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BATHYMETRIC FLUCTUATIONS AS AN EFFECT OF BREAKING WAVE ACTION BASED: EXAMPLE OF A SELECTED SECTION OF THE BALTIC SEA COASTAL ZONE

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Abstract: Transformations of the bottom of a section of the coastal zone of the Baltic Sea were determined based on its corings. The measurements were performed before and after a storm. The method of determining the transformations involved combining bathymetric plans. This way, deepening and shallowing areas of the bottom were identified. The changes result from the return of currents on the bottom and from a lower degree of the littoral current and direct effect of the waves.

Keywords: bathymetric fluctuations, return currents, the Baltic Sea

INTRODUCTION

It is common knowledge that breaking waves shape the bottom very dynamically. This, however, relates not only to the impact of waves defined as their range described as the wave base, but the fact that they generate various types of currents, including undertows. The knowledge of the changes in bathymetry is of high practical importance. It refers to the foundations of hydro-technical facilities, changes in the shoreline (its subsidence or aggradation), the possibility of military landing operations or changes in people's bathing patterns in the coastal zone.

A wave in deep water is an oscillation wave but when the depth amounts to less than 1/20 of the wave's length, a translation wave develops (Książkiewicz 1972). The analysed area between groynes is located in the breaking waves zone. Therefore, translation waves occur within its range. Unlike in the case of translation waves, the propagation of free waves occurs with no profile deformation. The heights of translation waves approaching the shore considerably increase until breaking at the moment of reaching the critical depth while the length decreases (Druet, Kowalik 1970). The circulation of currents generated as a result of wave action is extremely complicated. It depends not only on the parameters of the waves but also on the angle of attack of the waves on the shore. While undertows on groynes coasts usually flow along them towards the open sea (Basiński 1965) before encountering an obstacle, typically a sandbank (if the undertows are not strong enough to break it), they spread in a fan-like way, developing centric over-deepenings. The currents are extremely dangerous to swimmers due to the velocities reaching up to 10 $m \cdot s^{-1}$ (Choiński, Kaniecki 1996; Książkiewicz 1972; Marsz 1966). While the literature on changes in shorelines and the bottom in the coastal zone is impressive (Photointerpretative Atlas…, 1990; Hueckel 1972; Leontiew et al. 1982; Tarnowska 1977) one should study short sections of the coastal zone in such conditions. This results from the high dynamics of the changes over short periods of time, and a high degree of the zone's individualism.

STUDY AREA AND METHODS

The study area included the coastal zone in Mielno, located between 300.0 and 301.0 km of the coast (Basiński 1965). The measurements were performed in two pools between three groynes, perpendicular to the shore. To the west, the boundary was a single-row groyne, a two-row groyne was located in the middle (the western pool), and to the east the measurements were confined to a single-row groyne (the eastern pool) (Photo 1). The distances between them amounted to 67 and 88 m, respectively. The lengths of the groynes amount to several tens of meters each (with the central one being the longest). Their accurate lengths depend on the changes in the shoreline and oscillate from several to a dozen metres annually. The isobaths in the analysed zone are generally parallel to the shore, whereas the maximum depth does not exceed 3 m.

On 1 August, 7 August and 3 September 2008, the measurements were performed between the groynes and in their forefield by means of an acoustic Garmin probe coupled with GPS 12 GARMIN. The entire surface of the bottom is covered in sand with varied grain sizes. Therefore, precise determination of the depths was not problematic and was performed with an accuracy up to 0.1 m. Moreover, the measurements were performed in each case in the conditions of no waves on the surface.

The objective of the measurements was to determine changes occurring on the bottom directly after a storm and to determine changes in the bottom relief over a longer period of time, i.e. between storms. In the above case, the measurements have more than just a cognitive aspect. Because of the location of the analysed section of the shore (i.e. the central part of the bathing area in Mielno), such research also has a purely practical aspect. It shows the scale and rate of changes in the bathymetry of the bottom, having a considerable effect on the safety of the bathers.

Photo 1. Study area: the upper photo – the western basin between the western and the central groynes; the lower photo – the eastern basin between the central and the eastern groynes

STUDY RESULTS

Fig. 1. presents the bathymetry as of 1.08.2008. In the period preceding the measurements (July) the intensity of wave action was low. Only on four days (9, 15, 24, and 25.07), the sea state reached 4–5^{o} B. It oscillated between 0 and 2^{o}B. Weak winds from the N-W prevailed whereas the strength of the wind usually varied from 1 to 3^{o}B (Dziennik… 2008). Such a long period of a very weak wave action certainly contributed to obliterating the previous post-storm bottom relief. This is evidenced by the gentle, i.e. undisturbed course of the isobaths. They bend distinctly only along the central, two-row groyne. The obliteration of the groyne funnels is typical of the western and eastern groynes where they develop as a result of intensive waves generating an undertow. The remains of the funnel at the two-row groyne suggest that the undertow was there at its strongest. The biggest depth was registered at isobath 2.5 m north of the end of the eastern groyne. It is an area of only several tens of square meters. The mean depth for the entire analysed pool on 1.08.2008 amounted to 1.24 m. It was calculated after a planimeter measurement of fields between the isobaths. This permitted determination of the bathigraphic curve.

