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ESTIMATION OF MORPHOLOGICAL CHANGES OF THE ODRA RIVER VALLEY IN MEANDERING SECTOR BETWEEN CHAŁUPKI AND THE OLZA RIVER MOUTH AFTER 1997 FLOOD

ROBERT GŁOWSKI[1], ROBERT KASPEREK[1], WŁODZIMIERZ PARZONKA[1], MIROSŁAW WIATKOWSKI[2]

[1] Wrocław University of Environmental and Life Sciences, Institute of Environmental Engineering, 50-363 Wrocław, pl. Grunwaldzki 24, Poland

[2] Opole University, Department of Land Protection, ul. Oleska 22, 45-052 Opole, Poland

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WSTĘPNA OCENA MORFOLOGICZNYCH ZMIAN DOLINY ODRY NA MEANDRUJĄCYM ODCINKU POMIĘDZY CHAŁUPKAMI (POLSKA) A BOHUMINEM (CZECHY) PO POWODZI W 1997 ROKU

Na polsko-czeskim odcinku rzeki Odry pomiędzy Chałupkami (Polska) i ujściem rzeki Olzy (Czechy) występują unikalne w europejskiej skali meandry (km 21,3 – 26,8). W XX wieku wystąpiło przerwanie dwóch meandrów podczas powodzi w 1977 i 1997 roku. Nastąpiło skrócenie długości rzeki na tym odcinku oraz wzrost spadku podłużnego. Erodowane i transportowane przez strumień rzeczny rumowisko osadzało się w różnych strefach odcinka meandrującego. Podczas powodzi w 1997 r. osadzające się rumowisko spowodowało zablokowanie wlotu do meandra nr I co spowodowało jego przerwanie. Artykuł prezentuje wstępną ocenę morfologicznych zmian koryta rzeki Odry oraz charakterystykę cech fizycznych i reologicznych osadzonego rumowiska.

Summary

On the Polish-Czech Odra river section between Chałupki (Poland) and the Olza river mouth there are unique in European scale meanders (km 21.3 – 26.8). In the 20th century the break-up of two meanders caused by floods in 1967 and 1997 occurred. The total length of meandering section has become shorter and the hydraulic gradient increased. The sediments eroded and transported by the stream have settled in different zones of the meandering section. In 1997 the inlet to the meander I was blocked by settled sediments causing the break-up of this meander. The paper presents the preliminary estimation of morphological changes of the river bed and the physical and rheological characteristics for settled sediments.

INTRODUCTION

The analysis of morphological changes of the river bed and valleys should be based on the knowledge of the physiographical, geological, geomorphological, hydrological and hydraulic factors. The river's activity resulting from its sinuous course causes bottom and lateral erosion, transport and sedimentation of particles. In effect of long-term lateral erosion the depth of the river bends gradually changes. During the flood events the river stream cuts off the meander and creates a new river bed.

On the Polish – Czech Odra river sector near the towns of Ghalupki (Poland) and Bohumin (Czech Republic) (km 20) and the Olza river mouth (km 27.7) seven natural meanders exist which are unique in this part of Europe (Fig. 1). The length of the meandering sector is about 6 km. This part of the Odra river is not canalized. The river Olza right bank inflow of the Odra was regulated in 1930.

