alongshore non-uniformities may develop as local disturbances which are superimposed on the overall straight base pattern yielding a 3-dimensional morphological system. Examples of these local disturbances are the development of depressions (rip channels), crescentic and meander patterns, introducing an alongshore wave length of the bar system (in both plan form and crest/trough lines) of the order of 500 to 1000 m.

A rip channel (with length of 200 to 300 m and depth of 0.5 to 1 m) can be developed in the crest zone of the **inner** bar on the time-scale of a few days during minor storm conditions; the rip channel shows migrational effects (order of 100 m) in both directions along the shore, but the rip channel dimensions remain approximately constant during major storms events.

Figure 2 shows the longshore-averaged cross-shore profiles based on bed level soundings in seven transects with a spacing of 100 m covering the periods 18-24 Oct., 24-31 Oct., 31 Oct.-12 Nov. 1998.

Based on Figure 2, the basic overall features of the bars at the Egmond site are:

- 18-24 Oct. (pre-storm period): significant erosion of outer bar (about 10 m^3/m of sand is carried offshore); slight erosion of inner bar;
- 24-31 Oct. (major storm period): significant offshore migration of outer bar (about 20 m^3/m of sand is carried offshore) and inner bar (about 15 m^3/m in offshore dir.);
- 31 Oct.-12 Nov. (minor storm period): slight onshore migration of inner bar (about 5 m^3/m of sand is carried onshore; mainly in northern section of area); onshore bar migration is promoted by bores produced after wave breaking, which are especially effective during low tide conditions with water depths of about 1 m (ebb tide);
- 12-19 Nov. (post-storm period): no significant changes.

The **inner** bar shows migration of the order of 20 to 30 m in both onshore and offshore direction on the time scale of a storm month; the maximum cross-shore migration rate of the inner bar crest is of the order of 30 m over five days.

The temporal development of cross-shore profiles (after longshore-averaging) shows significant cross-shore exchanges of sand of about 1 to 2 m^3/m/day at the crests of the **inner** bar in offshore direction during major storm events and about 0.5 m^3/m/day in onshore direction during minor storm events.

The **outer** bar shows an overall offshore migration in the main transect of about 30 m, about 50 m in the south and stable in the north of the survey zone, yielding a more oblique orientation of the outer bar crest.

The trough zone between the outer and inner bar remained quite stable at -6 m during the whole storm period of about 6 weeks, which may be an indication that the amount of sand passing the trough zone is relatively small. Based on the sand transport data, the maximum amount of sand passing the trough during minor and major storm events ($H_{s,trough}$ is 2 to 3 m) is estimated to be about 0.5 to 1 m^3/m/day in onshore direction as most of the waves are reforming and shoaling in the trough zone. On a yearly basis the maximum amount of sand passing the trough will be of the order of 10 m^3/m in onshore direction.

The behaviour of the outer bar is of considerable interest for coastal managing purposes, because the outer bar zone is a potential location for shoreface nourishment. Sand nourishments in the outer bar zone may only benefit the inner surf zone and beach zone on longer time scales (5 years), because the annual amount of sand passing the deep trough zone is relatively small.

7. BEACH MORPHOLOGY

The beach zone landward of the -1 m depth contour is characterized by three-dimensional features such as swash bars, beach bars, low tide terraces, beach cusps, ridges and runnels and rip channels. Dominant processes on the beach are onshore mass transport of water by shoaling/breaking waves and wave runup followed by offshore recirculation through runnels and rip channels. Longitudinal (alongshore) profiles of the beach surface near the waterline show the presence of sand waves with maximum variations (high and low areas on the beach) of about 1 m over a distance of about 500 m during the survey period.

The morphological processes on the beach are strongly affected by the water levels (neap-spring tidal cycle and the storm surge levels), the offshore wave conditions and the crest level of the inner subtidal bar.

The beach volume per unit width increases for increasing crest level of the inner bar. The daily beach volume changes (erosion/accretion) vary between 1 and 3 m^3/m/day in a storm month with wave heights up to about 5 m; the daily accretion is maximum if the crest level of the inner bar is at -0.5 m NAP; the daily erosion is maximum if the crest level of the inner bar is at -2.5 m NAP.

Beach volume changes of about 30 m^3/m can occur over a period of about 10 to 15 days in a storm month (maximum storm surge level SSL of about +2 m above MSL); the.

beach volume is almost continuously adjusting to a new equilibrium, if the bar crest level is continuously changing The overall beach erosion in a storm month can be of the order of -30 m^3/m (between inner bar and dune foot). Large scale beach restoration by cross-shore processes would require the supply of about 30 m^3/m over considerable alongshore lengths. Given a maximum supply rate of about 0.5 m^3/m per day (maximum onshore transport), this would take about 2 months of fair weather conditions. In practice it may take a full spring and summer period to restore the eroded beach after the storm season.

