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Dynamic processes at the mouth of the Wisła Śmiała River

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The coastline changes, which occurred at the mouth of the Wisła (Vistula) Śmiała River untill 1993, are presented. Coastline accretion on the western side, and retreating on the eastern side of the river mouth have been observed. Narrowing of the mouth due to accumulation of sand have also been noticed.The character of coastline changes allows the conclusion that the coastline have been naturally returning to the position of 1840.

INTRODUCTION

The work is dealing with a narrow coastal zone of the southern part of the Gulf of Gdańsk between Gdańsk–Nowy Port and the Wisła (Vistula) Passage. The area comprises the present-day mouth of the Wisła River (the Wisła Passage) in the vicinity of Świbno, the Wisła Śmiała River near Górki and the Wisła Martwa River in the region of Gdańsk–Nowy Port (Fig. 1).

The paper describes basic problems of lithoral hydrodynamics and hydrodynamic processes within the coastal zone of the mouth of the Wisła Śmiała. The coastline, its origin and changes over the last fifty-year period have been the major subjects of investigations. They have been carried out on the basis of both archival materials and field work. The aim of the investigations was to draw the coastline at the mouth of the Wisła Śmiała, analyse its changes between the measurements and recognize its shape compared with that known from archival materials. The analysis of the material enables defining the origin of the present-day shape of the coastline as well as more comprehensive learning the phenomena taking place at the mouth of the Wisła Śmiała.

GEOLOGICAL CHARACTERISTICS OF THE AREA STUDIED

The area studied is situated in the Gdańsk Sea-Coast with two characteristic spits: the Hel Spit and the Wisła Spit. There are also patches of a morainic plateau. The boundaries of the morainic plateau of the Pomeranian Lake District, Mazurian Lake District and Elbląg Elevation enclose a low plain built of fluvial deposits — the Żuławy Delta Plain. Throughout the delta area, there is a system of very low, winding ridges marking old river channels — river arms of the Wisła. They consist of sandy muds or sands, whereas the vast plains between them are made up of sandy muds, predominantly clayey (J. E. Mojski, 1990).

The development of the Wisła delta was conditioned by the evolution of the Baltic Sea, mainly as the erosional base to the Wisła. Through the palaeomorphologic evolution, an erosional depression in the form of a valley cutting the Miocene, Oligocene and Cretaceous deposits, has persisted along the Wisła. Its waters have deeply cut the Pleistocene surface, removing both the upper till of the Baltic Glaciation and underlying glaciofluvial series. That was the consequence

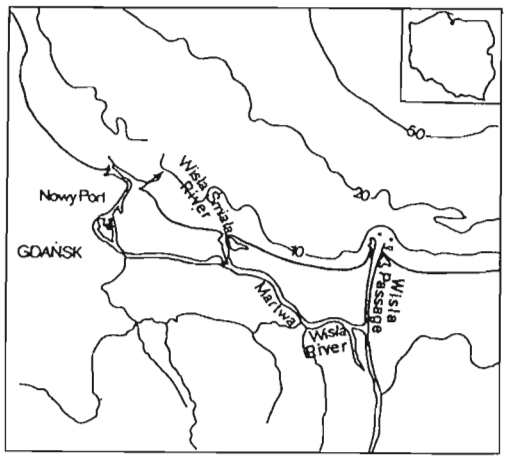

Fig. 1. Location sketch of the mouth of Wisła

Szkic lokalizacyjny ujścia Wisły

of the relationship between the erosional profile of the Wisła and contemporaneous erosional base determined by the sea-level of the basin which was forming in the Baltic area during the post-glacial period. The Wisła delta must have begun to form as a result of the Holocene sedimentation at the end of the Littorina transgression, that is hardly six thousand years ago (B. Augustowski, 1972). As early as at the final phase of the Littorina transgression, the Wisła was probably falling into a lagoon which had existed in the southeastern part of the Gulf of Gdańsk since at least the Pre-Boreal Period (S. Uścinowicz, J. Zachowicz, 1994).

