CHAPTER 229

COASTAL ZONE DYNAMICS DURING ARTIFICIAL NOURISHMENT

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Abstract

The nearshore zone of the Hel Peninsula has a hydro-geomorphological system which, together with the influence of the port at Władysławowo, causes permanent erosion of the basal and central part of the peninsula's sea coast. After a period during which traditional methods of coastal defence (seawalls, groynes) were used, a massive artificial nourishment of the dune and beach was realised in the years 1989-1995. The borrow material used was of lagoon and marine origin. The progress of morpho- and lithodynamic processes was evaluated basing on quantitative analyses of changes in topography and granulometry. In the land part of the coastal zone, accretion of deposits resulted in rebuilding of the dunes and beaches. In the nearshore zone, accretion occured on the beach slope, and resulted in the development of shore terraces and breaker bars (especially the outer breaker bars). This was accompanied, by related with the accretion, processes of erosion in the form of U-shaped troughs. These processes proceeded at small changes in the erosion/accretion (e/a) system of the nearshore zone in the whole region. Smaller input of sandy material into the nearshore zone resulted in gradual return of the e/a system to initial state. If the safety of the peninsula is to be maintained, artificial nourishment must be executed every year. Frequency and volumes of renourishment will depend on the quality of used material. Therefore new sources of borrow material must be seeked.

Introduction

Artificial beach nourishment, considered as one of the most environment friendly methods of coastal defence, was used in Poland several times (Basiński, 1992; Basiński & Szmytkiewicz, 1991; Mierzyński, 1985). However, these were experimental pilot projects, realized in small temporal and spatial scale, using rather small amounts of material. In this paper are discussed results of investigations of changes in the coastal environment caused by a large-volume nourishment project implemented on the Hel Peninsula coast (Fig. 1). The decision to use artificial nourishment resulted from the cathastrophic state of the basal part of the peninsula, and from the imminent danger of flooding of the hinterland of the narrow and

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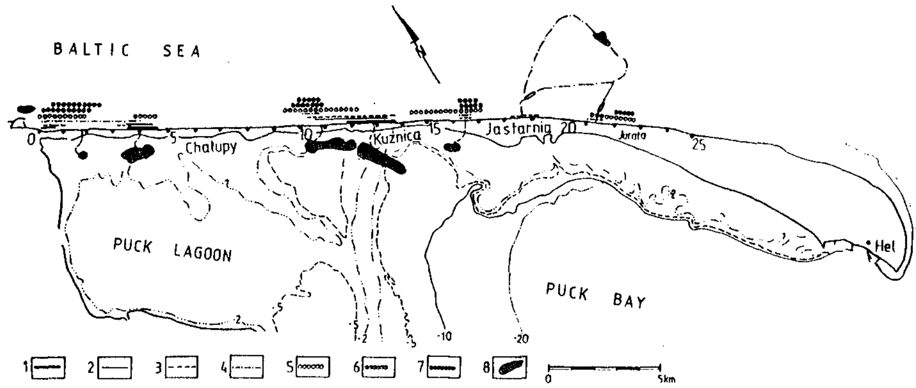

Fig. 1 Location of beach nourishment and borrow sites, Hel Peninsula 1989-1995. (1-7 - years of nourishment; 8 - borrow sites)

intensely eroded dune, at limited width of the spit. Strong storms in the autumn and winter of 1988/1989 resulted in a danger of breaking of the peninsula at 2-3 places.

The Hel Peninsula is an accumulative spit of 36 km length, which is an extension of the mainland to SE, and which shelters from the north the Gulf of Gdansk. In historical times it was broken several times. Analysis of maps from the period 1908-1978 (Zawadzka, 1994) has shown that the average rate of coastline retreat along the peninsula is -0.6 m/year (Fig. 2a). Processes of erosion in the period 1980-1987, directly preceding the nourishment project, are characterized by a similar spatial distribution as in the 70-year period 1908-1978 (Fig. 2b). The foredune became nearly completely eroded in the basal and central part of the peninsula along 17 km of coastline, resulting in a danger of breaking of the peninsula, especially at these stretches were the width of the spit did not exceed 100 m. In this situation, the decision was taken to use artificial nourishment as the most effective and least ingerentive method of coastal protection (Cieślak, 1994).

