Morphodynamics of a Microtidal Protected Beach During Low Wave-energy Conditions

M. Sedrati†, P. Ciavola†, J. Reyns‡, C. Armaroli† and V. Sipka∞

†Dip. Scienze della Terra
Universita di Ferrara, Via Saragat 1
44100 Ferrara, Italia
sdrmcf@unife.it

‡ Dept. Geography
University of Gent,
Krijgslaan 281-S8
B-9000 Gent, Belgium

∞ Laboratoire d’Océanologie et Géosciences
UMR 8187 LOG.
Université du Littoral Côte d’Opale
32 Avenue Foch
62930 Wimereux, France

ABSTRACT


This paper presents detailed hydrodynamic and morphological data from a field experiment spanning 5 days (10 tidal cycles, starting at Spring Tide conditions) undertaken in Lido di Dante, a microtidal protected beach in the Northern Adriatic Sea. This microtidal beach experienced intense erosion in the recent past and therefore it has been protected by groins, nourishments and a semi-submerged breakwater (Low-Crested Structures). During the fieldwork, an intertidal swash bar formed at spring tide under very low wave-energy conditions. The swash bar migrated 3.5 m landwards during two consecutive tides when the measured maximum significant wave height at the upper beach was around 0.2 m. This migration was associated with an onshore sediment transport, resulting from the erosion of the bar’s seaward slope. Once the tidal range decreased during the last tides and wave action ceased, the swash bar became static and only some non-significant changes were observed on both seaside slope and bar slip-face. The net volumetric change of this beach during the fieldwork was non-significant, in spite of the swash bar landward migration (cross-shore redistribution of the initial beach sediment budget). The wave attenuation generated by the beach protection structures was highlighted through comparison between wave measurements inside and outside the barrier. This had a significant role on swash processes and tide controlled duration of swash action, which controlled the cross-shore bar’s morphodynamics in the absence of significant longshore processes.

ADDITIONAL INDEX WORDS: Swash bar migration, Tidal control

INTRODUCTION

Sand bar systems are ubiquitous features along wave and tide-dominated, sandy coastlines. These bars develop under a wide range of hydrodynamic conditions and their morphology assumes a variety of configurations in which the form, size and numbers can differ significantly in space and time (KING and WILLIAMS, 1949; ORFORD and WRIGHT, 1978; GREEENWOOD and DAVIDSON-ARNOTT, 1979; AAGAARD et al., 1998; WINBERG and KROON, 2002). The protected beaches, where the coastal defence structures (breakwaters, groins, low crested structures, etc) are used to control shoreline evolution and to prevent erosion can also features sand bar systems (OBLINGER and ANTHONY, 2008; SEDRATI et al., in press). However, the main studies dedicated to these protected beaches use modelling to study wave and current interactions with structures (e.g. ZYSERMAN and JOHNSON, 2002; THOMALLA and VINCENT, 2003), and the impact of these structures on the shoreline evolution and beachface volume changes when little is known on the effect of these structures on beaches morphology and the field-based experimental studies of these environments are rare, particularly on microtidal settings.

The intertidal beach in microtidal settings often exhibits ephemeral morphological features termed swash bars (KOMAR, 1998). These swash bars (Type II of the GREEENWOOD and DAVIDSON-ARNOTT, 1979, bar classification), less visually apparent, are observed in several coastal configurations with different tidal ranges. They normally move shoreward within a small vertical range in response to the onshore migration of the upper swash and surf limits when the tidal range increases from neap to spring tide (KROON and MASSELINK, 2002). Once in an upper beach position, they can potentially contribute sediment to supply a foredune system by aeolian action and thus feed adjacent sand dune formations and in the same time play an important role in protecting the subaerial beach from storm erosion. Few studies have focused on beach morphodynamics and in particular on changes in swash bar amplitude and migration in a microtidal protected environment. This study, conducted over a 5-day period in May 2008, examined the influence of a LCS (Low Crested Structure) and groin system on wave transmission, and consequently, on the morphodynamics of a barred microtidal beach over several tidal cycles.
Morphodynamics of a Microtidal Protected Beach