The erosional profile of the Wisła was rissen by the Littorina transgression which forced the river to deposition. The Holocene sediments transported by the Wisła started to accumulate onto the Pleistocene substrate. The process took place repeatedly through the deposition of alluvial fans, at times of repeated migration of river channels of numerous Wisła arms over the mouth area.

A young delta fan was forming at the mouth of the Wisła Śmiała. Its subaqueous part is several times as much as the subaerial one. The latter is about 1 km in width. Thickness of the delta fan deposits amounts to about 10 m. Sand bars, made up of the material supplied by the Wisła, were formed within the Gulf of Gdańsk on the eastern side of the Wisła Passage (J. E. Mojski, 1990).

The process of delta progradation came to the end in the nineteenth century, when the main river current transferred from the Nogat River to the Leniwka River and found its way down to the sea through the mouth of the Wisła Śmiała. When the sluice was built on the Nogat, the river channel was straightened by digging a new passage at Świbno, and the Wisła Martwa as well as the Szkarpawa River were cut off, the whole water mass of the Wisła flew directly into open waters of the Gulf of Gdańsk.

HYDRODYNAMIC CONDITIONS

The major factor of all geomorphological processes, which take place within the zone studied, is wave action generating water flow. In the mouth of the Wisła, waves reach 20 cm in height and are one and a half times less than at the open waters of the Gulf of Gdańsk (K. Łomniewski, 1959). Apart from wave action, flows and sea currents play an essential part amongst dynamic processes of the shore zone. They result from the processes which take place in the southern Baltic. Sea currents are determined by both the sea-floor morphology and coastline shape. The sea-floor morphology is strongly affected by the compensative disruptive current which can transport a considerable amount of debris perpendicularly to the coastline, or carry it away towards deeper parts of the sea. Current velocity very rarely exceeds 50 cm/s (Z. Kowalik, 1990). Flow velocity in the river mouth is particularly important considering the sediment transport along the fairway. Before the Wisła Passage was digged, the flood-control of the mouth of the Wisła Śmiała, involving the flow concentration within one river channel only, had allowed the channel to be washed out, and the sediment to be removed towards deeper parts of the sea during spring thaws. The passage, digged in 1895, cut off the natural river arms of the Wisła from its main river channel.

There are two cycles of water circulation in the area studied. The first one, bidirectionally open, is between the mouth of the Wisła Śmiała and the mouth at Nowy Port. It enables unconstrained bidirectional water flow. The other one, separated from the mouth of the Wisła Śmiała by the Przegalina sluice, is a dead-end arm of the Wisła Martwa River (G. Kaptur, 1967).

The currents within the Wisła Martwa have been observed not to be of a river-current character (A. Majewski, 1980). Water flow within this river channel is characterized by a directional variability and stratification. Variations in directions of currents result from changes of sea-level and local anemobaric conditions.

In shallow waters of the shore zone, both sea-level changes and wind-generated currents, are equally important with those above mentioned. Prolonged, high winds blowing from the sea towards the land result not only in wind-generated waves but also in a flow of water mass in a landward direction. In case of shallow water which is characteristic of the shore zone, the whole water mass can be involved in the flow as deep as the sea-floor. Consequently, the nearshore sea-level rises. Winds from the land, on the other hand, push the waters out into the sea, and a sea-level fall takes place.

A prognosis of future sea-level changes is necessary to predict coastal erosion and analyse water exchange. The mean sea-level in the Gulf of Gdańsk, calculated for 90 years, is 498.7 cm (Z. Dziadziuszko, A. Wróblewski, 1990). The maximum sea-level was at Gdańsk–Nowy Port in January 1914 — 656 cm. Between 1946 and 1976, 110 stormy sea-level rises

above 550 cm, largely during autumn-winter seasons, were recorded. Considerable stormy sea-level rises usually take place once for two years, whereas low stands of sea-level can even last for two months. They influence the depth of fairways and the formation of ice-jams.