In the years 1989-1995 the largest project of artificial nourishment of a dune coast in Poland was realized. On the seaward coast of the Hel Peninsula, along a length of 23.4 km, 8 mln. m^3 of sand was supplied, gradually widening the range of sand suppletion works, which in total were executed along 14 km of the coastline. The material for nourishment was taken from the Puck Bay, from the sand trap at the port at Władysławowo, and from borrow sites at sea located to NE of the central part of the peninsula and to NE of Cape Rozewie (Zawadzka, 1993). In order to determine the effectiveness of the method, a comprehensive program of measurements and investigations was systematically realised. It included investigations of sediments and morphology of the seabed, beach and dune along the first 23 km of the peninsula's coastline. Each year 800-1000 sediment samples were analysed. Analyses of the variability of the dune, beach, beach slope, breaker bars, interbar troughs and of the deepwater slope to 10 m water depth were made. Comparison of maps of statistical grain size indicators (median diameter, sorting, skewness, steepness) on the background of proceeding changes in the shape of the nearshore bed and of its morphological forms, and taking into account the hydrodynamic conditions, has

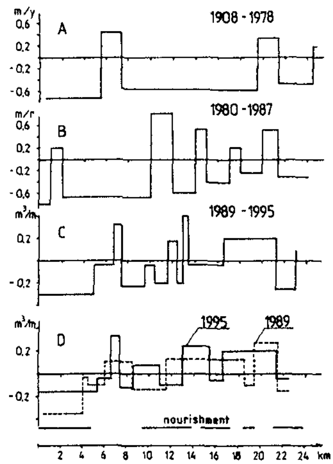

Fig. 2 Changes of coastline position, Hel Peninsula, 1908-1978, 1980-1987 and changes of the fill coefficient of the nearshore zone to -10 m MSL, 1989-1995. A-B - Zawadzka, 1990; C-D - Dubrawski, 1995.

shown that independtly of the local short term changes connected with artificial sand supply, in the coastal zone there is a hydro-geomorphological system, which forms relatively stable erosion/accretion trends in the coastal zone - also in conditions of artificial nourishment. Nourishment works carried out for 7 years have not resulted in a basic change of the gencral trend within the erosion/accretion system in the Hel peninsula region. Generally erosion has decreased, but its spatial distribution remained almost the same (Figs. 2c, 2d).

Characteristics of supplied material

For the nourishment material dredged from the Puck Bay and from sea borrow sites located at sea was used (Fig. 1). Deposits accumulated in the Puck Bay consist of fine and medium sand, well and medium sorted, and the median diameter (M_d μm) ranged between 139 and 237 μm. Marine material consists of medium sand of M_d 290 μm, medium sorted. Comaparative analysis of the "bay" borrow material and native material, using the R_j and R_A indicators (Manual, 1990), shows that these two sands do not fit satisfactorily. Highest stability of the supplied material may be attained when 2-3.5 larger quantities of material are nourished than the volumes resulting from calculations of deficiency of sand material in the basal part of the peninsula. In the central part, material borrowed from marine sources may be used in 1:1.5 (2) proportion. Grain size parameters of borrow material from the Puck Bay suggest that mass transport of that sand may proceed at speeds of 12-20 cm/s.

Nourishment started in 1989 at two sites: at Chałupy (km H3.5-4.5) and at Kuźnica (km H11.9-13.7). By 1993, about 5.85 mln. m^3 of sand were supplied, and the nourishment works were executed on 5 stretches of total length of 11.1 km. At the Chałupy nourishment field the resultant average volume of nourishment per metre of coastline was 510 m^{3}', at Kuźnica it was 730 m^3. On the other fields the average volume of nourishment per metre of coastline ranged between 100 and 330 m^3. In the next two years, until 1995, the length of directly nourished coastline grew to 14 km, and the total amount of sand supplied since 1989 increased to 8 mln. m^3. Most intensive nourishment was still realized at Chałupy and Kuźnica due to the highest defficit of sediments in the nearshore zone, and because of the limited stability of the nourished material.

Morphodynamics and lithodynamics of the region

The shore and the nearshore zone of the Hel Peninsula are characterized by a semistabile erosion/accretion system, with a strong predomination of erosional trend resulting from the hydrodynamic conditions in the region (Fig. 2).

The stable predisposition to erosion along given stretches of the coastline are caused by trough-like forms present in the sea bottom, which are obliquely oriented at an angle of 25-27^0 to the shoreline. In the western part of the peninsula they are of glacifluvial origin (Tomczak, 1994), in the eastern part they are remnants of the Yoldia Sea coastal systems (Musielak, 1989). Location of these forms influences the occurence of areas with permanent erosion of the sea bottom and shore. The stability of the erosion/accretion system is confirmed both by cartometric analysis of coastal change (Zawadzka 1990, 1994) and by means of modelling of hydrodynamic processes in the nearshore zone (Skaja & Szmytkiewicz, 1995). When wind blows from the west and north sectors, dangerous to the west and central part of the peninsula wave and current systems are generated. In extreme conditions current velocity may reach 2 m/s. Wind from the east results in higher energy supply to the east and central parts.

The variability of sediment transport characteristics in natural conditions, in the different zones of bottom and shore, influences the intensity with which the artificially nourished material is displaced in given meteorological conditions, resulting in different reactions of the erosion/accretion system of the coastal zone.

Transformation of morphological forms of the coastal zone

The caused by artificial nourishment increase of volume of the beaches resulted in adaptive transformation of the adjoining forms of the shore and nearshore zone.