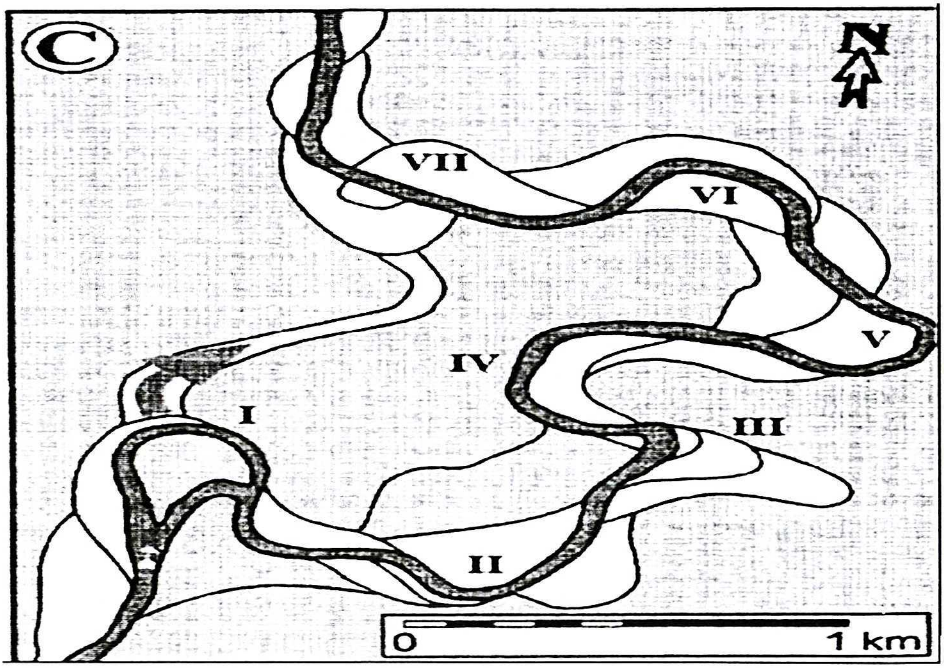

Fig. 1. Meandering sector of the Odra River, I, II ... – meander number

In the 20th century, the meandering sector was cut short twice. The first time, during the flood in 1977, it concerned the meander IV, what shortened the river course by about several hundred meters. The next change in the meanders of the river occurred during the catastrophic flood in 1997 in the frame of the meander I. In consequence of this flood with maximum discharge $Q = 2160\ m^3/s$ the Odra river course became shorter by about 510 m, and the free water surface slope in the frame of the new isthmus increased from about 0.6‰ up to 2.5–3‰.

The increase of hydraulic gradient caused significant increase of river erosion force and of sediment transport [3]. Recorded maximal water depths during the flood in 1997 in gauging stations Chałupki and Bohumin were about 6–7 m and the stream had a high erosion energy. The maximal water level of the flood wave overtopped the level of the lower edge of the road bridge, what caused the appearing pressure flow conditions in the bridge cross-section. Material transported by the river stream settled mainly in the inlet zone of meander I and blocked a big part of the river bed. In consequence, the right bank was cut short and a formation process of a new river bed was initiated.

Sedimentation of suspended and wash load in the inlet zone of meander I caused formation of new islands. Top layer of these islands is covered by mud of semi-cohesive or cohesive properties.

Changes in flow and sediment transport conditions in this region caused the development of islands, which soon became covered with vegetation (grass, reed and bush). Basing on Mokwa [2] it can be stated that the period of islands development can be relatively short. Initial vegetation cover causes increase in sediment accumulation and limits sediment transport capacity of the stream. Small vegetation cover significantly increases the islands developing process [2].

In European countries the return of ecological life to old river beds can often be observed. Newly created islands quickly become the resting and nesting place for many kinds of birds. Periodical activation of old river beds allow for fauna and flora development and can happen mainly during the floods. This process was observed on the Odra River in the region of Brzeg Dolny, after the catastrophic flood in 1997. In this region regeneration and biodiversity activation has been observed. Very important from ecological point of view is the restoration of fluvial processes and biodiversity. Three activated old river beds near the Brzeg Dolny are under permanent monitoring. Especially the data concerning the geometry, hydraulics, sediment transport and biodiversity are being collected. Similar processes have been observed by German researches on the lower sector of the river Inn [5] and during French studies on the river Ain [6]. Studies in these countries are focused on the control of the periodic inundations of old river beds and their influence on biodiversity.

Pro-ecological aim of these studies is very important and especially the fact that they are focused on saving these valuable wetlands as places of feeding, breeding, nesting and resting of birds on theirs migrational routes.

Polish ecologists and the WWF Auen Institut are sure that morphological changes in Polish – Czech border meandering sector have caused the creation of new habitat for many kinds of birds. These areas in United Europe are protected accordingly to EU Nesting and Species Instruction (92/43/EU) in NATURA 2000 network. River sectors with intensive fluvial processes (including meandering sectors) accordingly to the EU instruction 92/43/EWG should be included in the European network of protected areas NATURA 2000.

The paper is focused on the preliminary estimation of morphological changes of meandering border of the Odra River.

DESCRIPTION OF THE STUDIED SECTOR

After the flood in 1997 spectacular change in the Odra river bed morphology was observed in the inlet zone of meander I below Bohumin/Chałupki. This meander was cut off about 1 km below the road bridge. The right bank of meander I was cut short by the flood wave and a new river bed (isthmus) was formed (Fig. 2).