The data from a weather station at Gdańsk–Nowy Port show that the greatest number of calms is in summer. During all year, the wind speed does not exceed 5 m/s (*Warunki środowiskowe polskiej...*, 1993). The most abundant are southeasterly to westerly and northerly winds. Anemobaric conditions in a major way affect the sea-level.

A knowledge of ice-float occurrence conditions over the Gulf of Gdańsk is necessary to analyse the navigational conditions in the river mouth as well as to control an easy outflow of ice-float and flood waters (Z. Dziadziuszko, A. Majewski, 1990). The maximum duration of being covered with ice is about 90 days. The first ice usually appears at the end of December. The last one vanishes between mid-January and end of March. The maximum thickness of ice is 0.5 m.

Of different kinds of ice, ice-float predominates in the Gulf of Gdańsk. First, it appears in the Puck Bay and along the shore, then spreads out into its central parts. The ice-float rarely reaches far into the sea. Crowded together and crushed, ice-float masses are being pushed in towards the port by northerly winds.

Ice-jams are not a frequent phenomenon in the mouth of the Wisła Śmiała but they can be dangerous. There were ten ice-jams in the period 1946–1975 between Świbno and the mouth of the Wisła (Z. Dziadziuszko, A. Wróblewski, 1990).

A knowledge of hydrodynamic problems facilitates both understanding current situation throughout the area and predicting future evolution of the coastline.

BOTTOM SEDIMENT TRANSPORT

Bottom sediment transport in the mouth of the Wisła Śmiała is induced by waves and sea-current action. Within the shore zone, the alluvial fan sediments are derived from:

— a transport by the Wisła itself,

— the passage (completed in 1895),

— the eroded river floor,

— material dragged by the Wisła between 1895 and 1990 — 580 000 m^3/a (Z. Pruszak *et al.*, 1989),

— material transported in suspension by the Wisła during that period — 740 000 m^3/a, most of which was deposited in deeper waters beyond the fan (A. Tarnowski *et al.*, 1987–1990),

— a debris transported by nearshore currents — between 1895 and 1953 around 80 mln m^3 (S. Czernik, 1954).

There are three sites of deposition within the area studied:

— the Wisła mouth alluvial fan, cut off by the North Port breakwaters,

— the fan of the Wisła Śmiała, which may feed both mouth banks,

— and the fan of the Wisła Passage, feeding the region of the Wisła Śmiała from the east.

Alluvial fans cause wave-action conditions to be complicated and make the longshore transport difficult.

On the eastern side of the river mouth, the sediment transport from west to east prevails, chiefly due to northwesterly and westerly storm winds. The greatest amount of sand is transported during storms. In the locality of the mouth alluvial fan, the coastline curves owing to the fans shape, diminishing depths and a different sea-floor gradient, and so the westward transport predominates. The very intensive sediment transport resulting from a breaking of storm waves at the fan slope extends far into the sea. On the western side, the North Port is protected from northwesterly and northerly storm winds by breakwaters and therefore the sediment is transported here largely towards the west. The area located east of the port exhibits accumulative tendencies.

The analysis of the material presented in the paper clearly shows an accumulation process occurring on the western side of the river mouth, particularly intensive after the port had been built (Table 1). Of great importance is the unappreciated aeolian transport which causes the fairways to be sanded up. During easterly and northeasterly winds, the sand is deflated from the whole nonvegetated spit and transported into the river channel. A high unpreserved sand heap, located just near the river channel, makes the process easier.

COASTLINE CHANGES IN THE REGION OF THE MOUTH OF THE WISŁA

The main river current of the Wisła originally run into the Wisła Lagoon. In the XVIth century it carried about 85% of waters, but in 1800 the amount decreased to 65% (A. Majewski, 1969). The left river arm — the Leniwka River — was directed northwards and at a distance of 10 km from the Gulf of Gdańsk shore it branched into the Wisła Gdańska (with its river mouth at Gdańsk–Nowy Port) and the Wisła Elbląska. Beginning with the XVIIIth century, attempts to direct the main river flow into the Leniwka River were undertaken in order to prevent the Wisła Lagoon from shallowing. The attempts failed. The fan which was formed at the river mouth was the source area to a longshore sediment transport.