Accretion of nourished material on the beach and dunes was accompanied by an appearance of erosion along stretches east (downstream) of the nourishment fields. Gradually these phenomena moved also into the nearshore zone.

After the first season of nourishment, along 14% of the observed coastline well developed shore terraces were present, and their average width was 75 m (Dubrawski, 1995). After 4 years terraces occured along 45%, and after 6 years - even along 76% of the coastline (Table 1).

The intensive development of inner and outer bars took place after four years of artificial nourishment, during which 5.8 mln. m^3 of sand were supplied. One of the most significant features of the transforming during the artificial nourishment seabed was the generation of rarely occuring in the natural bottom profile U-shaped troughs. Maximum development of the interbar U-troughs also was observed after 4 years of nourishment. The maximum number of shore U-troughs appeared after 6 years of nourishment, suggesting increased current velocities in the shallow part of the nearshore zone.

Table 1. Changes of parameters of morphological forms in the nearshore zone, 1989/1995 (Dubrawski, 1995)

Year	Shore terraces		Shore slope		shore U-trough		Inner bar lower class		interbar U-trough		Outer bar higher class	
	%	l [m]	l [m]	slope	%	l [m]	%	[m²]	%	l [m]	%	[m²]
1990	14	75	133	1:33	4	76	26	37	8	144	33	303
1993	45	76	141	1:37	11	80	12	43	21	108	52	332
1995	76	81	135	1:33	19	85	17	43	9	71	45	335

The decreased volumes of nourishment in the period 1994-1995 resulted in stronger erosion on the beach and in smaller differentiation of morphological forms in the nearshore zone and of grain size composition within these forms, which suggests a gradual return to the state before artificial nourishment (Dubrawski, 1995). Analysis of the average crosshore profile showed stabilisation of the volume of the inner bar after 4 years of nourishment, and a steady development of the outer bar where redeposition of fine sands occurs. The shore slope increased its volume by 4.8% of the volume of nourished material, attaining maximum after 4 years of nourishment. Similarly to shore terraces, in the next years it was subjected to gradual reduction.

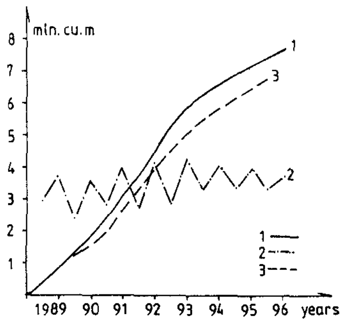

Fig. 3 Nourished stretches and net beach volume (1 - sum of annual suppletion; 2 - changes of dune and beach volume; 3 - sum of annual losses)

The balance of changes of the shore, evaluated basing on measurements carried out twice every year, shows that during the first 3.5 years, in spite of repeated nourishment, the volume of dunes and beaches remained at the level of 1989 (Fig. 3). When intense nourishment was carried out after strong storms of winter 1992/93, and after the relatively mild wind and wave conditions of the 1994/95 season with higher than average percentage of winds from the east, did result in stabilisation accretion on the beach and dune. After the annual amount of nourished material was reduced, the volume of material contained in the beach and dune decreased in spite of a consecutive mild winter season. In effect of 6.5 years of artificial nourishment, the volume of the shore (beach and dune) increased by about 1 mln. m^3.

Lithodynamics in conditions of artificial nourishment

Grain size analysis of bottom surface samples, taken each year from the seabed in the whole region before each annual nourishment works, show that the mean value of the median diameter has not changed significantly. Before the nourishment works began, the belt-like distribution of mean and fine sands was locally disturbed by zones of coarse sand and fine gravel, which indicated areas with higher wave and current activity. In these areas erosion of shore and bottom was observed (Fig. 4).