STUDY AREA

Lido di Dante is a small seaside resort in the Northern Adriatic Sea, 7 km from the town of Ravenna, in the area delimited by the outlets of rivers Fiumi Uniti to the north and Bevano to the south. The sandy beach of Lido di Dante has a concave shape in the northern part and is more than 2500 m long (ARCHETTI et al., 2000). The beach features two different sectors: the Northern one (study area, Figure 1) was subjected to erosion and therefore it has been protected by groins, nourishment and a semi-submerged breakwater (LCS); the Southern sector, in a natural state, is also under erosion and is backed by a dune system. The tidal regime in the Northern Adriatic is strongly asymmetric, showing both diurnal and semi-diurnal components and the tidal excursion in this area is low; the average spring tide range is 0.4 m and extreme year values are around 0.85 m. The most intense storm events originate from Bora and Scirocco winds with similar intensity; waves may reach 3.5 m every year and rise to 6 m every 100 years. Wind intensity is stronger from the shorter fetch sector of Bora (NE) where it reaches frequently 35 knots, whereas from the long fetch sector of Scirocco it seldom exceeds 30 knots (LAMBERTI et al., 2005). The Lido di Dante beach is characterised by remarkably heterogeneous sand, the median diameter (D50) of which ranges from 1.6 Phi on the upper beach to 3.2 Phi in the lower part of the profile.

METHODS

A five days field experiment was conducted at the southern cell of the protected beach of Lido di Dante (Figure 1) in May 2008. The intertidal beach morphology was monitored each low tide (except May 8th) from the foot of a terrigenous sand deposit on the upper beachface (sand used for the upper beach nourishment) to 1m depth. A 45 m-long central transect (Figure 2) and an additional 4 profiles, two on either side of the central transect (spaced every 10 m), were surveyed twice a day, at low tide, using a high-resolution laser electronic station with errors within ±3 mm for distance and ±0.0015° for direction and referenced to a temporary benchmark with known coordinates in m UTM. Net profile volumetric changes were calculated from elevation fluctuations relative to a horizontal reference plane of −3 m UTM. During the surveys, detailed observations of the bed morphology, of wave breaking, surf and swash bore activity over the intertidal beach were carried out.

Inside the barrier, the hydrodynamic measurements were made from two instrument deployments along the central transect with self-recording equipment. An acoustic current profiler with a built-in pressure sensor for recording water levels and directional waves (ADCP 1) was buried at x~ 52 m with the probes exposed to measure currents and wave parameters at an elevation of 15 cm above the bed. The second instrument (ADV) was fixed to a metal frame buried in the sand and deployed at x~ 25 m with a pressure sensor measuring at 5 cm above the beach surface and probes exposed to measure currents at an elevation of 15 cm, this instrument was exposed at low tide during the first two days of the campaign before being relocated at x~ 30 m. A second ADCP was installed outside the protected area with similar deployment characteristics as the first one. All instruments were synchronously logging at a 2 Hz acquisition frequency for 9 min every 15 min. Additional offshore wave parameters were collected by the Buoy of Cesenatico (23 km to the south of Lido di Dante) and wind speed and direction were recorded at Porto Corsini (12 km to the north of Lido di Dante).

