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Morpholithodynamic Properties of the Shore Zone on the Coast of Szczecin

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Abstract

The paper deals with the southern part of the Baltic Sea shore zone, called the Coast of Szczecin, from the morpholithodynamical point of view. The coastal zone is divided into three types, namely coast, shore and nearshore. The morphodynamic character of the shore is presented in distinguished cliff and sandbar-dune areas. Further, lithological properties of the shore zone sediments are discussed. Finally an attempt of both qualitative and quantitative estimation of sediment supply to the nearshore zone is described, as are the natural conditions affecting its further transportation.

1. Introduction

The Coast of Szczecin is included – as regards maritime administration (Maritime Office, Szczecin) – within the 345.5–428.2 kilometre of the coast line, i.e. 82.7 km long. The cliff coast is 32.9 km long, and the sandbar-dune – 49.8 km long.

In this paper the coastal zone is defined according to the modified classification of S. Rudowski (Racinowski 1974). Within the coastal zone one can distinguish coast, shore (beach), nearshore.

Coast is the ascending strip of land, to the base of which the swollen storm waters flow. When this embraces the Pleistocene plateau slope, we speak of *cliff coast*. If the coast is the dune bar, it is called the *sandbar-dune* coasr. It results from the fact that here the contemporary coastal dunes replace the typical sandbar deposits.

Shore (beach) is the area along which the *coast line* changes at different levels. In the lower part of the shore, where this meets the sea water, is *surf flow zone*.

Nearshore is the area just below the sea surface the bed of which is subject to transformed surf waves. In this part of the shore zone, the shallow nearshore of 6 m in depth can be distinguished, where a strip about 100–300 m wide clings to the shore, where the submerged bar fields are formed. The deeper nearshore is located within the depths of 6–10 (14) m below sea level.

The present report has been worked out on the basis of perennial researches, which carried out in the Geotechnical Department of the Technical University of Szczecin. Other scientific and research institutes' publications and archive materials concerning this subject have also been used here. Due to the quantity of material, the references mention only the synthesising pieces of elaboration, which include detailed lists of subject literature. We would also like to draw attention to the fact that the detailed and retrospective literature overview concerning Baltic shores, as well as the area discussed until the mid 1990's is included in the paper by Mader (1995).

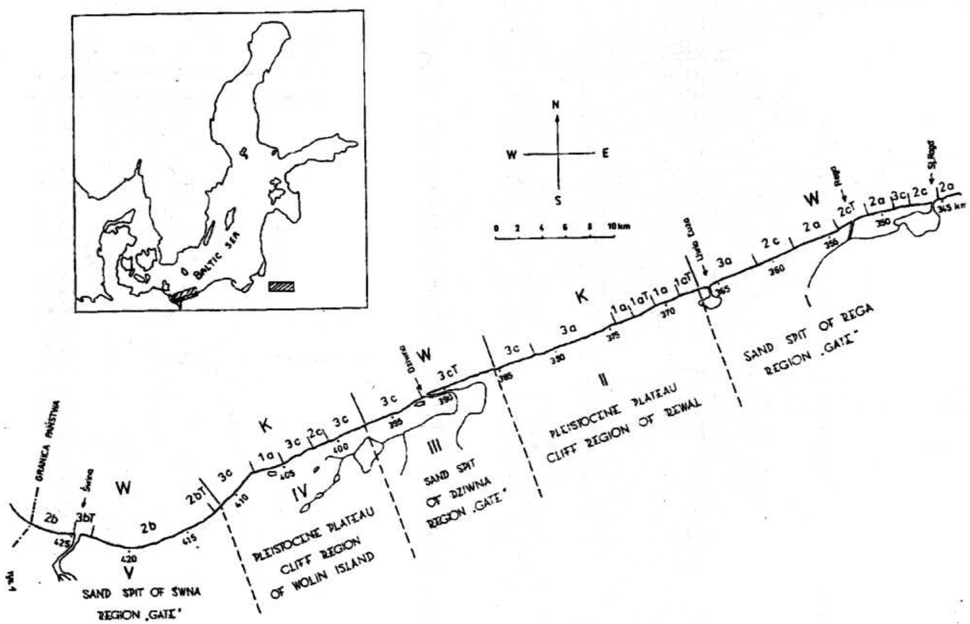
2. Morphodynamical Character of the Shore

On the Coast of Szczecin one can distinguish five cliff and sandbar-dune areas being in contact with one another (Figs. 1–3). Their general overview began from the eastern side.