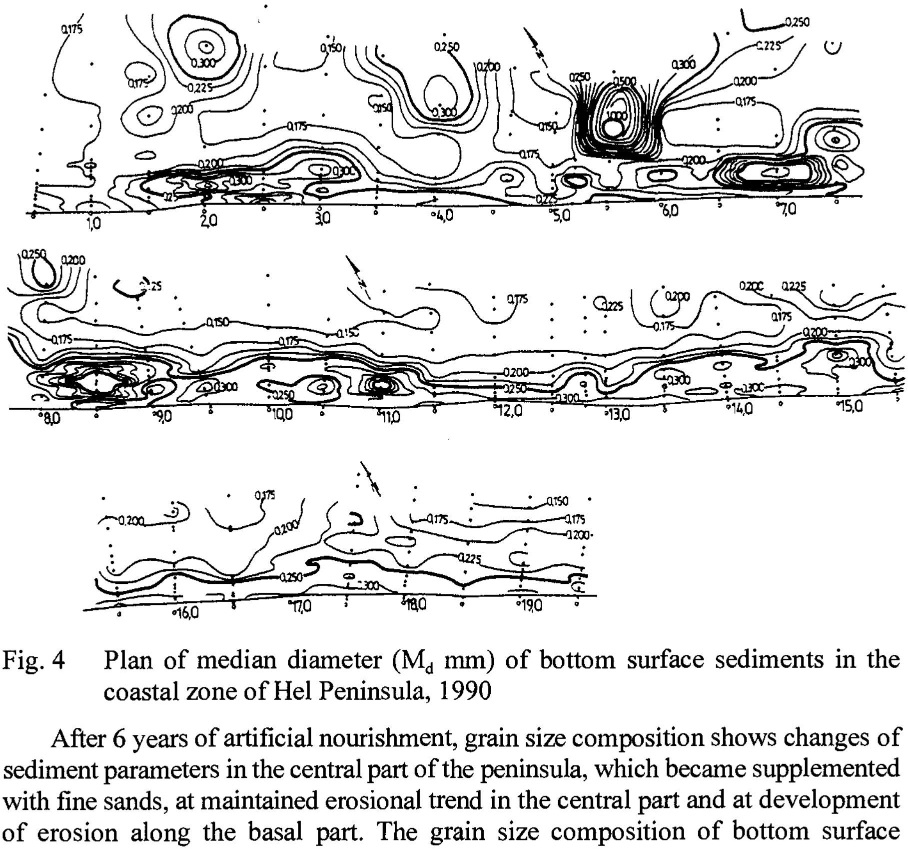

Fig. 4 Plan of median diameter (M_d mm) of bottom surface sediments in the coastal zone of Hel Peninsula, 1990

After 6 years of artificial nourishment, grain size composition shows changes of sediment parameters in the central part of the peninsula, which became supplemented with fine sands, at maintained erosional trend in the central part and at development of erosion along the basal part. The grain size composition of bottom surface sediments in the 10-12 m water depth zone was characterized, after 6 seasons of nourishment with sand from the Puck Lagoon (Puck Bay), by a slight decrease of the median diameter from 253 μm to 238 μm in 1993 and to 225 μm in 1995. The median diameter of beach deposits, which were successively supplemented with mean and fine sand, was after three years of artificial nourishment nearly the same as in prenourishment conditions.

The average grain size composition of deposits in the nearshore zone remained nearly unchanged through 3 years of nourishment. In the fourth year, due to erosion of nourishment fields during strong storms of the 1992/93 season, beach deposits became slightly coarser and the nearshore zone was supplemented with large amounts of fine sand, and the median diameter of bottom surface deposits in the nearshore zone decreased to 206 μm. It may be supposed that the stability of nearshore zone

