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BANK DEFORMATIONS ON SOME WATER RESERVOIRS IN BULGARIA AND CZECHOSLOVAKIA

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Abstract: The rational utilization of water reservoirs in compliance with environmental protection requires not only their hazardless functioning, but also a professional evaluation of the inundation region of the reservoir and of the stability conditions of the bank line.

Banks formed of clayey rocks are susceptible to almost all of the acting factors. However, the analysis of the factors and conditions of bank deformations of some water reservoirs in Bulgaria and the former Czechoslovakia has shown that technogenic and regional geological factors play the dominant role in bank deformation. Abrasions and landsliding are the most important geodynamic processes, participating in bank deformation. Based on the data on the origin and intensity of all geodynamic processes affecting bank zone formation, genetic classification of types of banks were proposed for Bulgarian, Czech and Slovak water reservoirs under study.

Key words: abrasion; slope erosion; sliding deformation; technogenic factor

1. INTRODUCTION

Comprehensive utilization of water reservoirs in Czechoslovakia and Bulgaria lays increased stress upon the study of all factors which participate in the origin of bank deformations on waterworks.

Dams are man-controlled constructions, which are, at the same time, exposed to important effects of natural, especially hydrometeorological factors; they are ranged, from the viewpoint of the study object, application and control, among natural sciences and technical disciplines including the ecological stability of the landscape.

Waterworks should be understood as complex, natural and technical systems consisting of natural and technical subsystems in the process of interaction. To be aware of such interactions means to increase the possibility of rational and comprehensive utilization of waterworks; to neglect it could cause large or considerable damages.

The retreat of the bank line under the influence of abrasion, erosion and landsliding entails not only a menace of destruction of important engineering structures on the banks of water reservoirs, but it also means an intervention into the environment where irretrievable damage to soil occurs. For example, the banks on the Orava waterwork retreated by up to 150 m (till 1984) and the arable land was depreciated by landsliding far upwards the slope (Horský, 1984). On the Nechranice waterwork, the 20 years' operation washed off the soil from 1 ha area (Spanilá, 1989). The banks of the Žermanice waterwork abraded, during 22 years' operation, a total volume of about 106,000 m^3 (Woznica, 1982). The retreat of banks on waterworks in Bulgaria varies, in the average, within 12–60 m for the total period of their operation (Simeonova, 1989).

The construction of water reservoirs causes a sudden and profound alteration of hydrological, hydrogeological, geomorphological, and engineering-geological conditions, which gives cause to the dynamic development particularly of the bank area and its neighbourhood. Problems of water reservoir bank deformation therefore attract water managers' and waterwork operators' increased attention, aimed at safe function of the waterworks in agreement with the environmental requirements.

Practical experience has shown that not only a safely constructed water dam, but also a responsible evaluation of the inundation area of the water basin, together with contingent proposals for optimum utilization of the bank zone are fundamental requirements for a safe and rational operation of the waterwork.

Considerable attention is being paid to bank alterations, caused by filling water into the reservoir. They are a result of various basic factors, which should be studied as to their qualitative and quantitative expression, enabling the bank deformation to be predicted; such predictions could be used as a basis for a timely proposal of adequate safety measures in the sections exposed to danger.

2. CLASSIFICATION OF FACTORS AND CONDITIONS INFLUENCING THE ORIGIN OF GEODYNAMIC PROCESSES

Findings resulting from the research of water reservoir bank transformation in Czechoslovakia and Bulgaria enable an opinion to be stipulated that, in the case of banks formed by clayey sediments, the factors make themselves felt which trigger the engineering-geological processes ranging in the group of natural and technogenic ones. It has been established during the identification of the prevailing factors that their classification includes three main subsystems with their individual characteristics: technogenic, hydroclimatological and regionally geological.

A. The *subsystem of technogenic factors* depends on the type of reservoir and its main purpose, manipulation with the water level and thus on the fluctuation range of water levels.

B. The *hydroclimatological subsystem factors* involve: hydrological factor (horizontal water level movements under the influence of winds), temperature, precipitations, ice formation, sunshine, etc.

C. The *regionaly geological subsystem factors* are determined by: (a) geological formations and lithological structure of the region, physical and mechanical character of rocks, tectonic elements of the inundation area and its surroundings, and (b) geomorphological and hydrogeological conditions.