The sandbar-dune area of Rega Gate (km 345.5–367.0). The coast height varies from 2 and 7 m on the eastern side to 6 and 10 m on the western side. The coast consists of the frontal dune, which is built of medium and fine sands. Organic soils come to the surface at the dune base in some places. The average width of the beach changes during the year from 13 to 65 m. The shore-line consists of shore curves, the chord of which is 300–500 m, but on the eastern side it can be even 2000 m long. Generally 11 km of the shore is now in the phase of intense abrasion, and 8 km – in a state of unstable development. Only 3 km of the shore is stable section. Over 30 years the annual average loss of land is estimated at 0.2 m, however, after a heavy storm it can be even 1 m. Post-stormy losses of shore are eliminated relatively quickly due to the natural blowing of sediment to the dune slope lying at the sea's edge. This process occurs with winds blowing rectangularly or at a certain angle from the sea side. In order to stabilise the shore, to protect upper and lower parts of dune embankments wicker or geotextile matresses, strengthened with concrete blocks are used. The upper part of the dune coast is reinforced biologically. Natural development of the shore, its destruction and reconstruction hindered by the breakwater in Mrzeżyno where the Rega River fall to the Baltic Sea.

The nearshore is about 99.8 km^2 in area. In its shallower part, that lies in the land adherent strip of around 100–300 m width, is the changeable submerged bar area with two or three low torn-out strips of submerged bars.

The cliff area of Rewal Plateu (km 367.0–385.7). The cliff coast is the sea-devastated slope of the ground moraine cliff, which is formed by sandy clays with gravel admixture. This material contains some thin interbeddings of medium and fine sands, thereby the ground water is filtered from the cliff wall. In the area of Śliwin there is a Mesozoic clayey xenolith in the cliff wall. The average cliff height



K -Cliff shore:
Geomorphological attributes:
1 - typical cliffs without dune screens,
2 - cliffs with front close-to-edge dune screen,
3 - cliffs with ower-edge dune screen.
Development tendencies:
a - continuous devastation (phase of continuous development),
b - full stabilisation (phase of extinct abrasion),
c - temprorary stabilisation (phase of unstable development),
T - techogenic shore - development formed by hydrotechnical buildings influence.

W- Dune shores:
Geomorphologic attributes:
2 - dune shores of medium height (15-8m),
3 - low dune shores (below 8m).
Development tendencies:
a - destruction dominates (phase of abrasion development),
b - stabilisation and accumulation of sea sand dominates,
c - changeable development directions (phase of unsteady development),
T - techogenic shore - development formed by hydrotechnical buildings influence.

Fig. 1. Morphological types of the Szczecin Coast according to L. Bohdziewicz (1963) in 1958–1959 with the regional division made by the authors is 1992