RESULTS

Morphological changes

Figure 2 documents in detail the topographic changes measured at the main transect during the field campaign. The intertidal beach featured a distinct berm (between x~ 7 m and x~ 20 m) with a quasi morphological form of a “low amplitude bar”. This berm, backed by a well developed trough, resulted from the erosion of the terrigenous sand deposit of the upper beach caused by a number of previous storm events. This berm was not affected by hydrodynamic processes during low to medium energy events observed during this field campaign.
No significant morphological changes were recorded on the intertidal beach during the two first surveys (05 pm and 06 am). The third main transect survey (06 pm) features a significant erosion of the seaward side of the berm and the formation of a very small but distinct swash bar, ~3 m wide and ~0.1 m high. During the next high tide, the seaward side of the swash bar progressively grew in height (~0.09 m) and width (~2.8 m) and also migrated onshore by ~3.5 m. This increase in bar crest height was associated with significant seaward slope erosion and an important slip face accretion. More erosion was observed on the lower seaward side of the berm and/or the new swash bar. The upper trough of the swash bar was quite narrow and confined by the seaward side of the berm. No bedforms were observed on the bar, while small symmetric ripples were present in the narrow upper trough and more important ones were observed in the lower eroded zone seaward the swash bar. Furthermore, some significant bed level lowering was observed on the crest of the berm but was not taken into consideration for this study because it was caused by the consistent human trampling of the upper beach on these sunny days of the beginning of the summer season. The subsequent topographic surveys of the main transect (until the end of the field campaign) highlight the stability of the swash bar while a relative significant erosion was observed on the lowest part of the seaward side of the swash bar. The profile volumetric variability (Figure 3) during the fieldwork was extremely small (well below of 0.48 % of the total cross-shore volume, taking into account the error margin) in spite of the swash bar formation (06 pm – tide 3) and landward migration (07 am – tide 4). These patterns (morphological changes and beach profiles volume stability) were likewise observed along the other four surveyed profiles. The volumetric stability evidenced by this microtidal beach seems to correspond to the cross-shore redistribution of the initial beach sediment budget under the swash processes responsible of the swash bar formation and migration. In general, the most important morphological changes (swash bar formation and migration) associated with a quasi cross-shore profile volume stability were recorded during two consecutive tides at spring tide while non significant changes and a relative volumetric fluctuation were recorded during the rest of the field once the tidal range decreased and significant wave action ceased.

Hydrodynamics
An event summary of wave, tide conditions during the field campaign is shown in Figure 4. Spring tide occurred at the start of the campaign and decreased during the last tides. The tidal curves were very asymmetric during the measurements and the amplitude difference between two consecutive high tides was around 0.25 m. Maximum offshore wave heights occur before the start of the field campaign in response to the end of high energy event caused by “Bora” winds coming from the NE to E and with speeds that reached a 6 ms⁻¹ peak. During the three first tides, the offshore wave conditions were relatively more energetic, with $H_s$ values exceeding 0.5 m. Low wave conditions with $H_s < 0.3$ m prevailed during the rest of the campaign. Waves on the lower beach ($x \approx 52$ m) showed significant attenuation relative to the deepwater heights, as a result of the dissipation caused by the low crested structures while wave breaker patterns were quite persistent over the upper beach ($x \approx 25$ m). Waves at any measured shallow water depth were not depth-sensitive, and significant wave heights values (0.04 to 0.05 m) were almost constant. On the upper beach, largest $H_s$ values were measured at high tide. However, when the upper beach instrument was relocated from $x \approx 25$ m to $x \approx 30$ m during the last four tides, the measured significant wave height values remained stable at any measured water depth.

At the lower beach, the mean currents were mainly driven by the tide. Throughout these low wave energy conditions, the
The decrease in tidal range during the campaign. First tides and their intensity decreased in parallel with the southward. Both mean currents were more energetic during the directed offshore when the most longshore current was directed to zero at high tide. Furthermore, the cross-shore current was most currents occur during the rising and the falling tide and are close to zero at high tide and reached up to 0.18 m\(s^{-1}\) for offshore cross-shore directed current and 0.21 m\(s^{-1}\) for northward longshore directed current at low tide (max water depth ~0.5 m). At the very shallow water (upper beach), the strongest mean cross-shore and longshore currents occur during the rising and the falling tide and are close to zero at high tide. Furthermore, the cross-shore current was most directed offshore when the most longshore current was directed southward. Both mean currents were more energetic during the firsts tides and their intensity decreased in parallel with the decrease in the tidal range during the campaign.

DISCUSSION

The Low-Crested Structures (LCS) protecting the Lido di Dante beach seems to play a significant role in wave energy dissipation in any offshore wave-energy condition. At the start of the campaign when the offshore wave heights were > 1m, the waves lost up of 80 % of their energy. However, during medium (three first tides) and low (rest of the campaign) energy conditions, the waves lost up of 70 % of the energy during the propagation over the LCS. If we add to this energy attenuation inside the barrier, the fact of the absence of any significant longshore and cross-shore current driven circulation at the lower beach, the morphodynamics of the upper intertidal beach must be considered in isolation from the subtidal morphodynamics and appear to be clearly related to the swash processes.