The analysis of factors and conditions of bank deformations on some Bulgarian and Czech and Slovak water reservoirs pointed at the predominant role of technogenic and regional geologic factors, particularly affecting the occurrence and intensity of geodynamic phenomena.

The technogenic factors, namely the variations of water level in the reservoir (hydrological factor), are often ranged among decisive ones for the very substance of deformation of water reservoir banks during quick and deep water regime changes, compared with the natural regime, which affected the banks before. These variations of water level during the operation of waterworks depend directly on economic requirements of power plants.

3. WATER RESERVOIRS MONITORING

It results from practical experience that banks formed by clayey rocks are sensitive to all influencing factors. This was the reason why water reservoirs in these rocks were chosen for bank deformation studies (Table I).

On selected water reservoirs, the occurrence of maximum and minimum free water levels during the entire operation of reservoirs or during a specific time interval has been analyzed. All the mentioned water reservoirs can be divided according to the values of maximum amplitude of operation level into four groups: (1) amplitude up to 5 m; (2) amplitudes 5–15 m; (3) amplitudes 15–25 m, and (4) amplitudes exceeding 25 m. Analysis of variation amplitudes of water levels in reservoirs reveals that, is some cases, these values attain almost 50% of the maximum depth of water basin. Typical water reservoirs with considerable fluctuation amplitude are waterworks G. Traykov, Topolnitsa, Žermanice, Nechranice, Orava, etc. The banks of all these reservoirs are heavily afflicted by geodynamic processes, particularly by abrasion and landsliding (Figs. 1–4).

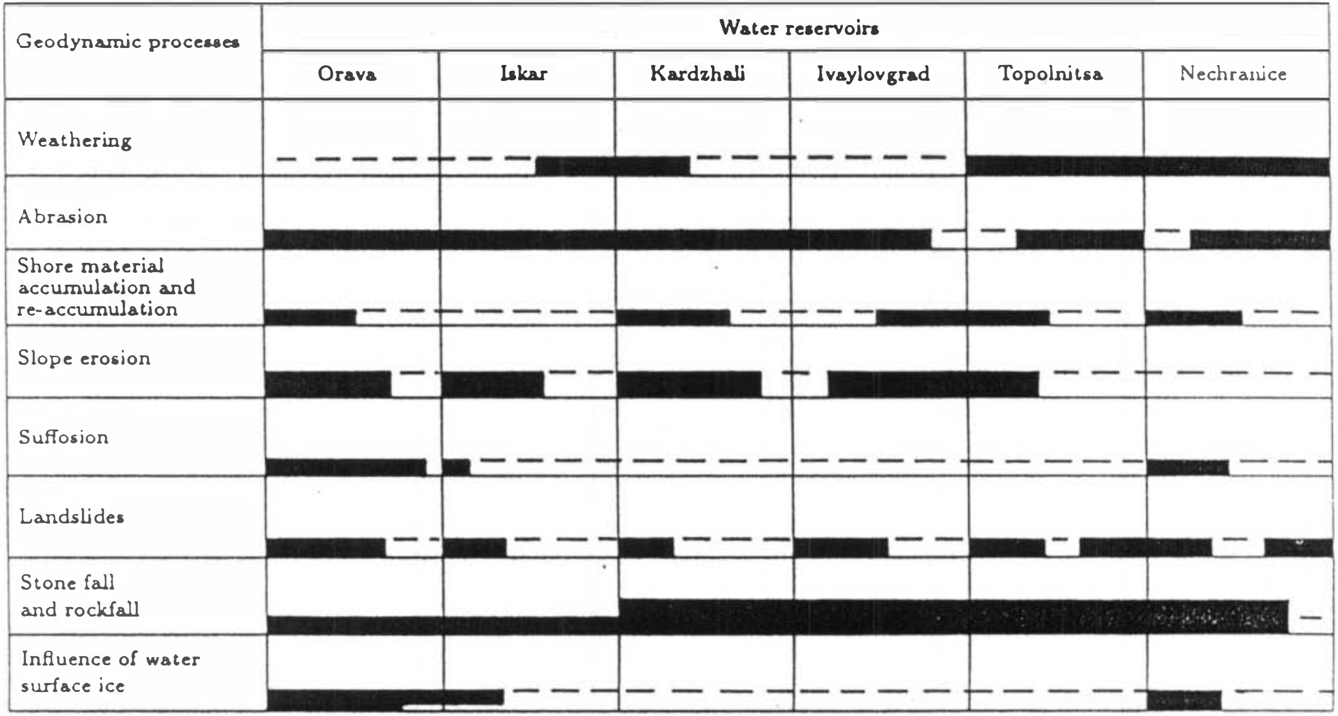
Observations of bank deformations on waterworks in Bulgaria and Czechoslovakia, caused by swollen water level after filling the reservoirs, prove the occurrence of engineering-geological processes quoted in Table II. The chart shows that weathering makes itself felt very intensively particularly in areas with dry climate (460 $mm \cdot yr^{-1}$; some Bulgarian water dams < 300 $mm \cdot yr^{-1}$), but also elsewhere in areas with low rain precipitation.