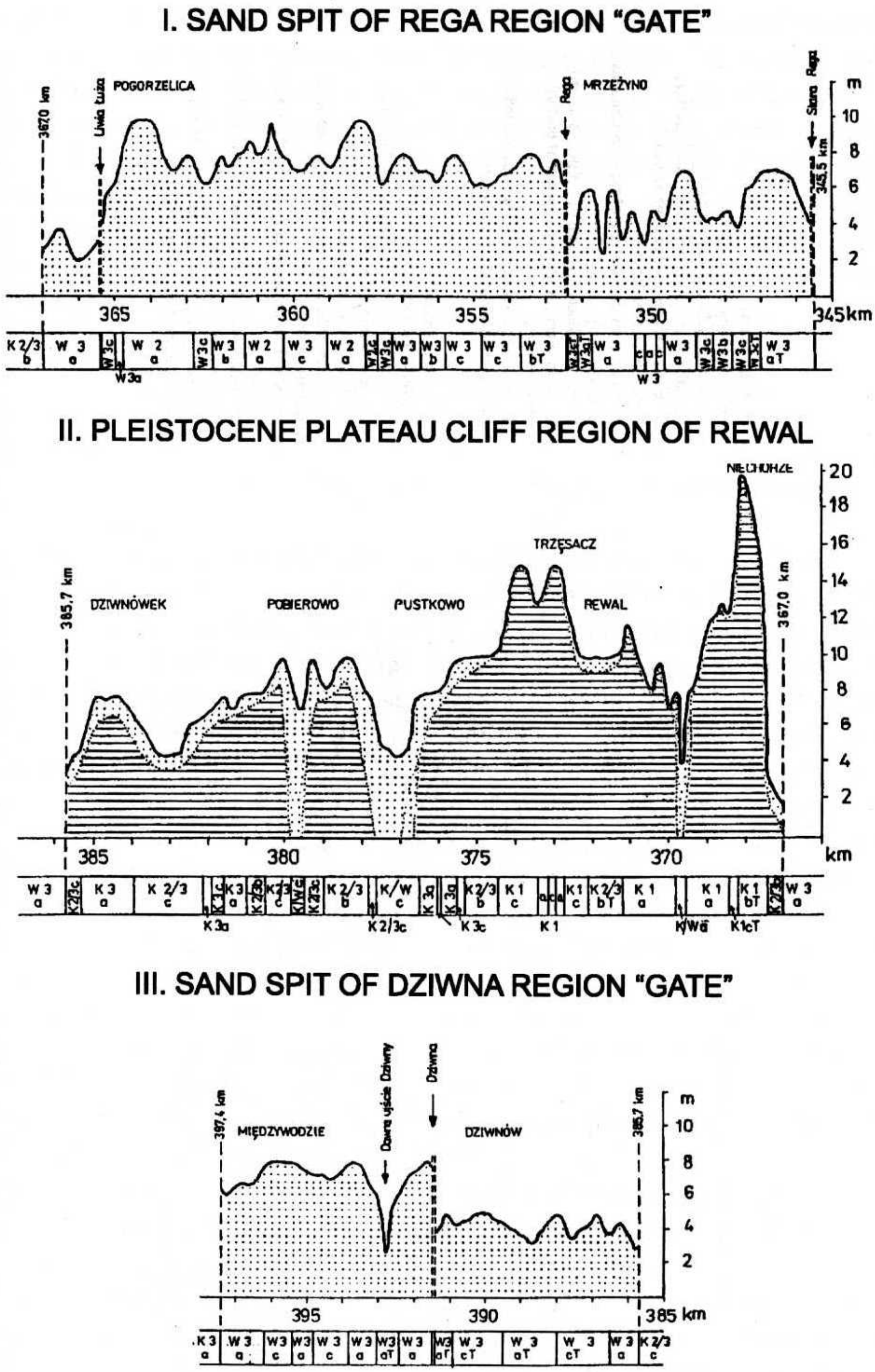
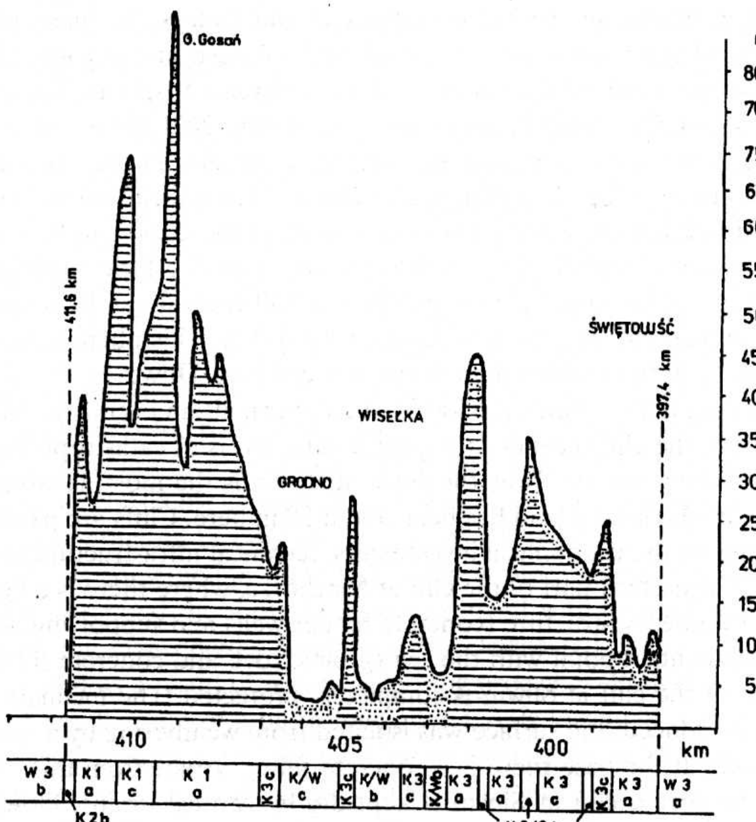


Fig. 2. Typology of morfodynamic regions (I–III) of Szczecin Coast. Symbols are explained in the Fig. 1. Horizontal lines in profiles have been used to mark Pleistocene formations of the hills; Holocene dune sedimentation has been marked with dots

IV. PLEISTOCENE PLATEAU CLIFF REGION OF WOLIN ISLAND



V. SAND SPIT OF ŚWINA REGION "GATE"

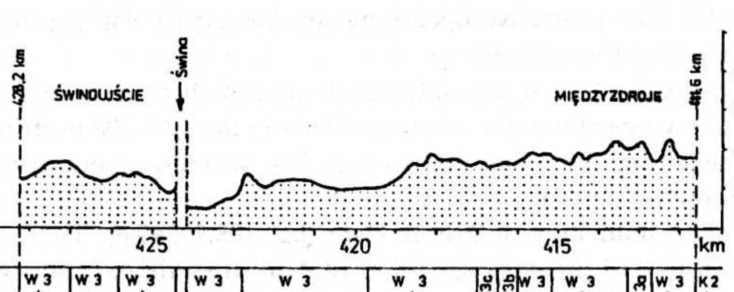


Fig. 3. Typology of morfodynamic regions (IV–V) of Szczecin Coast. Symbols are explained in the Fig. 1. Horizontal lines in profiles have been used to mark Pleistocene formations of the hills; Holocene dune sedimentation has been marked with dots

is 9 m, but it lowers distinctly from the east (16–20 m) to west (7–10 m). The upper cliff edges are built in addition, of eolic sands in the form of *aeolian sands.*

The cliff walls are slit by three vestiges of old valleys. In these places the coasts consist of eolic sands with layers of mid-cohesive and organic Holocenic soils. The average width of the shore oscillates between 10–50 m. The shore-line is corrugated, but the chord of shore arcs are mainly 200–300 m. At a distance of about 6 km the coast is greatly devastated, especially in the sections in km 368–371 and km 382–385. At a distance of about 7 km the cliff coast is in a state of unstable development. Only 4-km-long section of the coast can be considered to be in the phase of stabilisation, even if the sea state is a little too high.