8. CONCLUSIONS

A complete and accurate data set of hydrodynamic, sediment dynamic and morphodynamic parameters is available for detailed analysis of the short-term and small-scale physical processes at the Egmond site and for testing of point, profile and area models. The hydrodynamic data cover the whole scala of wave conditions from calm weather with low waves up to storm conditions with offshore wave heights up to 5 m in combination with tide-, wind- and wave-induced currents up to 2 m/s. Most of the sand transport data sets have been obtained during the Pilot experiment and only cover minor storm conditions with offshore wave heights up to about 2.5 m. Data sets of sand transport for conditions with major storm events are missing. The morphodynamic data sets include the transformation of a straight bar system into a three dimensional pattern with oblique and crescentic plan forms and the development of a rip channel in the inner bar system.

REFERENCES

Van Rijn, L.C., 2000. Hydrodynamics, sediment dynamics and morphodynamics during storm events 1998 in the nearshore zone of Egmond; overall analyses and implications for model evaluation, Report Z2897, Delft Hydraulics, Delft, The Netherlands.

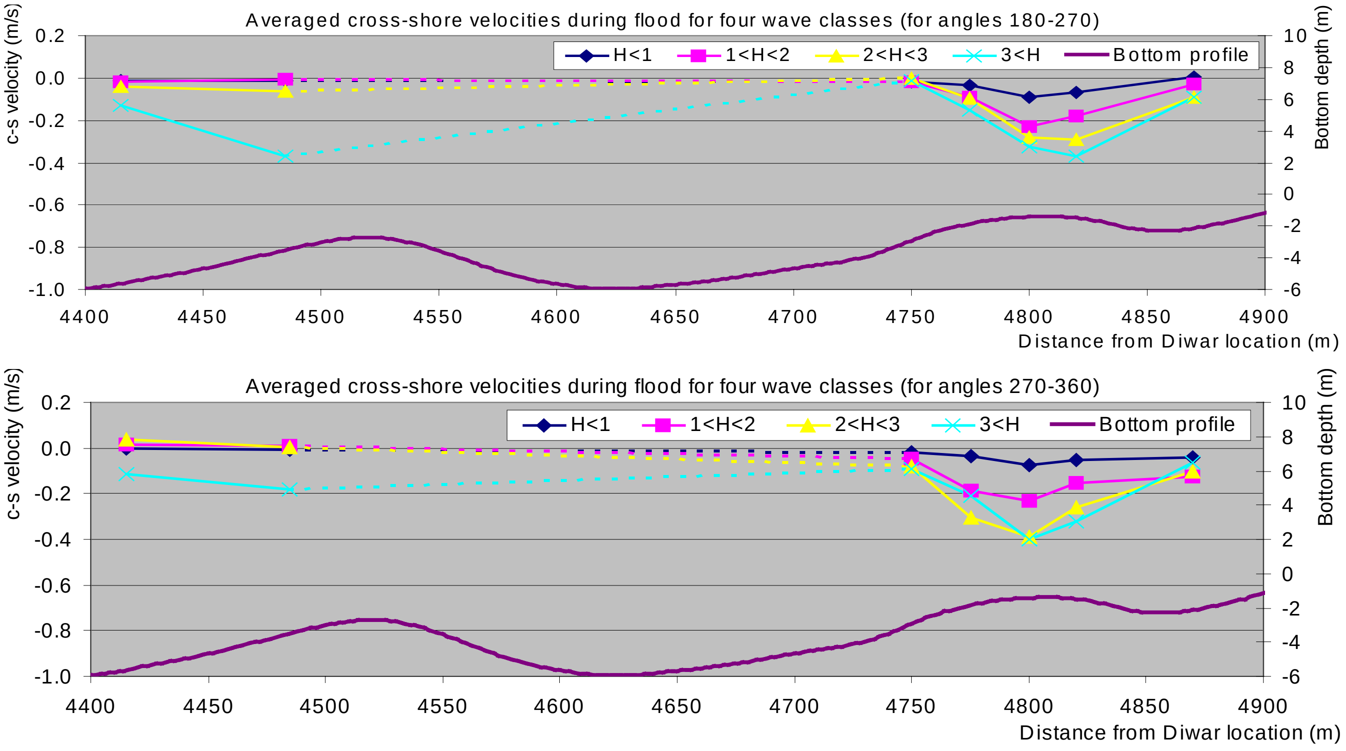

Figure 1 *Cross-shore current velocities during flood along bed profile of main transect (main experiment); four wave height classes; southwest= 180-270 degrees, northwest= 270-360 degrees; positive velocities are onshore-directed; negative velocities are offshore-directed; DIWAR=offshore wave bouy*