The abrasion proceeds in all water reservoirs and is particularly intensive on clayey-to-sandy and loess banks. The stronger the impact winds and the larger the inundation area and movement of water levels, the more intensive the abrasion. Broken material accumulates in the lower parts of the reservoir and in bays. The slope erosion prevails in the Bulgarian water reservoirs, but it can be found, to a lower extent, also in the Orava reservoir. The suffosion processes develop particularly in loess clays and in the eluvial zone of clayey sediments. A typical example is the Orava dam water reservoir, partly Nechranice, and rarely on Bulgarian dams.

Table I. Research of bank deformation on some water reservoirs in Czechoslovakia and Bulgaria

Water reservoirs	River	Water area [km^2]	Perimeter of banks [km]	Max. depth [m]	Fluctuation [m]	Abrasion activity [m . yr^{-1}]	Geological situation
1. Nechranice	Ohře	13.5	20	48	19	0.5–0.3	Clay and clayey sediments (Tertiary and Quaternary)
2. Orava	Orava	35.0	30	40	15	1.0–5.0	Clayey sediments (Paleogene and Neogene) claystones, flysh
3. Šance	Ostravice	3.0	7	50	36	1.0–3.0	Claystones, sandstones and clayey sediments (Quaternary)
4. Žermanice	Lučina	2.5	15	37	15	1.0–6.4	Clays, claystones
5. Olešná	Olešná	0.7	5	16	2	1.0	Claystones, sandstones, flysh (Paleogene), silty loam, gravel
6. Rozkoš	Rozkoška-Úpa	10.0	57	26	3	1.0	Clays, claystones, terraces gravel, loan
7. Hracholusky	Mže	4.6	36	34	14	0.8–3.2	Crystalline rocks, phyllites, clays
8. Iskar	Iskar	30.0	35	70	28	3.0	Granites, weathered crystalline rocks and residual soils (Quaternary)
9. Ivaylovgrad	Arda	23.0	73	72	16	3.0	Phyllites, detrites, landslide materials
10. G. Traykov	Kamchiya	17.3	62.5	55	25	1.0–5.0	Limestones, clayey sediments (Quaternary and Neogene)
11. Kardzhali	Arda	16.1	85.0	101	36	3.0	Weathered metamorphism formations, deluvial soils
12. Topolnitsa	Topolnitsa	5.7	35.2	65	27	1.0–3.0	Weathered metamorphism formations, deluvial soils
13. G. Dimitrov	Tundza	11.2	38.5	44	13	1.0	Weathered granites, sandy-clay formations

Table II. Intensity of bank deformations observed on some selected water reservoirs



The intensity is expressed by the width and length of the hatched area. The width expresses the volume and the length the frequence of the geodynamic processes.

Landslides are typical of the banks of the Orava and Nechranice water reservoirs, and of some sites in the Bulgarian dams. Massively occurring are tumbling-down and pouring-down phenomena. The effect of water surface ice on the bank formation is typical of the Orava water dam and, in a lower degree, also of Nechranice.