On January 31/February 01.1840, a huge ice-jam extending from Gdańsk to Wiślinka as well as a strong head of the Wisła waters (6 m above mean level) caused dunes to be burst. Swollen waters formed a new river mouth at Górki — the

Table 1

Coastline changes at the mouth of the Wisła Śmiała River between 1986 and 1993

Investigated area	Number of survey profile	Number (true bearing)	Ammount of coastline changes [m]					
			1986	1990	1992	04.1993	08.1993	10.1993
West side of the mouth of the Wisła Śmiała	1	028	0	(+)4.0	(+)26.0	(+)18.0	–	(+)21.0
	2	030	0	(+)9.0	(+)32.0	(+)18.0	(+)22.0	(+)48.0
	3	040	0	0.0	(+)32.0	(+)10.0	(+)32.0	(+)33.0
	4	046	0	(+)4.0	(+)27.0	(+)2.0	(+)35.0	(+)55.0
	5	050	0	(+)17.0	(+)10.0	(+)5.5	(+)42.5	(+)36.0
	6	060	0	(+)2.5	0.0	(–)1.0	(+)21.0	(+)7.5
	7	070	0	(–)8.0	(+)5.0	(–)2.5	(–)6.0	0.0
	8	080	0	(+)20.0	(+)16.0	(–)4.0	(–)7.0	(–)10.0
	9	090	0	(+)25.0	(+)17.0	(–)7.0	(–)11.0	(–)8.0
	10	100	0	(+)23.0	(+)10.0	(–)5.0	(–)14.0	(–)16.0
	11	110	0	(+)13.0	(–)3.0	(+)2.0	(–)21.0	(–)22.0
	12	120	0	(+)43.0	(+)44.0	(+)41.0	(+)34.0	(+)45.0
	13	127	0	(+)12.0	(+)75.0	(+)85.0	(+)85.0	(+)102.0
	14	130	0	(+)8.0	(+)75.0	(+)87.0	(+)88.0	(+)91.0
	14a	138	0	–	–	(+)66.0	(+)68.5	(+)63.0
East side of the mouth of the Wisła Śmiała	15	070	0	–	–	–	–	0.0
	16	080	0	–	–	–	–	0.0
	17	090	0	(–)4.0	–	(–)17.0	–	(–)1.2
	18	100	0	(–)3.0	–	(–)37.0	–	(+)12.0
	19	110	0	(+)27.0	–	0.0	–	0.0
	20	120	0	–	–	–	–	–
	21	000	0	–	–	(–)82.0	–	(–)82.0
	22	000	0	–	–	(–)66.0	–	(–)135.0

(+) — accretion of coastline; (–) — retreat of coastline; the authoress' observations based on bathymetric plans of the mouth of the Wisła Śmiała River (the Navy Hydrographical Bureau, 1986–1993)

Wisła Śmiała River. The development of the Wisła Gdańska fan had been inhibited and then the fan was subjected to degradation. The shore in the region of Westerplatte, formerly of an accumulative character, started to be eroded. It is proved by the presence of numerous relics of coastal consolidations (A. Majewski, 1969).