Further measurements were performed on 7.08.2008. In the period preceding the measurements (between the 2nd and 7th August), strong waves were recorded on one day (5th August. At 9:30 a.m. the sea reached 7–8^{o} B and at 1:00 p.m. – 6–7^{o}B whereas the wind at those times reached 5–6^{o}B and 7–8^{o}B, respectively. On the remaining days, the sea usually oscillated between 1 and 3^{o}B. As a result of strong waves, the bottom was remodelled as shown in Fig. 2. A shift in the isobaths (1.0; 1.5, and 2.0) is evident towards the shore in comparison to the state from 1.08.2008. The greatest changes occurred along the central and the eastern groynes. Small changes occurred in the course of the shoreline, and the balance of its subsidence and aggradation approximates zero. To the north–west, a zone with a considerable area appeared, covered by the 2.5 m isobath whereas the biggest depth recorded there amounted to 2.8 m. The determined mean depth for the entire analysed area on 7.08.2008 amounted to 1.32 m. Therefore, an overdeepening by 8 cm occurred in comparison to the previous measurements. Assuming that the shoreline is relatively stable, on the one hand the deepening of the bottom presumably results from clastic material carried along the shore by the littoral current, and on the other hand, by the undertows. The effect of the aforementioned currents on the bottom overlaps with the modifying effect of the range of the wave base.

For the purpose of an accurate determination of the changes in the bottom of the analysed area, the bathymetric plan from 1 August was compared against the bathymetric plan from 7 August 2008. The resulting image is presented in Fig. 3. The over-deepenings are clearly distinguished, separated by shallower areas. The former occur along the groynes or in their vicinity. The overdeepenings

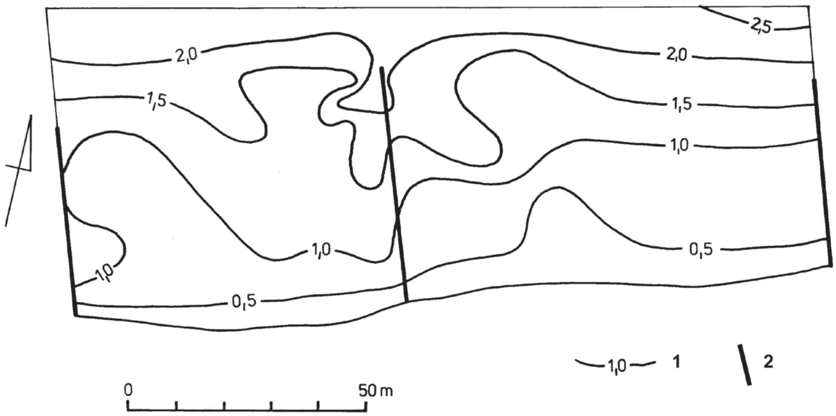

Fig. 1. Bathymetry – 1 August 2008: 1 – isobaths (m); 2 – groynes

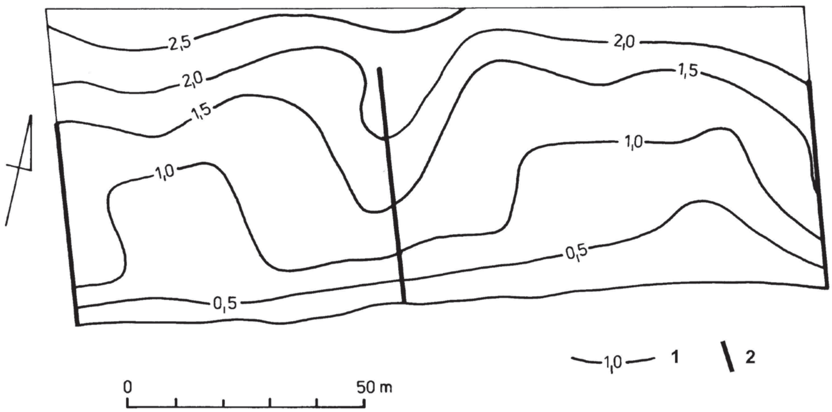

Fig. 2. Bathymetry – 7 August 2008: 1 – isobaths (m); 2 – groynes

reach up to 0.5 m – the eastern and the central groynes up to 0.7 m. The shallow areas indicate considerably smaller values, i.e. from 0.2 to 0.3 m for the east part of the central groyne. The analysis of the depth of the studied pool shows that in the above case, 36.8% of the area became shallower, and 73.2% deeper.