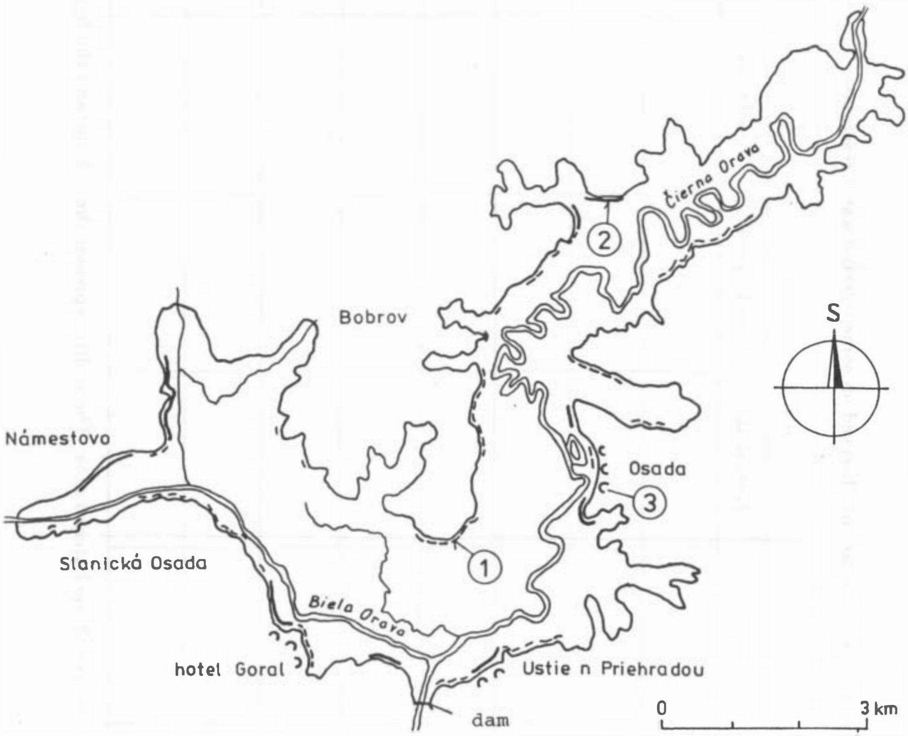


Fig. 1. Situation in the inundation zone of the Orava waterwork with indication of the bank deformation type (modified according to O. Horský).
.1 – abrasion; 2 – extreme abrasion; 3 – landslides.

General regularities of the development of geodynamic processes on water reservoir banks are typical of the above-mentioned water dams.

This partial specification of the occurrence of geodynamic processes points to the fact that the bank deformation process consists not only in pure attacking the bank line by the effect of wind waves. It is a complex of geological processes which induces changes of engineering-geological conditions along the entire bank zone, where the operation regime of water levels is the decisive condition for the stability of water reservoir banks.

The activation of geodynamic processes is caused, above all, by the formation of new hydrogeological conditions, particularly the varying regime of water levels.