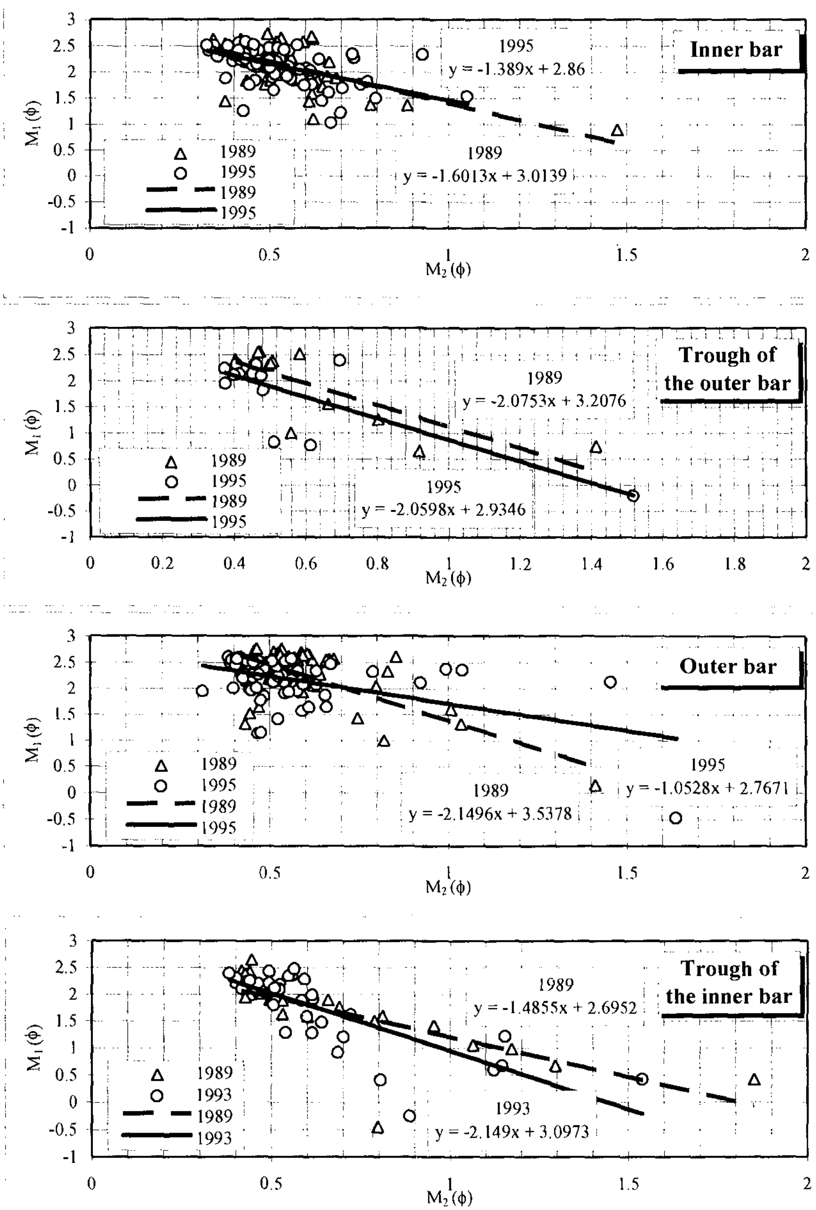

Fig. 5 Relationship between mean diameter (M_1) and standard deviation (M_2) of sediments in breaker bars and bar troughs, Hel Peninsula, 1989-1995

forms built of artificially supplied material, which was finer than the natural material, is smaller than in case forms built of material present before the nourishment project, and that thay will quicker undergo transformation.

Small changes in the grain size (evaluated using mean parameters) of the nearshore forms during the nourishment are proof of an inner stability of the hydrogeomorphological system and that the finest particles are displaced outside the active zone. However, at the same time within each of the morphological forms in the nearshore zone proceeded distinct granulometric changes, indicating a different distribution in the wave and current field (Basiński & Szmytkiewicz, 1991). Development of the shore terraces and the breaker bar zone was accompanied by deepening and widening of the troughs. Increased nearbottom current velocities in the troughs, which increase is largest in the trough between the inner and outer bar, suggest a transformation of the erosion/accretion system (Fig. 5). The development of interbar troughs is connected with the existence of gradient currents (Pruszak & Zeidler, 1995). Probably gradient currents increased in the nourished areas, and in effect U-shaped troughs developed.

The median diameter in the interbar troughs increased by 150 μm, from 280 μm in 1989 to 430 μm in 1995, in spite of relatively mild hydrodynamic conditions in the last winter season. After the strongest storm season 1992/93 the median diameter in the troughs was even up to 480 μm. In areas of most distinct development of U-shaped troughs, the median diameter exceeded 1000 μm, which could be related with current velocities of over 1 m/s (current velocities require confirmation by field measurements).

The decrease from 260 μm to 220 μm of median diameter of sediments building the breaker bars indicates that the accumulated in them material will be moved at lower initial current velocities. This fact may be the reason of quicker transformation of the outer breaker bars.

In conditions of a growing amount of supplied artificially material, of steadily growing length of nourished stretches, and of variable hydrodynamic conditions, the lithodynamic system of the Hel Peninsula nearshore zone was characterized by a variable spatial distribution of fields of erosion and accretion. Basing on analysis of the changes of median diameter of sediments and their mean values, calculated for each of the morphological zones (beach, shore slope, interbar troughs, breaker bar zone and deepwater slope), areas with finer or coarser sand were determined. This allowed to draw plans of of the surface erosion/accretion system of the nearshore zone, and to evaluate its dynamics.

Before artificial nourishment works started, there were 4 erosional areas along the basal part of the peninsula, covering all morphological zones: the shore slope, breaker bar zone and the deepwater slope. Along the central part of the peninsula, the shore slope and the breaker bar zone were eroded. Along the eastern part, alternatingly located zones of erosion and accretion occured, indicating routes of sediment transport to the deepwater slope and then out of the observed area.

In spring 1990, after the first artificial nourishment campaign, the initial system of erosion/accretion areas did not change along the basal and central part of the peninsula, though local accretion of the supplied material in the breaker bar zone and on the shore slope was observed. East of the fill field at Chałupy and Kuźnica (central part) the breaker bar zone was supplemented with fine sand material, at simultaneous erosion of the deepwater slope (Fig. 6). Influence of the fill material was observed in the interbar troughs and on the outer bar to 8 m water depth and up to 1.5 km from the fill field. On the other hand, segregation of the nourished material resulted in an increase of coarse sand and gravel on the beach and at the water line. No significant change of grain size was observed on the outer breaker bar.