The river current of the former Leniwka became much more active and, being the main channel of the Wisła, about 14 km shorter. A constrained, more intensive flow of the Wisła Gdańska resulted in a deepening of the river and a falling of relative water level. The newly formed mouth of the Wisła remained unchanged for a few years. As bottom erosion in the delta area was increasing, the first islets made up of the material discharged by the Wisła began to form. Numerous shoals, islets and spits, which were being formed at the forehead of the river mouth, separated some parts of the Gulf of Gdańsk from the sea, causing them to develop into lakes gradually inundated with the sediment supplied through wave and sea-currents action (A. Majewski, 1969). The sediment supply caused the submarine alluvial fan in river mouth to be considerably developed. The Wisła waters formed themselves mouth channels within the fan, and the coastline was shifted seawards. When another channel was digged in 1895, the former Leniwka was lengthened northwards and the main Wisła channel again shortened by 9 km. The regulation works also included the cutting off with sluices of all the river arms of the Wisła, i.e. the Nogat, Wisła Elbląska, Wisła Gdańska and Wisła Martwa. The mouth of the Wisła at Świbno is an embanked channel, through which 2 mln m^3/a of sediment has been discharged into the Gulf of Gdańsk and deposited just at the mouth. This results in a progradation of a submarine delta of total capacity exceeding 140 mln m^3 (K. Łomniewski, 1960) and appearing as a number of islets of unstable shapes and sizes. The fan at the mouth of the Wisła Śmiała has been gradually degradated due to sea action since the passage was digged and the material supply ceased. Beginning with 1895, expanding tendencies of the coastline have been observed on the western side, and retreating on the eastern side of the river mouth. The amount of sediment deposited by the river in the form of a fan in the period 1840–1895 was about 109 mln m^3 (Lierau, 1892).

Between 1895 and 1929, the total increase of the mass of sediments deposited at the Wisła mouth was 57.1 mln m^3. In 1953 the amount increased to 83.58 mln m^3. This caused the gulf coastline to be changing permanently. Untill 1929 the coastline shifted by 1100 m on the western and 800 m on the eastern side of the river mouth (A. Rożankowski, 1938). From 1907 to 1967 the coast extended by 150 m in the western part, and 250 m at the river mouth. This was accompanied by a narrowing of the mouth from 250 m in 1907 to 90 m in 1940. East of the breakwater the coastline retreated by 150 m at that time.