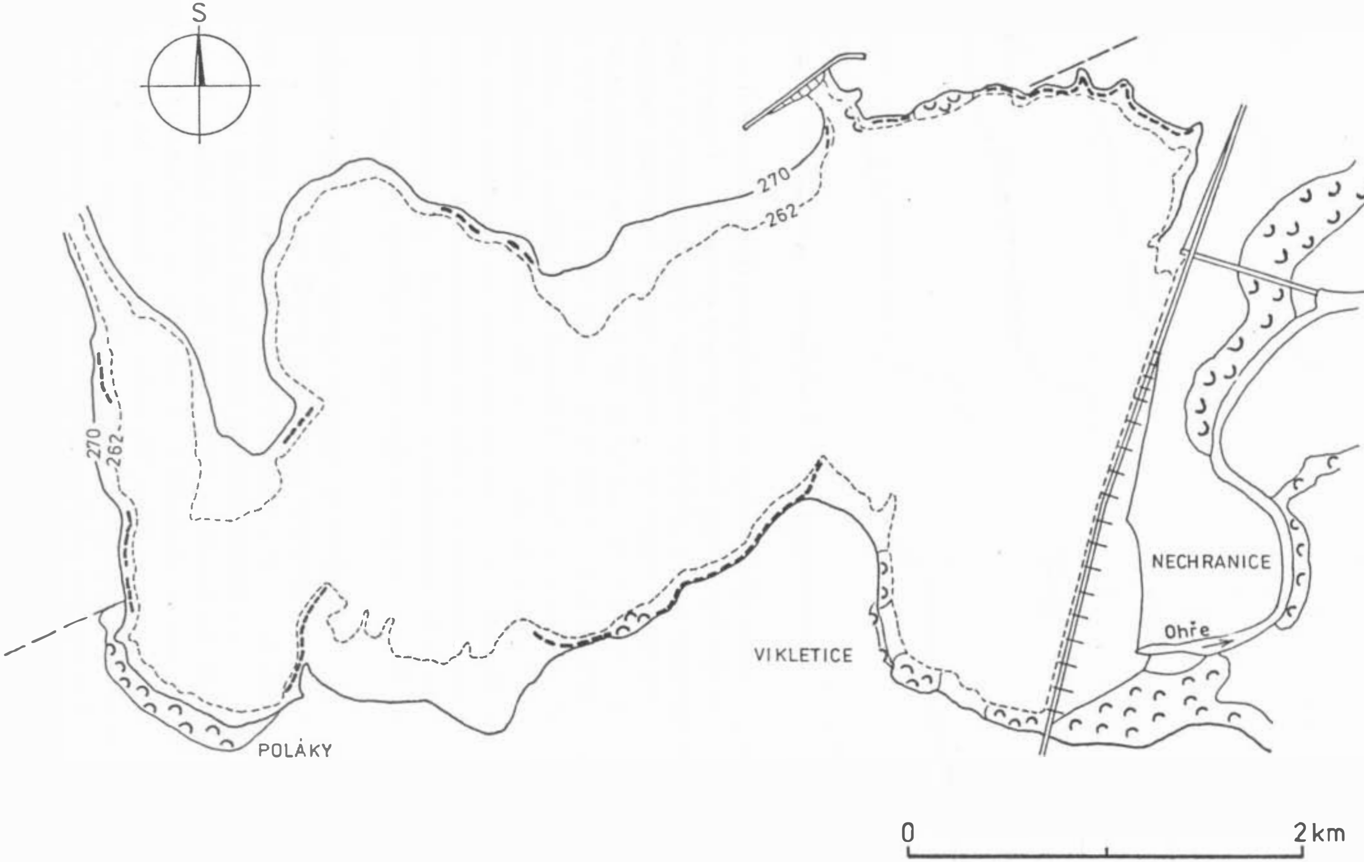


Fig. 2. Situation in the inundation zone of the Nechranice waterwork with indication of the bank deformation type (modified according to J. Rybář). ∪ ∪ ∪ landslides; – – – abrasion.