On the basis of historical data from the last 200 years it can be assumed that the average annual cliff recession is between 0.1–1.0 m. This phenomenon occurs more intensively in the eastern than in the western part. However, this data differ slightly, as during heavy storms the losses of coast can attain even 2 m. After relative stabilisation, the cliff recedes at a greater rate and is of catastrophic character during heavy winter storms. Now the coast at Śliwin is the most devastated: over the last 30 years the loss of land has been about 20 m here. Cliffs are partly protected, depending on the economical investments, technical infrastructure and tourist importance. The eastern part of the cliff at Niechorze, where there is a lighthouse, is protected by a heavy structure (concrete fender wall) and supporting active protections at the contact point with the sea (groins, rock and concrete fillings). The small section of the cliff at Śliwin is completely protected. The inclination of the cliff scarp was reduced, the surface was isolated from weathering by a special geomembrane, and at the base there is a concrete filling. Apart from this, the entire strip of the protected cliff at Śliwin is kept dry by vertical drains. However, the devastation of the coast has been intensified to the east and partly to the west of this structure. Ruins of a monumental church in Trzęsacz are protected by rock fillings at the cliff base. The western lower cliff section (Pustkowo–Dziwnówek) is stabilised in principle. In some places the fore-cliff dune is tightened to the wall of the low cliff. The protective operations are limited to planting bushes on the scarp and inserting the rock fillings.

The nearshore, adjacent the cliff, has an area of about 28.5 km^2. In the shallower part of the nearshore are submerged bars in the 100–200 m strip contacting with the land. They have one or two very low submerged bars, whose profile change very quickly in time.

The sandbar-dune area of Dziwna Gate (km 385.7–397.4). The coastal dunes in the eastern part of this area are lower (3–5 m) than those in the western part (higher than 6 m). The front dunes are built mainly of medium sands. Organic soils are revealed in some places in the western part of the sandbar. The average width of the beach oscillates between 5–40 m over the year. Corrugation of the shore line has shore arc with 200 or 300-m-long chords (occasionally even 500 m). The entire eastern section of the sandbar is in the phase of abrasion. The western part of Dziwnowska Sandbar is undergoing a phase of unstable development. The annual average losses of shore in the eastern part of this region are estimated at around 0.4 m, and in its western part – around 0.2 m. However, in some places the upper dune edge recedes at about 1.0 m towards the land during heavy winter storms. The eastern part of Dziwnowska Sandbar is especially protected for economic and touristic reasons. The breakwater, which is situated in Dziwnów at the drift of the Dziwna River mouth to the Baltic Sea, has a very serious influence upon the abrasion process in this part of the Sandbar. During heavy storms the low and narrow embankment of the dune coast can be broken and sea water can flow over to Wrzosowskie Lake and Kamieński Lagoon. The shore of Dziwnowska Sandbar area is protected by a system of active bank (open-work groins, T-shaped groins, remains of an underwater sill). The upper part of the beach and base of the dune embankment are protected by mattresses and concrete fillings, which prevent sand from being washed-out and blown-away. The middle and upper parts of the dune slope are protected using biotechnical methods. The coast section in Dziwnówek, which is most exposed to devastation, is protected by a steel sheet pile wall with superstructure by concrete seawall with fender beam. At the base and in the sides of this construction there is a concrete block filling. Some attempts are being made to rebuild the shore by its nourishment with dredged material. In the western part the Dziwnowska Sandbar is less devastated, and the coast shortage is reconstructed as a result of natural deposing processes. Protective operations in this part of Sandbar are of a biotechnical kind, only locally in the form of groins.

The nearshore adjacent to the land has an area of about 23.5 km^2. In the shallow nearshore there are some disrupted fields of low chains (1–2) of submerged bars in the 100–300-m-wide land strip.