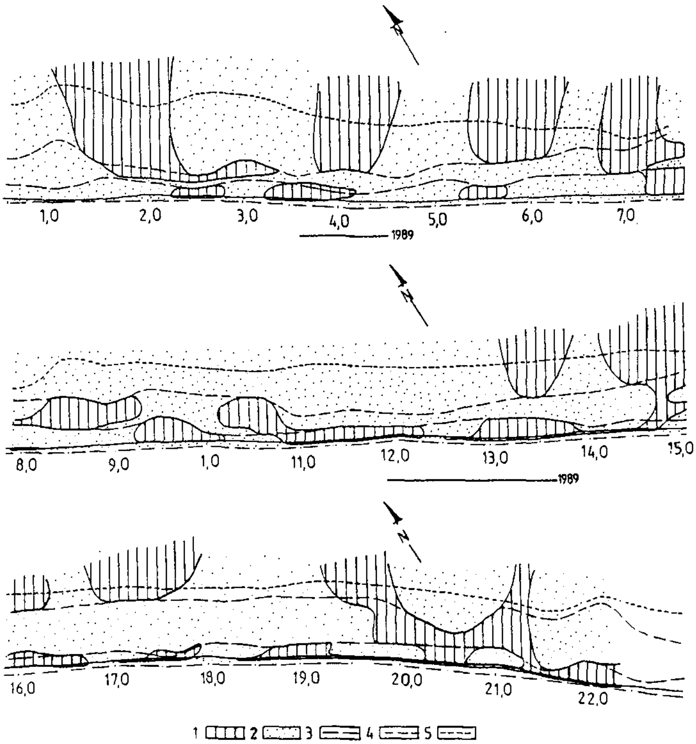

Fig. 6 Erosion/accretion system of surface sediments, Hel Peninsula, 1990 (1 - areas with erosive trend; 2 - areas with accretional trend; 3 - range of shore slope; 4 - range of breaker bar zone; 5 - 10m depth contour)

After two years of nourishment (in 1991), while distinct accretion occured in the shallow water and breaker bar zones, also development of areas of erosion of the breaker bars and deepwater slope was observed east of the fill field located in the basal part of the peninsula. In the central part, zonal accretion on the shore slope and on the breaker bars was observed, accompanied by erosion in the same zones east and west of the fill field. Rhythmically occuring erosion/accretion surfaces, encompassing the breaker bar zone occured in the eastern part, suggesting a development of circulation cells of 1 km order. In the Chałupy area, in effect of segregation of the material, the beach became saturated with mean and fine sand, while percentage of mean and coarse sand grew on the shore slope. The process of washing out of the shore slope proceeds at simultaneous enrichening of the breaker bar zone and of the deepwater slope with fine sediments. The influence of the fill material was observed in the breaker bar zone 2 to 3 km east of the fill field. Further migration of the fill material is limited by a convex bottom form at km H7.0-7.5, which is considered to be a natural boundary of a lithodynamic unit of the nearshore zone. Observations at Kuźnica showed that the fill material is transported over larger distances than in case of the Chałupy field. Within the shore slope and inner bar zones the material was transported 3 km, and in the outer bar zone - about 5 km to the east of the fill field. East of the Kuźnica fill field two independently occuring in 1990 areas of scour, one on the shore slope and the other on the deepwater slope, were transformed into an oblique to the coastline and cutting through the breaker bars zone of intense transport.

After the third year (in 1992) of artificial nourishment of the western stretch of coastline with material from the Puck Bay, supplemented with material from the sand trap at the port at Władysławowo, the inner bar and its inner trough became richer in fine sand. Deposition of sediments grew also locally in the outer bar zone. The large supply of material from the fill resulted in a shallowing of the interbar trough and in supplementing the balance of sediments up to about 1.5 km east of the fill field. Areas of bottom scour formed in 1991 became filled with sands of 225-250 μm diameter. Finer material (less than 150 μm) was deposited in the 8-10 m water depth zone about 3 km east of the fill field. Accretion in the area of transport of the fill material was always accompanied by erosion, which indicates a nonuniform character of the transport. In 1992, due to the continuing suppletion of the shore at Kuźnica, the system of shore terraces became distinctly developed, and the median diameter of sediments accumulated in them was 275-300 μm. The shallowing of the shore slope was accompanied by deepening of the trough before the inner bar and in its transformation from a V shape to a U shape. Suppletion of the inner bar occured at a distance of 1 km and of the outer bar - at a distance of 2.5 km east of the fill field. The change of zones of wave energy dissipation resulted in a local rebuilding of the double bar profile into a single bar profile, which was built of medium sands. The new system of eroded and accreting bottom surfaces suggests a distinct stabilisation of lithodynamic processes over a stretch of 5-6 km east of the fill field at Kuźnica.

Intensive development of large erosive forms, encompassing nearly all the morphological zones appeared after 4 years of nourishment (1993), pointing to the development of oblique to the coastline routes of sediment transport. The field at Chałupy still supplemented the coastal zone to a distance of 2.5-3.0 km east of the field, and to a water depth of 6 m. In the nearshore zone a strip of 350 m width seaward of the water line, and reaching to 4 m water depth, was supplemented at a length of about 3.5 km. Predominance of wind from the NW sector in autumn and winter of 1992/93 resulted in the generation of distinct "upstream" zones and of new routes of sediment transport out of the nearshore zone. The obliquely situated erosive areas were characterized by larger grain sizes than the average values determined for the whole observed area, and crossed all analysed nearshore zones. The larger rates of loss of fill material over the deepwater slope occur, among others, along the defined routes of intensive transport (Fig. 7).