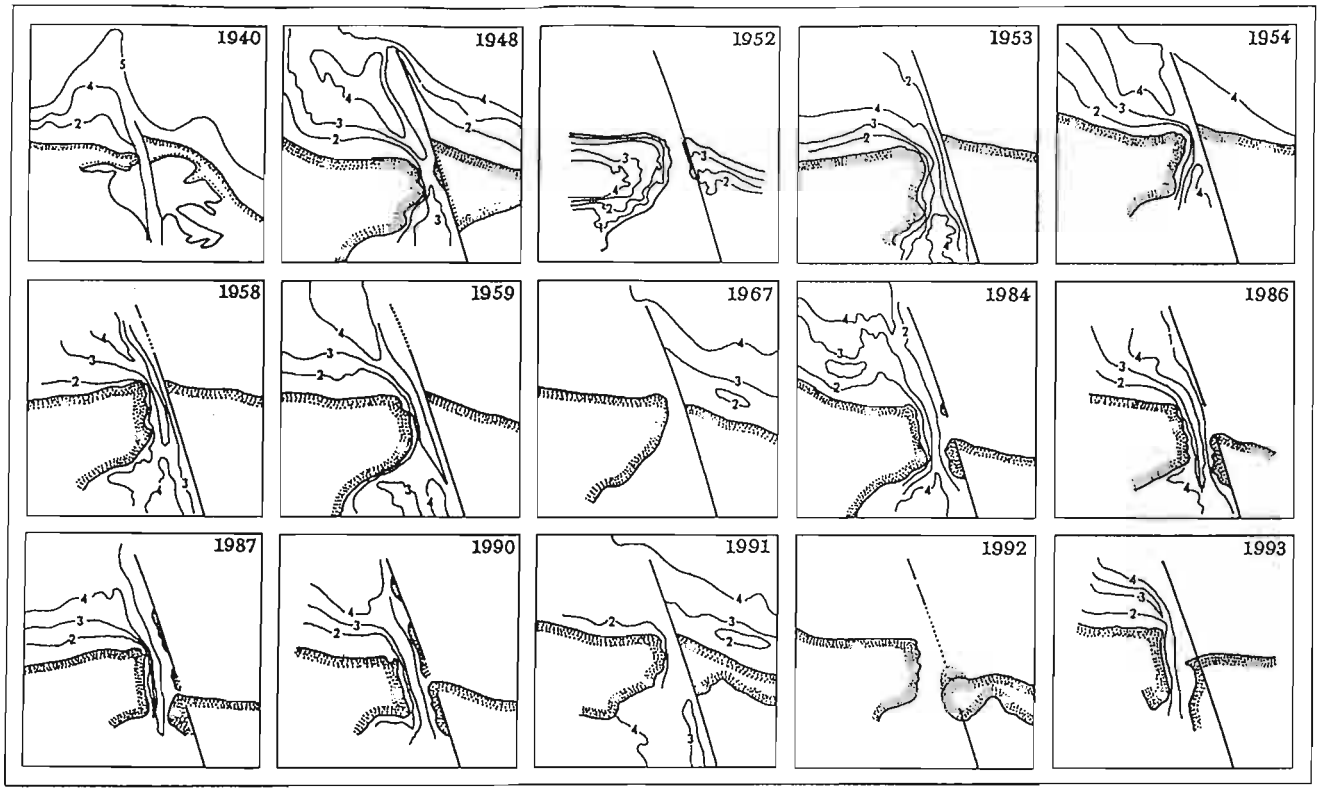

Fig. 2. Changes of coastline at the mouth of the Wisła Śmiała River in 1940–1993

Zmiany linii brzegowej w ujściu Wisły Śmiałej w latach 1940–1993

COASTLINE CHANGES AT THE MOUTH OF THE WISŁA ŚMIAŁA DURING THE LAST FIFTY YEARS

The coastline changes at the mouth of the Wisła Śmiała after the Second World War are shown in cartographic materials produced by the surveys engaged in the navigation (Fig. 2). These are, first of all, bathymetric plans produced by the Gdańsk Nautical Office (currently the Nautical Office in Gdynia) and the Hydrographical Bureau of the Republic of Poland. The position-hypsometric map at the scale of 1:2000, produced in 1952 by the Regional Enterprise for Geodesy and Cartography as well as the nautical maps published by the Navy Hydrographical Bureau (nos. 2, 52, 101), have also been used hereto.

The bathymetric plan of the mouth of the Wisła Śmiała, produced 15–31.07.1948, precisely shows an increasing coastline accretion in the eastern part compared with the western part of the mouth. The distance from the left entrance top (LET) of the breakwater to the coastline on the eastern side of the mouth was 320 m. The coastline on the western side retreated landwards by 120 m at that time.

The bathymetric plan produced a year later, i.e. between 18.08 and 31.08.1949, confirmed the situation of the previous year. The additional information is that the mouth became narrower due to a deposition which took place within the river channel on the eastern side. Another bathymetric plan produced four years later (12–15.12.1953) as well as the position-hypsometric map from 1952 show a different configuration, i.e. a coastline retreat on the eastern side of the mouth of the Wisła. It is noteworthy that such a retreating caused the coastline on both sides of the mouth to be in a *vis-á-vis* position.

In the sounding plan produced 9–15.07.1954 a distinct accumulation process on the western side, near the Górki Zachodnie harbour and a narrowing of the fairway in the mouth by 6 m, compared with the situation of 1953, can be observed.

The sounding plan which was made four years later, in the periods 23.05–26.05.1958 and 28.09–18.11.1958, confirmed the tendencies to accumulate deposits on the western side of the mouth and a further narrowing of the fairway.

The bathymetric plan, produced between 20.08 and 05.09.1959, provides another evidence of a progressing accumulation process on the western side of the mouth.

The nautical map of the Gulf of Gdańsk no. 52, published by the Navy Hydrographical Bureau in 1967, confirms the above-mentioned tendencies, i.e. a coastline accretion on the western side and a retreat on the eastern side of the mouth. The coastline changes are clearly visible as this map is compared with the German nautical map of the Gulf of Gdańsk no. 29, scale 1:75 000, corrected 3.12.1943.