The cliff area of Wolin Island Plateau (km 397.4–411.6). Polands highest cliffs are in this area. The average height of the cliff wall is around 25 m, but it varies between 7 and 90 m. The cliff walls consist mainly of fluvioglacial medium sands with an admixture of rocks, stones and gravel. Sometimes moraine clays represented by sandy clays with an admixture of rocks and gravel can be found there. Some places boast silty clayey xenolith of Mesozoic sediments. The cliffs are covered by eolic sands. The cliff walls are slit here by three valley lowerings, which are now closed from the sea side by 2.5–7.0-m-high coastal dunes. Thus, this section has the character of a so-called cliff-dune coast (area of Wisełka and Grodno). The average annual width of beaches varied from 7 to 40 m. The shore-line is corrugated, and the length of shore arc chords is about 200–300 m (maximum 500 m). There is an active cliff along the entire distance. However, in km 400.5–410.5 the sediment is deposited periodically on the shore. Between 410.5 and 411.6 km the stabilised cliff coast can be observed and in front of it there is a low embankment of cliff dune. The cliff on 407.5–410.5 km is the one, devastated most intensively. No protective operations have been undertaken to protect the sea shore from abrasion due to Wolin National Park. Land devastation processes proceed naturally therefore in the entire section discussed. On the basis of historical data it is assumed that during last 300 years the land recession rate is about 0.5–0.9 m/year. During the last 35 years the upper cliff edges receded at the rate of 3 m/year in the eastern part of this area, and in the western part – even 5 m/year. These changes can be noticed easily in the bird's-eye photos, with the help of which changes in upper cliff edge location are observed. The material, which falls down from the devastated cliff walls, masks the rate of cliff base recession to a great extent.

The nearshore adjacent the land has an area of about 21.2 km^2. The shallow nearshore contains some disrupted fields of low chains of submerged bars in the 50–200-m-wide land strip.

The sandbar-dune area of Świna Gate (km 411.6–428.2). In Poland the length of this region is 16.6 km. The frontal coastal dunes are 2–4 m high. In their hinterland there is an entire system of older dunes creating the area of Świna Gate. The coastal dunes consist mainly of medium and fine sands. Between Międzyzdroje and Świnoujście the 9-km-long section of the coast has an accumulative character. It is estimated that the land increases at ca. 0.4 m yearly. In the 5-km-long section, accumulation and abrasion processes are balanced. The abrasion process dominates the accumulation only in a section about 2-km-long, lying to the east of the breakwater in Świnoujście and to the west of Międzyzdroje. The average width of the beach oscillates between 15–90 m in a year. The average length of shore arc chord is around 300–500 m. The protective operations are limited to biological development of dune coastal dunes in order to prevent them from blowing-away and washing-out by weak flows of stormy water.

It is difficult to determine the lower border of the nearshore due to the very gradual slope of the sea bottom. It can be assumed that this nearshore in Poland has an area of approximately 35 km^2. In the shallow nearshore there are some low and changeable submerged bars with distinct 2–4 embankments in the 100–300-m-wide land strip.

3. Lithological Properties of Shore Zone Sediments

3.1. Sediment of Cliff Coast

Cliff walls contain sediments with a changeable layers system, as well as sediments indicating considerable age, genetic and lithological differentiation, which has a significant influence upon the development of geodynamic processes in cliff walls.

The Pleistocenic sediments, such as glacial clays, fluvioglacial sand-gravel or silty sediments are the predominant formations creating the cliff.

Moraine clays build mainly the cliff walls in the Rewal Plateau. They are represented by sandy clays and clayey sands with admixtures of gravels and stones. The percentage share of the basic fractions is included within $f_z = 0.5$–10%, $f_p = 37$–66%, $f_\pi = 20$–36%, $f_i = 9$–19%. Quartz, feldspar, muscovite constitute the basic components of the mineral framework. The silt fractions contain quartz, formless sillica, crystalline and formless calcium carbonate, ferrous oxides and hydroxides. Illite is the most characteristic of silty minerals, smectite – less characteristic, kaolinite appears sporadically. In thick-grained fractions there are chips of crystalline rocks, limestones and sandstones. **Siltstones** are represented by clayey or silty sands. They are similar to glacial clays in respect of mineral properties. The cohesive soils that create cliffs are generally characterised by natural moisture $w_n = 8–15\%$, consistency index $I_c = 9–20\%$, filtration coefficient $k = 10^{-10}–10^{-12}$ m/24 h.

The narrow sandy interbeddings in the cohesive soils play an important role in the development of cliffs, which are built of such soils. They make up a complicated system, by the help of which the ground water infiltrates from the land causing the change of clay consistency, which in the end is the reason for development of landslides on the cliff walls.

Among cliffs there are **Mesozoic rocks** usually in the form of accidental inclusions or glaciotectonic ground escapes. These sediments have a mainly silty, clayey or loamy character. In clays the content of fraction < 0.002 mm very often exceeds 40%, while in little cohesive soils the fraction 0.06–0.002 mm predominates its content being more than 60%. The mineral framework of these soils consists mainly of quartz, feldspars, muscovite, ferruginous aggregates, shapeless silica, carbonates. The clayey minerals are represented by smithite and ilmenite. Characteristic of these is natural moisture $w_n = 35–47\%$, consistency index $I_c = 30–60\%$ and filtration coeficient oscillating between $k = 10^{-11}–10^{-13}$ m/24 h.