In the last year of observations (1995), in the nearshore zone of the basal part of the Hel Peninsula accretion occured over large areas of the shallow water zone adjacent to the fill field. Locally in the central part erosive areas appeared, independently of the development of massive breaker bars, which are a transient zone

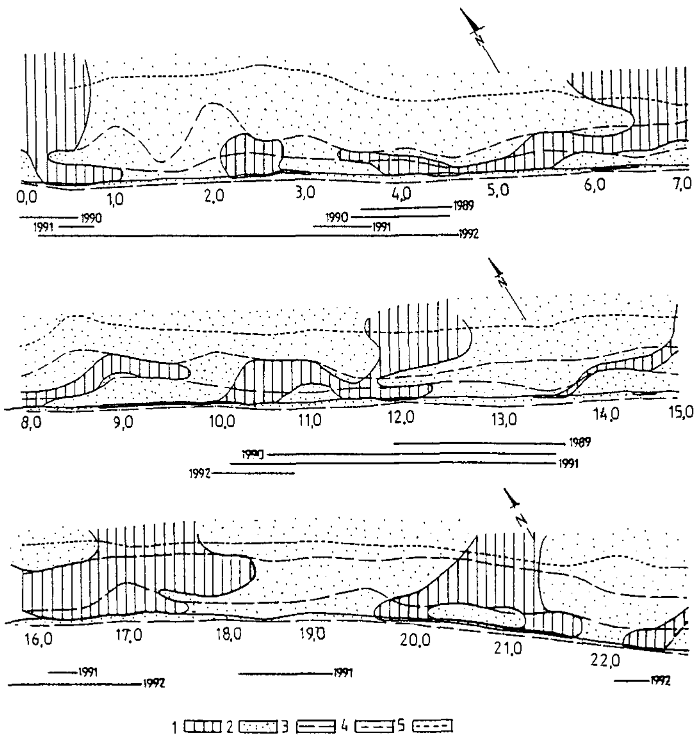

Fig. 7 Erosion/accretion system of surface sediments, Hel Peninsula, 1993 (explanations as in Fig. 6)

of deposition. Also distinct zones of higher energy appeared, which caused scouring of breaker bars east and west of the fill field at Kuźnica, formation of deep interbar troughs, and erosion on the deepwater slope. Hydrodynamic conditions at the break of 1994/95 resulted in the formation of two distinct circulation cells in the central and eastern region (Fig. 8). The direction of sediment transport out of the intensely artificially nourished region in the central part suggests an influence of a trough form situated obliquely to the coastline. A very similar arrangement of sediment transport routes (accretion in the central part of the system and erosion in the outer zones) was observed in the Jastarnia-Jurata region. The distribution of the eroded and accreting surfaces in the nearshore zone suggests that bottom forms farther offshore and deeper situated influence the ncarshore zone, steering circulation at winds from the NW to NE sector.

The highest percentage of nearshore surface, subjected to processes of erosion in the breaker bar zone and on the shore slope, occured before artificial nourishment began (Table 2). The area of redeposition of the sediments was located on the deepwater slope below the breaker bar zone. Accumulation on the beach, shore slope and in the breaker bar zone caused increased erosion of the deepwater slope. After a period of strong storms at the break of 1992/93, processes of erosion increased again in the shallow part of the nearshore zone (shore terraces and breaker bars), but weakened below the breaker bar zone due redeposition of the sediments.

