Oceanologia (2017) 59, 18—27

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia/

ORIGINAL RESEARCH ARTICLE

Application of Dean's curve to investigation of a long-term evolution of the southern Baltic multi-bar shore profile

Grzegorz R. Cerkowniak[*], **Rafał Ostrowski**, **Zbigniew Pruszak**

Institute of Hydro-Engineering, Polish Academy of Sciences (IBW PAN), Gdańsk, Poland

Received 29 February 2016; accepted 10 June 2016
Available online 24 June 2016

KEYWORDS
Cross-shore profile;
Bars;
Shoreline position;
Dean's curve;
Nearshore sediment resources

Summary The paper presents the results of studies on the long-term evolution of the multi-bar cross-shore profiles. The analysis is focused on time-dependent variability of shoreline position, a modified parameter *A* of the conventional Dean's equation and a parameter *F* describing the amount of nearshore sediment resources in the multi-bar cross-shore profile. The study also deals with interrelationships between these quantities. The analysis is carried out using field data collected at Lubiatowo, Poland, on the dissipative shore, representative for the south Baltic. The considered coastal segment is found to be stable in the long-term scale. The results of analysis show that the parameter *A* can either increase or decrease together with the shoreline advance. It is concluded that the shoreline position change is a parameter unsatisfactorily representative for behaviour of the seashore. The use of the Dean's approximation for estimation of the sediment resources *F* on the multi-bar seashore profiles is found reasonable to eliminate the effects of peculiarities of such shores.

1. Introduction

A typical sandy multi-bar coastal zone constitutes a complex morphological system described by a characteristic cross-shore profile with large bed forms (bars) and a shoreline, as well as a beach and dunes. While behaviour of the shoreline and beach forms is the key indicator of coastal dynamics in the longshore direction, the spatial-temporal evolution of the subaqueous cross-shore profile is driven mostly by processes

---

[*] Corresponding author at: Institute of Hydro-Engineering of the Polish Academy of Sciences (IBW PAN), Kościerska 7, 80-328 Gdańsk, Poland. Tel.: +48 58 522 2933; fax: +48 58 552 4211.
E-mail address: g.cerkowniak@ibwpan.gda.pl (G.R. Cerkowniak).

Peer review under the responsibility of Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.oceano.2016.06.001

occurring in the direction perpendicular to the shoreline. Variety and intensity of coastal morphological changes depend on impact of waves and currents. This impact has a random character and is variable in time and space. Recently, the severity of extreme marine hydrological and hydrodynamic events is said to increase due to climate change (see e.g. Shaltout et al., 2015; Tsoukala et al., 2016). The morphological changes are observed across the entire coastal zones built of sandy sediments, even at the depths of 15—17 m (see e.g. Uścinowicz et al., 2014). On the other hand, in some cases, extensive technical interventions in the shallow water coastal regions have minor influence on nearshore morphodynamics (see e.g. Kubowicz-Grajewska, 2015).

Loss of wave energy due to breaking in the surf zone is strictly related to the presence of underwater bars. A well-developed bar system causes multiple wave breaking and as a result smaller part of deep-water wave energy reaches the shoreline vicinity and the beach than in a case of shore profile without bars (see e.g. Komar, 1998; Pruszak et al., 2008). The cross-shore profile shape can be therefore assumed as a key factor ruling the wave breaking and energy dissipation process. The layout and number of seabed forms (bars) on the cross-shore profile is an indicator of the wave breaking pattern. The number of bars is frequently said to depend on seabed inclination and sediment grain sizes, as well as on the offshore wave climate (see Dolan, 1983; Katoh and Yanagishima, 1993; Moore et al., 2003; Pruszak et al., 1999).

The precise quantitative assessment of evolution of a coast is very difficult, particularly in a case of the multi-bar sandy sea shore. Many coastal parameters are subject to changes which can be of various quality. For instance, retreat of the dune toe can be accompanied by the shoreline advance but in some circumstances both the shoreline and dune toe can move either landwards or seawards. Erosion observed simultaneously at the dune, emerged part of the beach and the shoreline can be compensated by accumulation of huge amounts of sand in the nearshore region, e.g. by volumetric expansion of the bar system. The situation becomes even more complicated if the coastal morphodynamics is considered in multi-scale time domains. Thus, there has been a need to elaborate a reliable method of accurate estimation of coastal evolution trends. Such a method, proposed herein, seems to yield reasonable results independently of peculiarities of an analysed seashore segment.