Table 2

Basic parameters of the mouth of the Wisła Śmiała River

Date of measurements	Scale	Distance from the left entrace top (LET) to coastline [m]		Minimum width of fairway [m]		Ammount of accumulation in the east part of the mouth [m^3]	Comments
		east	west	distance from left	width		
15–31.07.1948	1:2000	400	320	450	52	–	
12–15.12.1953	1:1000	370	390	460	57	–	
9–15.07.1954	1:1000	360	420	420	47	–	
23–26.05.1958	1:500	360	392.5	410	52	–	
28.09–18.11.1958	1.2000	384	390	424	64	–	
20.08–5.09.1959	1:2000	364	394	454	74	–	
16–26.04.1967	1:1000	370	426	380	42	–	
3–12.10.1984	1:1000	400	572	420	67	230	
19.06–4.07.1986	1:1000	420	570	420	64	220	
30.10–11.11.1987	1:1000	398	610	414	60	256	dredged
18–27.04.1990	1:1000	450	–	456	90	270	
28.09.1992	1:1000	380	670	400	90	320	
29.04.1993	1:1000	400	662	518	110	–	dredged
10.08.1993	1:1000	440	–	440	78	–	
8.10.1993	1:1000	428	–	430	71	340	

The bathymetric plan of the mouth of the Wisła Śmiała produced during the period 3–12.10.1984, displays a growing accumulation on the western, and a retreating on the eastern side. The distance from the LET of the breakwater to the coastline on the eastern side of the mouth was 572 m and decreased as much as 252 m in comparison with that of 1948.

In 1987, a pier in the Górki Zachodnie yacht harbour was being covered up by sediments, and the fairway was narrowing. The coastline retreated on the eastern side by 20 m.

The bathymetric plan from 1990 shows a further accumulation process on the eastern side of the mouth (continuing covering the pier up) and the formation of shoals near the breakwater on the channel side. A wooden screen, which was just close to water, is shown in the sounding plan. Now the screen is deeply on land.

The bathymetric plan produced in 1993 very clearly displays a growing process of accumulation on the eastern side of the mouth. The wooden pier in the yacht harbour was completely covered up and the land area shifted as far as 65 m south of the harbour pier (Table 2).

SUMMARY

Many parts of the southeastern Baltic coast are threatened with systematically progressing erosion. An increasing process of destruction affecting the coastal area refers not only to the Hel Spit and Jastrzębia Góra coast, but also to the region of the mouth of the Wisła Śmiała. Episodically repeated catastrophic storms are the major threat to the areas lying in the immediate proximity to the sea (A. Majewski, Z. Dziadziuszko, 1985).

The mouth of the Wisła Śmiała, is the outflow channel to the swollen Wisła waters and the entrance to a complex of yacht and fishing harbours at Górki Zachodnie. During the last tens of years the mouth has been narrowing and shallowing.

The stone breakwater protecting the entrance has been destroyed by stormy waters. Concrete blocks have been washed away from its crown and its protective layer thrown about. Over its greater part the crown has been below the mean sea-level. That is why fishing boats, yachts and ships have been subjected to run aground or get shattered against the blocks. The lack of a breakwater has quickened the process of jamming the river mouth.

The studied part of the Gulf of Gdańsk coastline is an area where backshore is covered by an anterior dune, vegetated in many places. Its maximum height reaches 23 m at Górki Wschodnie. It should be agreed with opinion of A. Majewski and Z. Dziadziuszko (1985) that it is most unlikely to sea waters to be able to encroach upon the Żuławy Delta Plain through such a natural barrier.

Increasing coastal erosion has been observed at the mouth of the Wisła Śmiała since the 1960s. The spit and then a breeding-ground of waterbirds at the Ptasi Raj Lake will soon be encroached by the sea and probably lost for ever unless the degradation of the narrow dune belt is restrained. There have already been overflows of sea-waters from the gulf into the lake during storms when sea-level rose by 1.5 m. As soon as waves erode chutes in the sand, the spit will turn into a number of islets which then will be washed away. After the storm which had taken place in January 1992 the Ptasi Raj Spit was washed away and destroyed to a great extent. Over a much

area the spit was a flat, nonvegetated, sandy bar over which sea-waters could easily flow into the lake during a high stand of sea-level. There is also expected considerable coastal erosion on the western side of the river mouth. The evidence is the foundation of navigational buildings, standing originally upon a dune, now being on beach.