The intertidal bar that was formed between the second and third main transect surveys is a quasi-static type of bar typical of low-wave energy settings (WINBERG and KROON, 2002). Its growth results from sediment stirring by surf bores and subsequent particle entrainment by swash processes (HUGHES et al., 2007). The morphodynamic implications of the twice daily sweep of the tide across the intertidal profile and particularly the upper beach where the swash bar was formed differ between two consecutive high tides because of the asymmetric tide impact. The swash bar was formed during a relatively lower high tide when the swash processes were more concentrated on the seaward side of the berm, where the onshore directed cross-shore currents were more energetic. The swash bar showed important erosion of the seaward face with associated bar crest accretion during the following high tide. During this phase, the upper beach exposure time to hydrodynamic processes and particularly to swash processes was more important (in space and time). Thus induced a swash bar migration according to a classical mechanism in which, the sediment is entrained at the seaward slope of the bar by breaking waves, bores and/or swash action; when the sediment-laden uprush overtops the bar crest, the efficiency of the backwash is greatly reduced, and sediment is deposited landward of the bar crest (OWENS and FROBEL, 1977; DABRIO and POLO, 1981). The decrease in tidal range during the following high tide limited the swash processes action and associated morphological changes to the seaward side of the swash bar (relative volumetric changes). The high tide limit measured for the 8 am surveyed profile and associated hydrodynamic conditions were quasi similar to the high tide limit of the 7 am surveyed profile (swash bar migration) and associated hydrodynamic conditions but no swash bar migration was recorded. The variation in the rate of morphological response between these comparable phases can probably be attributed to the role played by the beach gradient in controlling bar migration (HAYES, 1972; MASSELINK et al., 2006). If the swash bar migration rate recorded at several beaches and associated tidal environments [e.g. STEPANIAN (2002) in megatidal; KROON and MASSELINK (2002), VAN HOUWELINGEN (2004), AAAGAARD et al., (2006), SEDRATI (2006) in macrotidal; ANFUSO et al., (2003), JACKSON et al., (2007) in mesotidal; BALOUNI et al., (2003, 2004), SEDRATI et al., (in press)], in microtidal settings] range from 0.5 to 3 m/day, the associated wave-energy conditions may be remarkably different. In the case of a protected beach (the same field site), Sedrati et al. in press, showed that the migration processes under medium-energy conditions (Hs < 0.5m) of a pre-existent swash bar are more controlled by wave processes when the tidal regime impact is neutralised (symmetric tidal curve and few centimetres of tidal range during five consecutive tidal cycles). However, the migration mechanism observed during this campaign was more related to combination of tide and swash processes and was quite similar to the situation observed by BALOUNI et al., (2004) who attribute the swash bar origin and migration to the permanence of swash processes during slack water in absence of wave forcing.

CONCLUSIONS

The morphodynamic nature of an intertidal bar on a structure protected microtidal beach at Lido di Dante exhibited an important dependency on tide-modulated swash processes, closely similar to

Figure 4. Hydrodynamic conditions during the field campaign, the grey lines for the ADCP 1, the black lines for the ADV and the dashed line for the offshore wave height: a) water levels (m), b) significant wave height (m), c) cross-shore mean currents \(U\) (ms\(^{-1}\)) and d) longshore mean currents \(V\) (ms\(^{-1}\)). Offshore \((U)\) and southward \((V)\) directed mean currents are negative.
the swash bar morphodynamics described at other sites in literature. At the same time, the present observations show bar behaviour different from that found during a previous experiment at the same beach (medium-energy conditions and symmetric tidal curve). These facts elucidate the difficulty to relate intertidal bar morphologies on this kind of beaches with a single hydrodynamic process and/or mechanism, and the complex relationship between tide-wave processes and wave attenuation caused by coastal protection structures.

LITTERATURE CITED


BALOUIN, Y., CIAVOLA, P., ANFUSO, G. and ARMAROLI, C., 2003. Relationship between swash bar migration and swash duration: field assessments at Lido di Volano Beach, Adriatic Sea, Northern Italy. 3rd IAHR Symposium on River, Coastal and Estuarine Morphodynamics, Barcelona, 1121-1133.

BALOUIN, Y., CIAVOLA, P., ANFUSO, G. and ARMAROLI, C., 2003. Relationship between swash bar migration and swash duration: field assessments at Lido di Volano Beach, Adriatic Sea, Northern Italy. 3rd IAHR Symposium on River, Coastal and Estuarine Morphodynamics, Barcelona, 1121-1133.


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