The subsequent measurements were performed on 3 September 2008 (Fig. 4). They were preceded by stable weather conditions (Dziennik…, 2008). Over 28 days between the consecutive measurements, there was only one storm (on 17 August). The strength of the wind amounted to 5–6°B at the sea state of 6–7°B. On the remaining more than 20 days, neither the strength of the wind or the state of the sea exceeded 3°B, therefore offering favourable conditions for obliterating the "live" bottom relief from 7 August 2008. This resulted in a gentle course

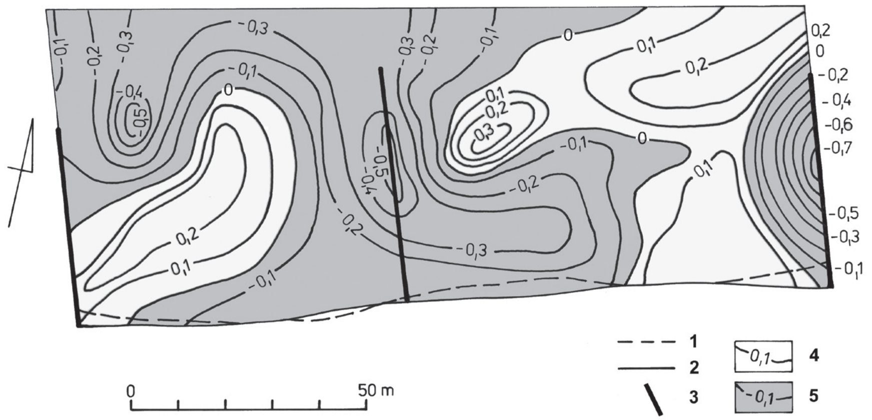

Fig. 3. Difference in depth between 1 and 7 August 2008: 1 – coastline – 1.08.2008; 2 – coastline – 7.08.2008; 3 – groynes; 4 – accumulation areas; 5 – erosion areas

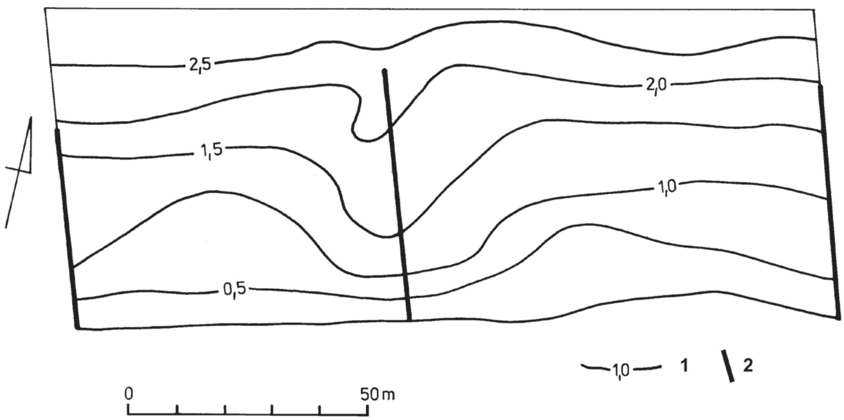

Fig. 4. Bathymetry – 3 September 2008: 1 – isobaths (m); 2 – groynes

of the isobaths approximately parallel to the shore. Their bending only occurs along the two-row central groyne. Therefore, the groyne funnels were obliterated. Similarly as in the previous situation, i.e. from 1 August 2008, the greatest overdeepening in the central groyne suggests that the undertow is the most active there. In this case, the biggest depths exceed 2.5 m, and the zone covered by the isobath is the largest for the three measurement series – it continuously extends from the seaward tips of the side groynes. The mean depth of the entire analysed pool (calculated as previously) amounted to 1.44 m. Therefore, in comparison to the previous measurement period an over-deepening by 12 cm was recorded. In order to determine the changes in the bottom bathymetry against its state from the previous measurement series, the bathymetric plan from 3 September 2008 was compared with the bathymetric plan from 7 August 2008. The resulting image of the differences is presented in Fig. 5. The zones of over-deepenings and shallow areas are evident. The former are strongly dominant. As much as 79% of the analysed area deepened. The shallower areas, occupying only 21% of the bottom, are particularly common along the landward sections of the groynes, and near the shoreline. The maximum over-deepednings amounted to more than 50 cm (in the seaward zone between the central and the eastern groynes), and the maximum shallow areas also more than 50 cm (near the shore along the eastern groyne). The shoreline between the subsequent measurement series was relatively stable, not subject to considerable shifts. This is the effect of the „optimum" angle between the attacking wave crests and the shore. Should the angle be too small, the shore would have been washed out (Rudawski 1962).