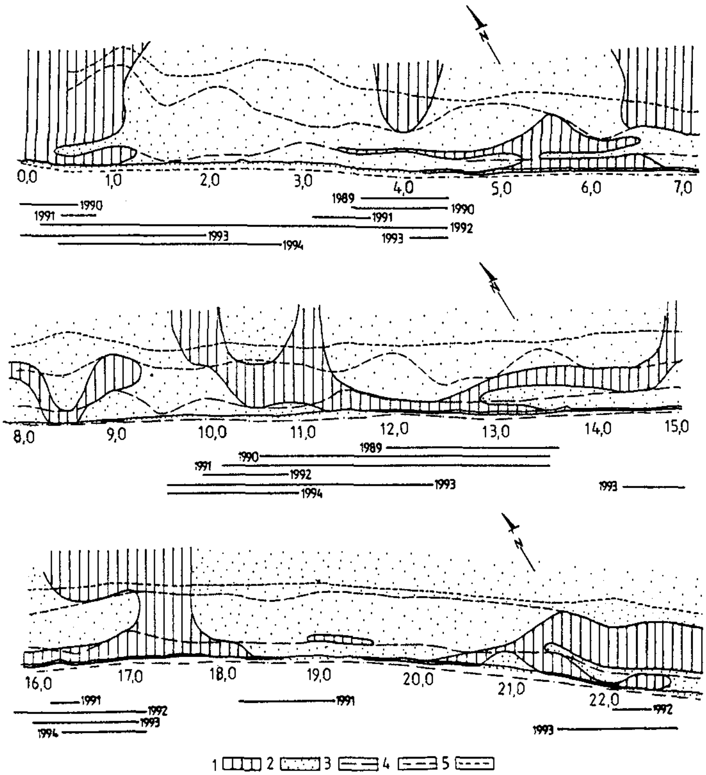

Fig. 8 Erosion/accretion system of surface sediments, Hel Peninsula, 1995 (explanations as in Fig. 6)

Table 2. Percentage of eroded nearshore zone surface, Hel Peninsula, period 1989-1995 (on the basis of granulometric parameters)

Year	Erosion (in %) of nearshore zone (to 10 m water depth)		
	Whole nearshore (0.0÷-10.0 m MSL)	Shore slope & breaker bar zone	Deepwater slope
1989	35.2	46.5	20.5
1990	21.0	16.9	33.7
1991	22.0	21.1	27.5
1993	29.0	36.4	19.4
1995	23.4	22.6	27.9

Obtained results show that in intensive hydrodynamic conditions the shallow part of the nearshore zone and the breaker bar zone was being destroyed over 36 to 46 % of its surface. Stabilisation on the shore slope and breaker bars is connected with development of processes of erosion on the deepwater slope, indicating that in the erosion/accretion system proceed compensatory processes.

Summary

The six years of artificial nourishment along the Hel Peninsula, due to the restoration of dunes and to the improvement of sediment balance in the coastal zone, resulted in higher safety of the coast and its hinterland. The total volumetric change in the strip from dunes to breaker bars inclusive was over the whole period 1.8 mln. m^3, i.e. about 28% of the total volume of the nourishment in the period 1989-1994 (Cieślak et al, 1995), in that about 12.5 % remained in the dunes and beach, and 15.5 % remained in the shore terraces and breaker bar zone. The rest was transported outside of the investigated area. Significant amounts of fill material were accumulated in the developing shore terraces, which at the end of the analysed period covered 3/4 of the length of the observed coastline. Terraces improve the stability of beaches and dunes because they dissipate wave energy.

Breaker bar height increased by 11.8%, and cross-section area by 22% in refrence to the 1989 state. Formerly present stretches with no breaker bars disappeared. A decisive change in the shape and volume of breaker bars took place. Participation of small breaker bar forms decreased. Massive breaker bar forms developed, especially after the fourth year of artificial nourishment. During the last two years of suppletion, when volumes of supplied fill material were reduced, the percentage of breaker bars of each of the volumetric classes began to stabilise at the levels of the period preceding the nourishment works, indicating a predominant influence of hydrodynamic processes. The grain size composition of fill material indicated that it may nourish especially zones with lower hydrodynamic activity. Gradual reduction of massive breaker bars caused by reducing the volume of annual artificial nourishment will result in the future in higher levels of danger to the coast. Development of shore terraces and breaker bars was connected with local changes in the erosion/accretion system, which appeared especially through the generation of U-shaped troughs and areas of scour downstream of the fill fields and terraces.

Observed morpho- and lithodynamic changes of the coastal zone during artificial nourishment are of adaptative character and proceed within an existing, well established hydro-geomorphological system of the Hel Peninsula. Gradual reduction of the volume of artificially supplied to the erosion/accretion system material will result in a slow return of the shore and seabed forms to the state present before artificial nourishment began. In the conditions of prevailing winds from the west sector and of generated by them waves and currents, and of the system of macroformations of the outer part of the coastal zone and of the breaker bar zone, there is a natural predisposition to transport a part of the sediments of the dynamic layer to east and north. This requires repeated artificial nourishment in the west and central part of the peninsula, in order to ensure relative stability of permanently eroded stretches, especially when too fine fill material is used. In periods when prevail winds from the east, morphodynamic processes in the erosion/accretion system become stabilised.

The basic recommendation, resulting from grain size and sediment transport analyses, is that borrow sites with grain sizes better fitted to open sea hydrodynamics should be seeked. Sand from the Puck Bay is very easily moved, and only for a short period supplement the areas with sediment defficit. Material with parameters ensuring 40-50% better stability in the whole strip from shore to outer bar than the

presently used sand should be used. Maintaining the present state of the coast requires annual nourishment of the order of 0.6-1.0 mln. m^3.

The presented results show that artificial nourishment, as any other method, has a limited range of application, and - as any other technical ingerence into the coastal zone - causes changes in the wave and current system which result in a development of negative morpho- and lithodynamic effects.

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