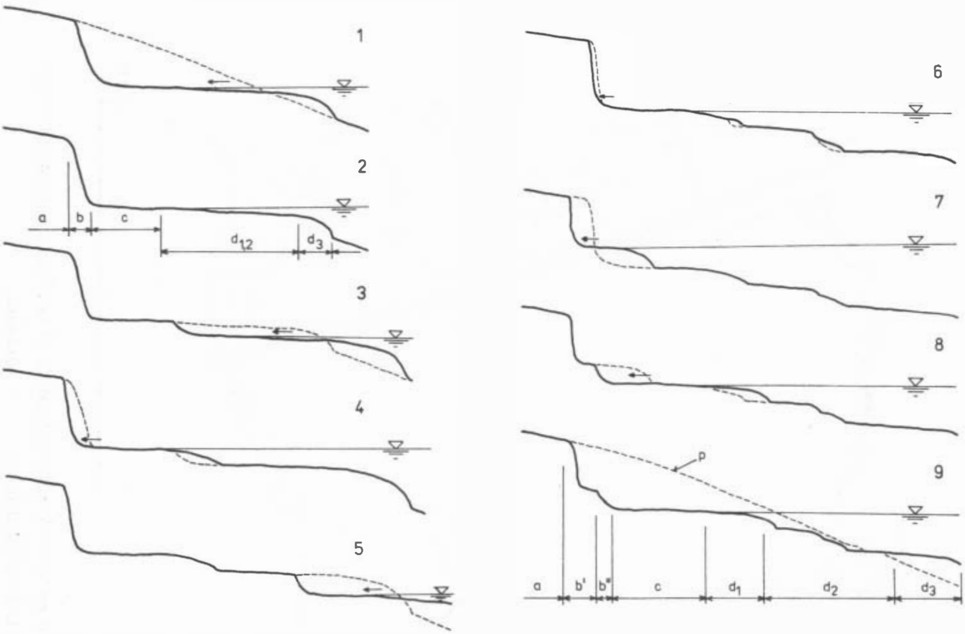


Fig. 3. Layout of the geomorphological development of the bank profile under the effect of water level fluctuations. **1** – original bank; water level at operation elevation; **2** – formation of the accumulation pile strand under water (equilibrium condition of the bank slope); **3** – dropped water level in the reservoir; the wave motion affects the lower part of the abrasion platform; **4** – increase of water level in the reservoir; the wave motion affects the toe of the abrasion block pile; **5** – water level drop; geomorphological modelling of the abrasion platform; **6** – water level rising incites the destruction of the abrasion block pile; the abrasion material accumulates particularly in individual terrace zones; **7** – water level rise is considerable; water wave motion is particularly active at the toe and in the middle part of the abrasion block pile – maximum bank retreat; **8** – undermining of the abraded material at a successive water level drop; **9** – geomorphological development of the bank profile by abrasion effect: a – shore line, b (b', b'') – abrasion block pile, c – strand, d (d_1, d_2, d_3) – abrasion platform (upper, middle and lower parts).

Manipulation with water level affects the transformation process of reservoir banks by setting the limits of water abrasion and thus its overall extent.

The water level stabilization on a certain elevation can create a balanced condition of the inclination of the abrasion platform under water, created by the accumulation of the abraded material and its modelling under the effect of waves. However, even mere lowering or rising of the water level can cause an alteration of the stability conditions in the bank zone. When the water level is lowered, the upper end of the abrasion platform emerges and its middle and/or lower part are exposed to the effect of waves. The abrasion platform usually consists of non-consolidated accumulation material with a high erosion degree, so it readily abrades already under the action of low velocities of wind. In such conditions considerable deformations may be expected or, as the case may be, the entire abrasion platform under water, which serves as a breakwater for waves attaining the toe of the abrasion block pile, could be destroyed.

Fig. 4. Landslide due to the operation of waterwork Iskar. Photo G. Simeonova.

During the subsequent phase, when the water level is increased to the operation level, the wave motion energy affects, to the maximum degree, the toe of the abrasion pile. In such case, the bank retreat is the largest, because of the energy potential increased due to the formation of conditions favourable for the action of wave motion. It should also be considered that during the water level fluctuations, the clayey rocks are repeatedly dipped (soaked) and redried, that adversely affects their mechanical and physical qualities. Various phases of the geomorphological development of an abrasive-type bank are shown in Fig. 5.

The filling of the reservoir with water changes the hydrostatic and hydrodynamic stress in the slope, which is potentially exposed to the risks of sliding. The stress alteration can be caused by various reasons, particularly by the weight (mass) increase of the active sliding part and by the intervention of water into the sliding surface.

The water level fluctuations change also the hydrodynamic water filtration pressure from the landslide itself or from the rocks of the shearing zone.

Very pronounced is the loading state of rocks, originating from sudden rising or dropping of water level. The sudden drop or rise of water level in the reservoir

Fig. 5. Abrasion block piles (3 to 5 m height) are formed in Neogenic clays at waterwork Orava. Locality Polhoranka, 1983. Photo O. Horský.

Fig. 6. Landslide in the former village of Čermníky, which took place in 1969 due to fluctuation of water level in the reservoir. Photo T. Spanilá.