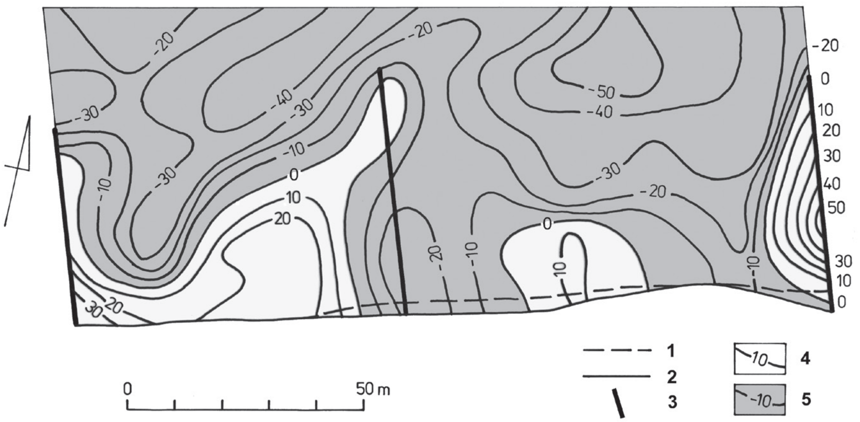

Fig. 5. Difference in depth in cm between 7 August 2008 and 3 September 2008: 1 – coastline – 7.08.2008; 2 – coastline – 3.09.2008; 3 – groynes; 4 – accumulation areas; 5 – erosion areas

Presumably, depending on the intensity and duration of a storm, the bottom transformations can vary significantly. In the above case, it is possible to compare the changes in the bathymetry with those from 1974 (Choiński 1977). In 1977, precise measurements of the pool confined to groynes from the west and the east were taken. This is equivalent to the western (i.e. left) part of the area analysed in 2008. The changes are presented in Fig. 6. Over several days of intensive waves (the waves reached a maximum height of 2 m), the morphology of the bottom underwent considerable changes. Analogical over-deepenings developed along the groynes, whereas they were considerably larger at the eastern two-row groyne. The maximum over-deepenings reached more than 80 cm, and the maximum shallow areas more than 30 cm. It was determined that the processes at

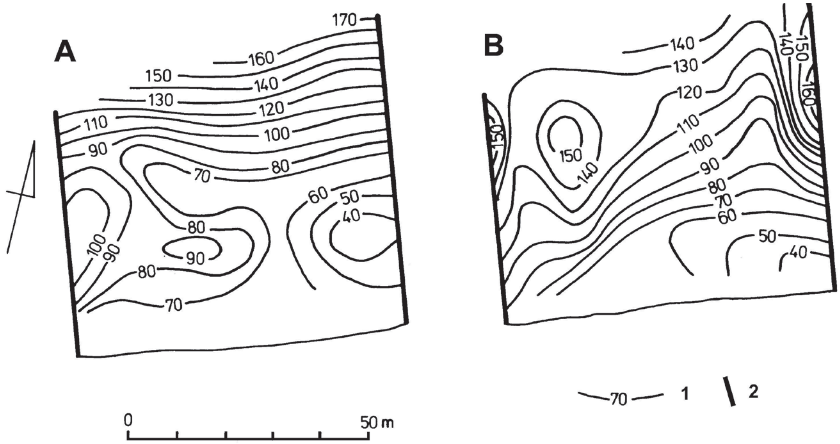

Fig. 6. Bathymetry – 3 September 1974 (A) and 13 September 1974 (B): 1 – isobaths (cm); 2 – groynes

hand (derivatives of undertows and littoral currents) have a bigger contribution to the modelling of the bottom in the breaking wave zone than the direct effect of waves. This observation is in accordance with the opinion presented by Scheidegger (1974).

SUMMARY

As a result of bathymetric measurements in three periods of time, the scale of changes in the height differences of the bottom after intensive waves was determined together with obliteration of shallow areas and over-deepenings in a long period with no high waves. Storms cause deepening of the bottom along the groynes as an effect of undertows. The phenomenon is most evident in the central two-row groyne. The over-deepenings and shallow areas amount to more than 50 cm. This type of research and its expanding seems to be well justified as it can facilitate the balancing transported sediments on the bottom, and will allow to determine the scale of the changes. In the above case, no extreme storms were recorded. A very interesting issue is the response of the bottom to extreme weather conditions, i.e. the "end" of the Beaufort scale. Assuming this kind of "basis" can be useful for long-term observations considering various hydro-meteorological conditions. This will allow for an identification of patterns determining the changes to the bottom at various parameters of wave action and various wave run-ups.

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