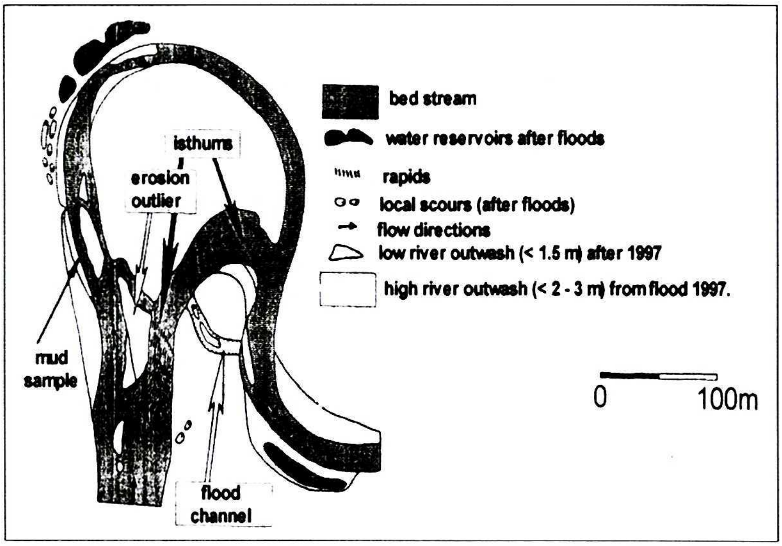

Fig. 2. The changes of the Odra River in meander I after the flood 1997 [7]

Authors performed the preliminary recognition of morphological changes of the Odra river bed and valley in the frame of meander I. Sediment samples were collected from top layer of newly created islets.

Spectacular and time dependent morphological changes in river bed layout were observed in the inlet zone to meander I.

These changes have resulted from intensive transport and sedimentation caused by the catastrophic flood in 1997 and by smaller floods. Morphological processes affected changes of river bed length, hydraulic gradient and valley geometry. Sedimentation creates good conditions for vegetation development during periods of low discharges and water levels. The top layer of studied island consists of fine-grained sediments (silt and clay). These types of sediments have semi-cohesive or cohesive properties.

PHYSICAL PROPERTIES OF MUDS

The basic physical and geotechnical parameters of the sediment samples taken from the studied islands were determined according to the Polish geotechnical standards. The physical and geotechnical parameters of studied mud samples are presented in Table 1.

Table 1. Main physical parameters of studied muds from the Odra River

Sample	Natural water content W [%]	Volume concentration of solids C_v [%]	Solid density ρ_s [g/cm^3]
1	55.00	24.78	2.48
2	52.08	26.94	2.49
3	38.66	38.53	2.53
4	40.77	36.39	2.54

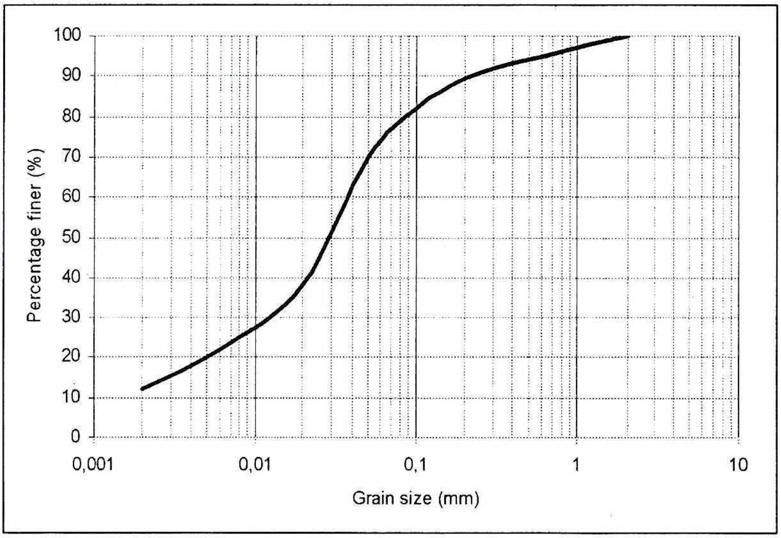

Fig. 3. Sieve curve for the Odra River mud

The characteristic particle diameter d_{50} (Fig. 3) of studied mud equals d_{50} = 0.029 mm. The content of about 74% of particles with diameter d < 0.063 mm causes cracking of the top mud layer during drying process.