Sobieszewo Island, separated by a stone dike from the Ptasi Raj Lake, is human made. It is likely that the occurring changes have led to restore the original state. The river mouth, which is the entrance to the port of Gdańsk–Górki Zachodnie, has been shallowing due to a deposition of sand by sea-currents. Simultaneously, the stone breakwater has been being broken and the coastline retreated. The nature reserve and the whole mouth of the Wisła could be saved by restoring the spit. One of the methods is to pile up the sand excavated from the port entrance area.

It is inferred from the analysis of the maps of the mouth of the Wisła Śmiała which have been produced over the last fifty-year period that the coastline changes appear to have been a continuation of the phenomena taking place in the South Baltic, particularly the Gulf of Gdańsk. These are hydrometeorological conditions (winds, waves and sea-currents related to pressure changes) inducing hydrodynamic phenomena, especially the bottom sediment transport.

The bottom sediment transport in the region of the mouth of the Wisła Śmiała is generated by waves and sea-currents. It results in both an accretion or retreating of the coastline and a sanding-up of the mouth.

A transport towards the north-west and north predominates on the eastern side of the river mouth, mainly due to storm wind action. The east coast is controlled by the breakwater and the dike running to Górki Wschodnie. On the western side a transport towards the west prevails. Waves running to the north-east, enter the river mouth during a high stand of sea-level, wash dune slopes around and then transport the material southwards. This causes the near-pier area at Górki Zachodnie to be sanded up. The course of this process is best displayed by the 1992 sounding. The total balance of sanding-up is 40 000–59 000 m^3/a.

It appears from the analysis of the coastline changes that the supply of the material to the alluvial fan by the river in the region of the mouth of the Wisła Śmiała ceased due to the Wisła Passage digged. Just as the fan development was dependent only on the sea dynamics, it began to degradate. This caused the coastline to be changing.

On the western side a coastline accretion as well as a narrowing of the river mouth has been observed during the last tens of years. On the eastern side a coastline retreat has been noticed.

The above-presented facts show a natural tendency of the coast to have been slowly returning to the position from before 1840. Untill 1993 the entrance to the Gulf of Gdańsk had been sanded up. That resulted from the growing destructive process which the east breakwater and the west spur had been subjected to. The sanding-up, variable depth of the fairway and low visibility of the breakwaters during high stands of sea-level cause the entrance to be very dangerous.

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PROCESY DYNAMICZNE W UJŚCIU WISŁY ŚMIAŁEJ

Streszczenie

Ujście Wisły Śmiałej powstało w 1840 r. Rozbudował się podwodny stożek napływowy, na którym spływające wody Wisły formowały rynny ujściowe. Rozwój stożka Wisły Śmiałej trwał 55 lat. Wykonanie przekopu Wisły spowodowało zahamowanie napływu materiału rzecznego do stożka. Na skutek działalności morza nastąpiła jego degradacja.

Obecnie stożek ujściowy zewnętrznej delty Wisły ulegał rozmywaniu, a nie bagrowane ujście Wisły Śmiałej — zapiaszczaniu. Kształtowanie stożka, uzależnione od dynamiki morza, było powodem zmian linii brzegowej. Suma odłożonego na stożku ujściowym rumowiska wynosiła 109 mln m^3. Zaobserwowano tendencje rozrostowe brzegu morskiego po stronie zachodniej ujścia oraz cofanie się po stronie wschodniej. Od wykonania przekopu Wisły obserwuje się stałe przesuwanie linii brzegowej. Zmiany te przedstawiają tab. 1 i 2 oraz fig.2. W ostatnich dziesięcioleciach obserwuje się narastanie linii brzegowej po stronie zachodniej i cofanie się linii po stronie wschodniej oraz zwężanie ujścia Wisły Śmiałej poprzez zapiaszczanie.