Sandy deposits of fluvioglacial origin are the main material forming the walls of the highest Polish cliffs on Wolin Island Plateau. There are mainly medium, more seldom fine and sporadically coarse sands and all-in aggregates. Fractions of 0.5–0.25 and 0.25–0.12 mm predominate here. The mineral framework consists mainly of quartz and a small quantity of feldspars. In thicker fractions there are limestones and sandstones, apart from chips of crystalline rocks. These soils are little moisturised and medium densed $I_D = 0.5–0.7$. The infiltration coefficient amounts to around 2–12 m/24 h.

3.2. Coastal-dune Formations

The hinterland of the shore zone there can exist 3 or 4 generations of differently-aged dune banks. Seaside dune bank is subjected to periodical devastation under the influence of stormy waters and strong winds blowing from the land or along the embankment. The front dune however, is reconstructed very quickly due to the favourable influence of sea water and wind.

The coastal-dunes are built mainly of medium sands, more seldom fine ones. More than 90% of the sand mass has a diameter of 0.5–0.12 mm. These soils are loose, $I_D < 0.3$. On the surface they are usually dry, and deeper – slightly moist. The filtration coefficient is around 5–20 m/24 h.

A very important problem concerning the coastal-dune shore is to determine the thickness of dynamic strata, which are continuously subjected to morpholithodynamic transformation. Different lithological settlements, which eolic settlements are based on, can be considered to be the sole of such a layer. Such sediments can be decidedly thicker (e.g. all-in aggregates, gravels) or finer (e.g. muds, clays) or organic-derived (e.g. peats, warps). They can also be – as far as graining is concerned – dune like, but containing chips of sea molluscs shells, or they can differ considerably in colour (e.g. grey, brown).

The entire sediment of coast dunes is set into motion, when winds blow faster than 7 m/s. Tendencies to sand deposition occur, when winds blow slower than 3 m/s.

3.3. Beach Formations (Shore)

These formations constitute superficially deposited sediment, which plays an active role in forming the longitudinal and transverse beach profile under the influence of sea water and wind. The abrasive platform, which is built of glacial clays or gravel-stony residues, can be considered to be the floor of the dynamic layer. In the sandbar-dune sections, the abrasive platform can be considered to be the roof of organic deposits, sands with mud interbeddings or sands with chips of sea molluscs shells. The thickness of shore dynamic strata oscillates between tens of centimeters in the cliff areas and more than 2 m in the coastal-dune areas.

Rapid differentiation of graining is a characteristic property of the shore sediment. During several or tens of hours the abraded coast is transformed completely into sediment. It happens within the section covering tens of hundreds of kilometres away from the washed-out coast. The beach material in the entire section of the Coast of Szczecin is characterised by similar graining. These are usually medium sands with gravel admixture. The dominant fraction 0.50–0.25 mm is fed back by elements diameters of 0.25–0.12 mm. There are practically no fractions smaller than 0,12 mm. On the beach surface, among sands there are stones but single boulders only in the cliff sections. The beach sediment is enriched in the gravel fraction also in places, where the abrasive platform is washed out intensively in the nearshore and its coarse elements are deposited on the shore.

It is considered that the beach sediment is washed out, when the storm water flow velocity is more than 1 m/s, and when it is around 0.2 m/s, the shore is reconstructed. The dry beach material is blown away, when the wind exceeds 12 m/s. Favourable conditions for sediment deposition occur, when the wind velocity is less than 3 m/s.

At the point of sea-land contact, the sediment is thicker in **the zone of surf flow**. Its lower part contains mixed coarse sands, all-in aggregates and gravels.

The beach and surf flow zone sediments consist of quartz in more than 80% in the sand fraction, other components are: molluscs, other minerals of crystalline rocks and chips of sedimental rocks. The crystalline rocks predominate in the gravel-stony fraction, sandstones, limestones and mudstones appear in smaller quantities.

3.4. Nearshore Formations

The nearshore of the Szczecin Coast lies is a relatively flat area with a slope of 1–6%, width of 800–1500 m and depth reaching 10–14 m below the sea surface. In the shallow nearshore this area shows some slight delevellings related to the occurrence of time-changeable bar profiles. In some places in the nearshore zone are rectangular or skew oblong sections of bed, caused by rip currents.

Basing on fragmentary observations the thickness of the sediment dynamic strata is estimated at 0.3–2.0 m. However, in the nearshore there exist places, where there is no contemporary bottom sediment and sediments creating the abrasive platform are revealed. These are concentrations of loamy and peaty formations or gravel-stony residual sediments. It is observed that the thickness and lithological properties of dynamic layer are differentiated. Nevertheless, it can generally be stated that the kind of sediment graining is subjected to relatively small transformations in the entire nearshore zone. The fine sands with predominating fraction 0.25–0.12 mm and supporting 0.5–0.25 mm prevail in the nearshore. In the deeper nearshore a wide area is covered by sediment, represented in more than 20% by silty sands with content of fraction 0.06–0.006 mm. In the shallower nearshore medium sands can also be found. In the nearshore there are also residual sediments, which are coarse sands, all-in aggregates and gravels.