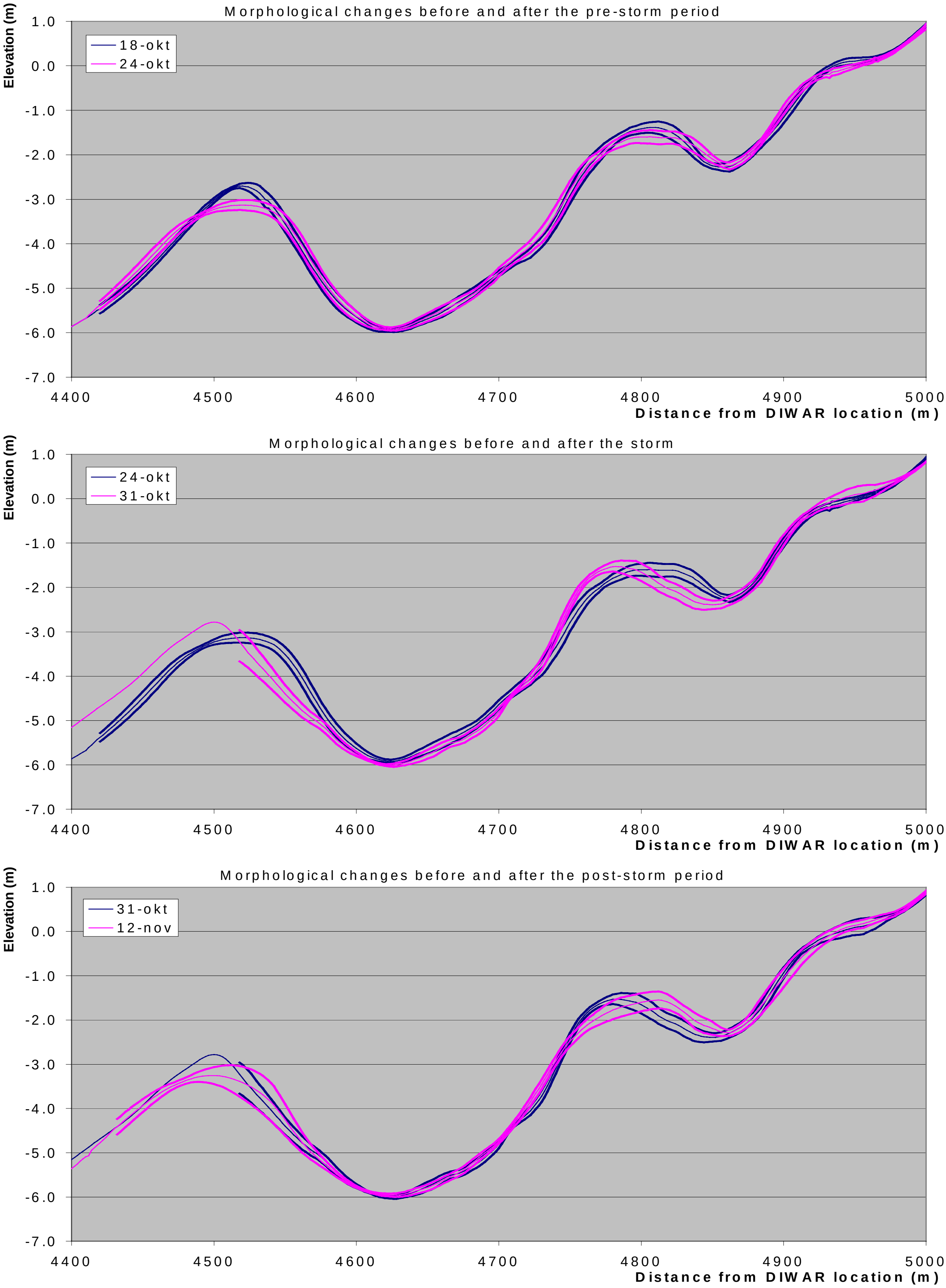

Figure 2 *Morphological changes (in m below NAP-datum) of the longshore-averaged bed profiles with standard error ranges for three events*