SETTLEMENT STUDIES

The sedimentation process of these materials can be observed in different emplacements of the river course. The sedimentation process can be observed in river reservoirs (upstream of river dams), in river mouths and other zones (meanders etc.) where stream velocity is reduced. During the process of sedimentation, fine particles formation of flocs can be observed, depending on concentration, chemical and physical properties of cohesive particles of minerals and of organic mater content. The flocculation occurs mainly in the case of predomination of solid particles finer than some 20–30 μm. The settlement is a consequence of formation of a deposit layer after the sedimentation. During settlement physical, geotechnical and rheological properties of mud change in time causing corresponding changes of the erosional behavior of the layer. The mud concentrations increase along with settlement time and the rheological mud behavior changes from Newtonian (low concentration c_v) to non-Newtonian (mean concentration c_v) and highly non-Newtonian (high c_v). The shear resistance increases with concentration, passing from easy erosion (low concentrations) to hard erosion (high concentrations). The process of settlement can be divided into four phases described by the relation $c_v = f(\log t)$ [1]:

1st phase: sedimentation of single particles and formation of flocs (aggregates),
2nd phase: quick settlement of the deposits layer with destruction of flocs and aggregates,
3rd phase: slow settlement of this settled layer, filtration through holes and fissures,
4th phase: very slow settlement and consolidation of mud, with filtration through the re-

latively uniform deposit layer. The relation $c_v = f(\log t)$ has often a linear character, where c_v is volume concentration.

Experiments were carried out in transparent plexi-glass column of 2.0 m height having internal diameter equal 64 mm.

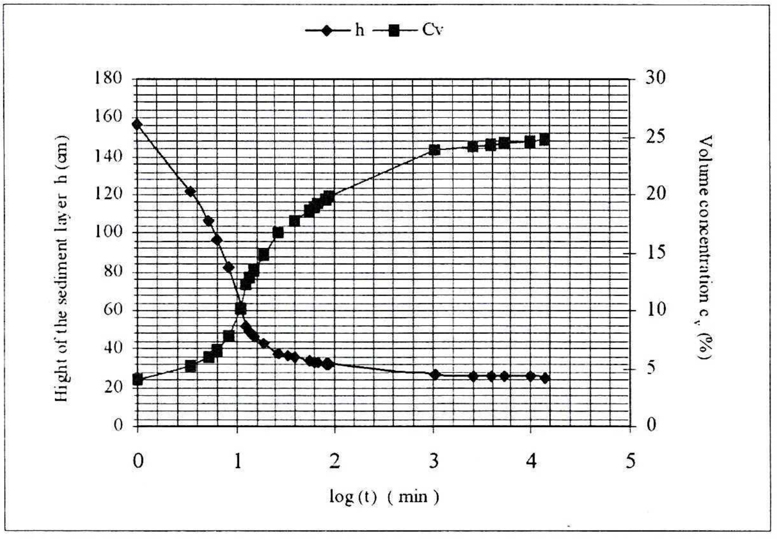

Fig. 4. Changes in volume concentration as a function of changes in the Odra River sediment layer height during sedimentation test

RHEOLOGICAL BEHAVIOR OF SEDIMENTS

The settled river sediments have a non-Newtonian behavior. We used the viscometer HAAKE for the determination of flow curves of sediments. The example of measured pseudo-flow curves $\tau = f(G_p)$ for different concentrations of sediment samples taken from the islands is shown in Fig. 5. For approximation of flow curves of settled and consolidated mud it is possible to use one of the 3- or 2 - parameter rheological models. In the case of river muds we used the 2 - parameter BINGHAM [3]:

$\tau = \tau_0 + \eta_p G$ for $\tau > \tau_0$

$G = 0$ for $\tau < \tau_0$

where: τ – shear stress, τ_0 – yield stress, η_p – plastic viscosity, G – shear rate

The relations between measured yield stresses τ_0 and concentrations c_v of studied muds is presented in Fig. 6. These relations allow for the determination of limit concentrations ($c_{v.lim}$) for the passage from Newtonian to non-Newtonian behavior. On the basis of this relationship it is possible to determine also the erosion ability for each settled layer. After Migniot [1], the critical shear stress τ_{er} for erosion of visco-plastic mud is a function of the yield stress τ_0. Migniot described two kinds of erosion where the value $\tau = 1.5$ Pa is a limit between the "easy" erosion zone and the "hard" erosion zone:

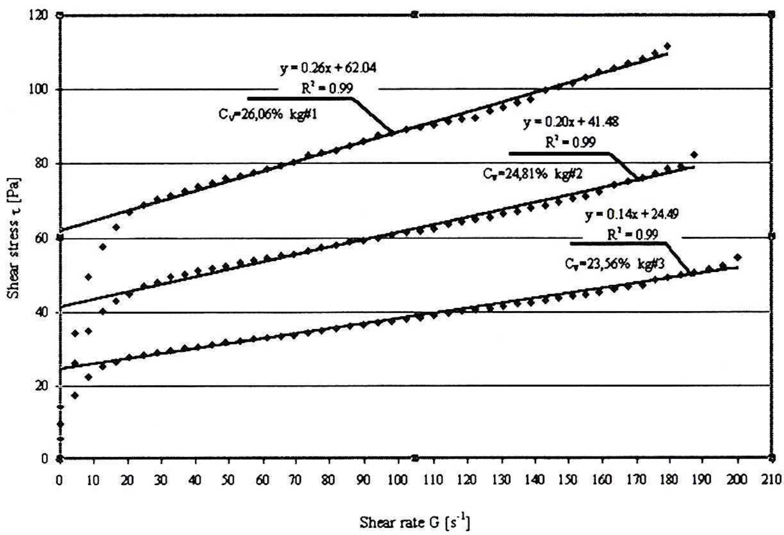

Fig. 5. Example of pseudo-flow curves for studied mud

easy erosion $\tau_{cr} = 0.317\ \tau_0^{0.5}$ for $\tau_0 < 1.5$ Pa
and hard erosion $\tau_{cr} = 0.256\ \tau_0$ for $\tau_0 > 1.5$ Pa

In the easy erosion zone the hydraulic erosion is possible by the flowing stream acting on the mud surface. As it can be shown (Fig. 6), the limit concentration determining the passage from Newtonian to non-Newtonian behavior equals for the studied muds about $c_{v,lim} = 17\%$.

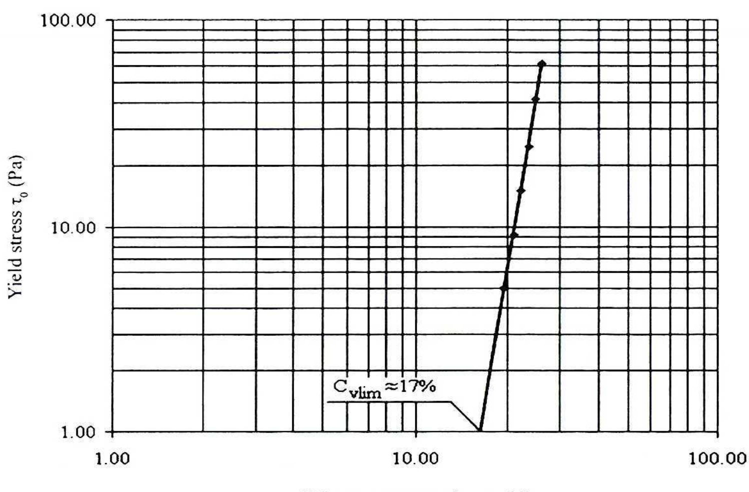

Fig. 6. Relationship τ_0 (c_v) for the Odra River mud

CONCLUSIONS

1. The meandering sector of the upper Odra (km 20.0 – km 27.7) is very important from water engineering and ecological points of view.
2. The formation of new meandering river path depends in the studied case not only on the natural river processes but also on human activity, in the first place on civic and hydrotechnical structures constructed in the frame of the meandering river sector.
3. During catastrophic floods of 1977 and 1997 the river cut two meanders No I and No IV, and shortened its linearly by about 20%, causing the increase of hydraulic gradient and of sediment transport.
4. The dynamic of river processes in the newly deformed meander I is very high. In the period 1997–2006 new islands were formed, in the first place by gravel and stones (bed load), and in the second place by fine particles type of silt (suspended load). The islands formed by fine particles are gradually covered with vegetation serving as nesting place for birds and other fauna species.

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