Single grains are transported in the nearshore, when the demersal water velocities are higher than 0.15 m/s. When these velocities exceed 0.25 m/s, the sediment is transported in the greater mass. All sediment components are put into motion, when water velocities are higer than 1.0 m/s. In the shallower part of the nearshore the entire sediment is put into motion at the sea state of 3°B, while in its deeper part the sea state must be higher than > 5°B to put the sediment into motion.

4. Fresh Sediment Supply to Nearshore and Tendency of Its Transportation

The deposits formerly building the sandbar-dune and cliff shores are the source of sedimental material in the nearshore.

On the basis of standard lithological research it can be stated that sandbar-dune coasts are created by sediments, which are in the last phase of graining differentiation. During the abrasion process of these coasts the washed-out material is collected in principle only in the shallowest nearshore, where it is transported rectangularly and parallel to the shore. In favourable conditions the sediment is deposited once more on the shore and coast dunes. The sediment coming from the washed-out sandbar-dune coasts can reach the deeper nearshore only in small measure due to typical hydrodynamic conditions in this shore zone in Baltic Sea.

It is therefore believed that the sediments creating cliff coasts are the basic source of material supplying the nearshore. The mineral land material reaching the sea is subjected to differentiation processes in respect of graining and is the basic material for building the dynamic layer of sediment in the nearshore.

On the basis of the morphodynamic character of the Coast of Szczecin it can be stated that the cliff of Rewal Plateau and Wolin Island Plateau, which are being devastated irreversibly, are the main source of fresh material for the nearshore. Knowing the length of the devastated coast of the cliff (L), its height (H), rate of recession (A), graining character of material creating coast walls and properties of sediment graining in the nearshore, it is possible to define approximately the rate of fresh land material supply to the sea.

In the case of the Rewal Plateau the length of this area is about 18.7 km, however, the coast is devastated actively only on a section of about $L = 17$ km. Its average height is assumed to be $H = 8.0$ m, and the recession rate $A = 0.3$ m/year. The presented values are greatly underrated and the obtained result represents the supply to the nearshore during years of the calm weather regime. The annual volume (V) of material, moving from cliff to the sea is estimated at:

$$V = L \times H \times A = 17\,000 \text{ m} \times 8 \text{ m} \times 0.3 \text{ m/year} = 40\,800 \text{ m}^3\text{/year}$$

The weighted average graining is: $f_z = 4\%$, $f_p = 56\%$, $f_\pi = 28\%$, $f_i = 12\%$, as the cliff coast consists mainly of loamy glacial soils and partly Holocenic eolic sands and clayey xenolith of the Mesozoic rocks. The average graining for the 15-km-wide coast touching the cliff along the 19-km-long section is: $f_z = 3\%$, $f_p = 95\%$, $f_\pi = 2\%$. This means that about 40% of the washed-out land material is transported to the deeper sea and only 60% of it remains in the nearshore zone. It can be assumed that each year only ca. 24.5 thou. m^3/year of the fresh land material is transported to the nearshore with an area of about 28.5 km^2. This also means that about a 1-mm-thick layer of the "fresh" mineral sediment is translocated through 1 m^2 of the nearshore.

The volume of fresh material supply to the nearshore from the cliff of Wolin Island Plateau was defined analogically. The length of this area is about 14.2 km, but walls are devastated actively in only the 10-km long section ($L = 10$ km). Their average height is assumed to be $H = 25$ m, and annual recession rate $A = 0.5$ m. The assumed values are also underrated in this case. The annual volume (V) of material, which moves from cliff to the sea is estimated at:

$$V = L \times H \times A = 10\,000 \text{ m} \times 25 \text{ m} \times 0.5 \text{ m/year} = 125\,000 \text{ m}^3\text{/year}$$

It can be assumed that approximately 70% of the cliff wall consists of fluvioglacial Pleistocenic sands, and the other part built of glacial clays and other less cohesive soils, as well as Mesozoic clayey xynoliths. The weighted average graining of the cliff material is: $f_z = 5\%$, $f_p = 75\%$, $f_\pi = 13\%$, $f_i = 7\%$. The average weighted graining for the 1.5-km-wide nearshore touching the cliff of Wolin Island Plateau in the 14-km-long section is: $f_z = 2\%$, $f_p = 97\%$, $f_\pi = 1\%$. This means that about 20% of the washed-out cliff is transported to the deeper sea and only 80% of it remains as sediment of the dynamic layer in the nearshore adherent to the cliff. It can be approximately assumed that every year only ca. 100 thou. m^3/year of the fresh land material is transported to the nearshore with an area of about 21.3 km^2. In other words, around 5-mm-thick layer of "fresh" mineral sediment is translocated through 1 m^2 of nearshore water.