Analysis of selected parameters of the multi-bar shore profile is a fundamental aim of the present study. The study concentrates on interrelationship between the parameter A of the modified Dean's curve approximating each cross-shore profile, shoreline position with respect to the long-term mean and the parameter F describing the amount of sediment resources in the nearshore part of the coastal zone. In the present analysis, the temporal scale of decades has been considered (period from 1987 to 2008) and the coastal zone with 2—5 bars. The parameter F, expressing nearshore sand resources and resistance of seashore to erosion, has been defined in accordance with the Dutch approach, adapted by Cieślak (2001).

2. Study site and field data

The analysis was carried out by use of data collected on the typical south Baltic shore, namely at the Coastal Research Station (CRS) in Lubiatowo. The station was established in 1968 and has been operated by the Institute of Hydro-Engineering of the Polish Academy of Sciences (IBW PAN). Since 1970s, numerous field surveys have been carried out at CRS Lubiatowo during which a lot of data have been collected. Some of these data have been used in studies published in scientific papers. The present article contains the Lubiatowo data unused till now, as well as the data already utilised but within a new interpretation.

The mean nearshore slope is $\beta = 0.015$ (0.04 at maximum very close to the shoreline) and the seabed is built of fine quartz sand having the median grain diameter equal to $d_{50} = 0.22$ mm. The Baltic can be assumed as the non-tidal or micro-tidal sea and water motion is therefore generated only by wind-driven waves and currents. The underwater bar system consists of 3—5 bars. The first stable bar occurs about 100—120 m from the shoreline, the second one ca. 250 m, the third one 400—450 m while the fourth one often overlaps with the fifth one constituting a large form 650—750 m from the shoreline. Aside from these stable bars, there is also an ephemeral bar in the form of a flat shoal located near the shoreline. The view of the considered coastal segment, its location in the south Baltic Sea and the layout of exemplary analysed cross-shore profiles are shown in Fig. 1.

The presence and layout of bars, together with instantaneous wave conditions, imply numbers and locations of wave breakings. In mild and moderate wave conditions, waves break over the first bar and sometimes also in the region of the second bar, that means 100—250 m from the shoreline. During storms, waves are subject to multiple breaking and constitute a few breaker lines over the bars located farther seawards. If the waves are very small, they reach the nearshore zone unaffected by the seabed and break in close shoreline vicinity. A typical storm of average intensity generates waves having a significant height of $H_s = 2.5$ m at water depth of $h \approx 15$ m. The maximum significant wave height can reach H_s equal to 3.5—4.5 m. In such conditions, wave period is equal to 5—8 s (while it does not exceed ca. 4.5 s in mild conditions). Due to wave transformation and breaking on the cross-shore profile, a part of wave energy E dissipates which qualitatively depends on the incipient (deep-water) wave height. For instance, as calculated by Pruszak et al. (2008), the deep-water waves higher than 1.5 m loose at least 60% of their energy in the nearshore zone of CRS Lubiatowo site (which implies that not more than 40% of wave energy reaches the shoreline vicinity).

Within the present study, cross-shore transects stretching several hundred metres seawards (most often about 900—1000 m) and shoreline positions along 2.6 km coastal segment have been analysed. The bathymetric profiles spaced by 100 m from each other have been measured since 1987 while the shoreline position data have been collected since 1983. The analysis has been focused on three selected profiles, numbered 6, 11 and 21 (see Fig. 1). The variability of cross-shore transect no. 21 in the period from 1987 to 2008 is shown in Fig. 2a while the shoreline evolution in the same time is presented in Fig. 2b. Locations of the selected profiles 6, 11 and 21 are also shown in Fig. 2a.

It can be seen in Fig. 2a that the changes in bottom ordinates attain 4 m while Fig. 2b implies that the scope of variability of shoreline position at some locations is almost 100 m.