The thin layer of active sediment, which has been stated as being in the cliff nearshore of Rewal Plateau and Wolin Island Plateau indicates clearly that in this layer there is intense movement of material along and across the shore. The phenomenon of washing-out and transportation occurs even at small demersal water velocities amounting to 0.2 m/s. Additionally, the fact taken into consideration should be that the abrasive platform of the nearshore enlarges its area due to successive movements lowering the Coast of Szczecin, these being estimated at 1–3 mm per year.

Unsaturated along-shore sediment flow transports the sediment from the nearshore of Rewal Plateau cliff to the east and west. However, it is such a small quantity that it does not cause any considerable creation of abraded coastal dunes. This sediment reinforces the bars, which keep it in the state of labile balance. It is believed that these bars are natural obstacles to weaken the recession rate of the sandbar-dune coast of Rega and Dziwna Gate.

The much bigger supply of sediment from the cliff of Wolin Island Plateau is the reason why dune-cliff sections in the area of Wisełka and Grodno are periodically reconstructed. However, the Wolin nearshore sediment is generally transported towards Świna Gate and deposited there on the shore. It causes a relatively effective increase of land in this section of the Coast of Szczecin.

The presented situation, limits in a great extent the possibility of artificial shore protection and reconstruction with the help of the nearshore dredged material on the Coast of Szczecin due to serious shortage of sediment.

5. Final Remarks

1. In the light of lithological research it can be noted that there is a close relationship between coastal dunes, beach and nearshore formations and Pleistocenic sediments creating cliffs and appearing in the abrasive platform. The cliff sediments are tractable to devastation (abrasion, superficial mass movements), which causes irreversible changes in configuration of the border-line between land and sea.

It is estimated that every year, about 166 thou. m^3 of the "fresh" mineral material passes from the cliffs of Coast of Szczecin to the Baltic Sea, thereof around 125 thou. m^3 has a diameter of over 0.06 mm and "reinforces" the widely-understood shore zone of the sea. The remaining part of the terigenic material is transported towards the deeper waters. This means that around a 1- or 5-mm-thick layer of the "fresh" mineral sediment is translocated through 1 m^2 of the nearshore daily. This material transforms its graining very quickly under the dynamic influence of sea water and is carried towards the sandbar-dune sections of the coast.

If the volume of "fresh" material could be laid on the entire nearshore Coast of Szczecin, it could be a layer of less than 1 mm/m^2. This value is equal to or much lower than the nearshore lowering rate of the Coast of Szczecin, which is estimated at 1–3 mm/year. This situation is the reason why the artificial supply of the dredged material to the shore causes artificial lowering of the local abrasive base and in the end intensifies land destruction.

2. On the basis of research conducted, it is assumed that the dune material is transported when the velocity of stormy surf water flow reaching the dune base is higher than 0.4 m/s or when the wind velocity is over 3 m/s. Thus, the coast dune embankments are devastated quickly on the one hand, but on the other, they can be reconstructed very quickly as the result of sediment-formative processes when there is a sufficient supply of sediment from the nearshore to the shore, as well as favourable hydro-meteorological conditions.
3. The beach sediment is also very trackable to translocate. Almost all the material is set into motion when the velocity of surf water flow is higher than 1 m/s or the wind blowing at the beach surface has the velocity greater than 10 m/s.
4. On the basis of existing research results it can be assumed that the entire nearshore sediment is put into motion given water demersal velocities higher than 0.2 m/s. Thus, when the state of the sea is ca. 3–4° B, it is possible to set into motion the medium and fine grained sands in the strip within isobaths 0–7 m below the sea level. When the sea state is 5–6° B, intensive sediment transport may occur in the strip between 0–12 m below sea level.
5. On the basis of research carried-out so far it is not possible to balance the sediment coming from the washed-out shores and deposits in other places in lithologically reasonable manner. Part of the land-originated-material is seized by the bars. It is in the state of labile balance there and cannot be deposited in the shore. At most it can be transported along the shore in form of sand waves and temporarily cling to it. It must also be assumed that part of the fine sandy material is deposited outside the stipulatedly assumed

lower border of nearshore and never returns to the abrasive platform. This happens especially in places, where rip currents appear.

6. The problem concerning hypothesis on the sudden increase of sea level in consequence of the "green-house effect" is not investigated purposely in this elaboration. It is believed that catastrophic storms, which exceed in intensity the phenomenon of the secular or millennium type, can bring about much more dangerous consequences for people and land.
7. The problem of the shore protection is not mentioned in the paper. Nevertheless it is believed that the immediate shore protection should cover only the shore sections, which are of significant value in an economic, technical or environmental sense. The manner of shore protection and the consequences in the nearshore and neighbouring sections of the shore zone should be analysed thoroughly. Not only technical but also suitably wide protective zones should be delimited in the hinterland in a considerate but consequential manner. Within the protective zone, human activity should be restricted or purposely programmed so that it would not cause any losses to the spatial economy. It should be an activity, which would not spoil the natural values of the shore zone and also not accelerate the rate of shore recession.

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