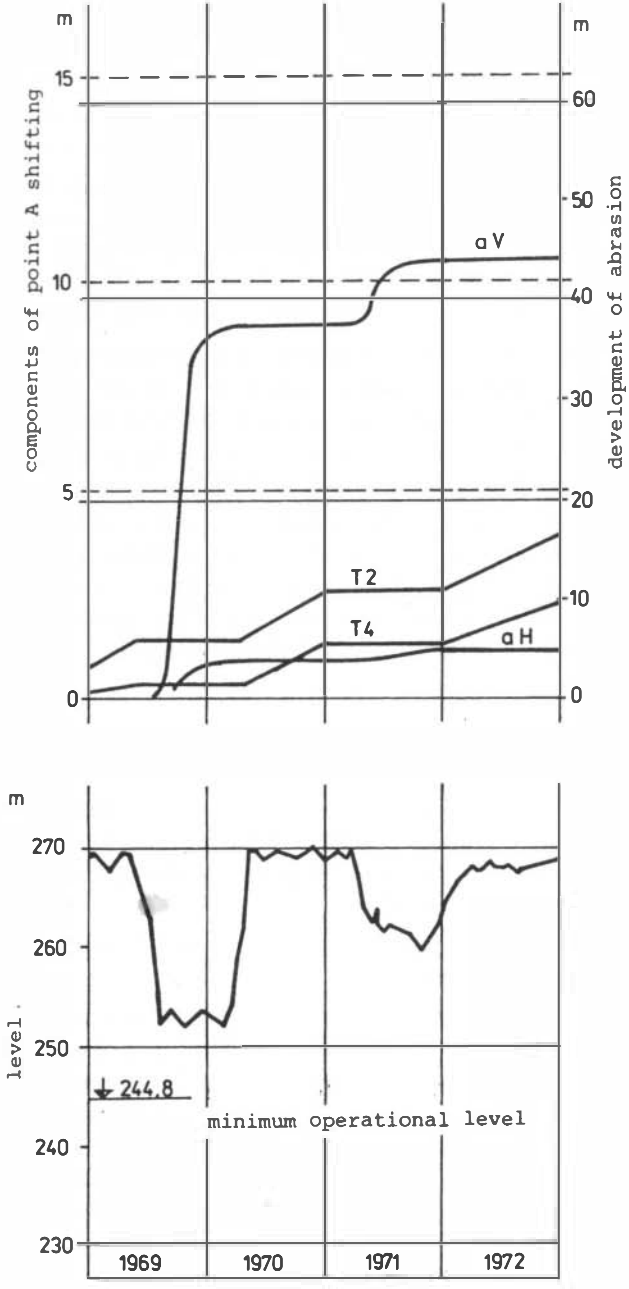


Fig. 7. Effect of water level fluctuation on the abrasion and sliding progress at waterwork Nechranice.

induces strong changes of groundwater level, which, in turn, induce the alteration of stability of soils or rocks of the bank slope by sudden surcharging or relieving, i.e. by increasing or reducing the hydrostatic or hydrodynamic pressure.

The maximum daily water level drop which is determined by the operation schedules is set at 1.20 m . day^{-1} for most of the monitored water reservoirs.

The actual maximum daily drop for the studied water dams varies within 30 to 85 cm . day^{-1}. However, at the Nechranice water reservoir, even the water level drop of 0.15 m . day^{-1} provoked the Čermníky landslide (Fig. 6), another landslide at waterwork Iskar was triggered at the water level drop of 0.11 m . day^{-1}; a sudden water level decrease caused several landslides at waterwork Orava (Horský, 1974).

A direct interrelationship of the occurrence of geodynamic processes with water level fluctuations on reservoirs could be established on the basis of observations of types and extents of deformation phenomena and with taking into account the physical and mechanical properties of rocks and the energy potential of wind waving at the shore line (Fig. 7, Spanilá and Rybář, 1983).

It has been further proved that the differences in the occurrence of various types of geodynamic phenomena are determined by the difference of geomorphological, engineering-geological and hydroclimatological conditions; thus, the abrasion process development is similar within the framework of the group of clayey sediments with the same lithological composition and characteristics.

4. DEFORMATIONS OF BANKS

On the basis of accumulated data on the origin and intensity of all exogenic processes involved in the formation of the bank zone, genetical classification types of the monitored water reservoirs were suggested with regard to their lithological structures, as presented in Table III.

In the case of banks consisting of clayey sediments, the abrasive and accumulation slope types are mostly involved.

The abrasion bank types are found practically everywhere, particularly in the higher bank slopes, where the formed abrasion block pile rises up to ten metres. From the geodynamic processes involved in the deformations of banks in water reservoirs, we can mention, in this case, the abrasion, tumbling, bestrewing, landslides, erosion, and weathering (Table III – 1, 2, 3; Figs. 8–9). Special attention should be paid also to the abrasion-type banks with the occurrence of landsliding deformations along the ancient or activated shear planes, where the intensive abrasion is caused by deteriorated physical and mechanical properties of landslide-impaired rocks.

The sections, where sliding deformations dominate and incite the abrasion process, are sometimes characterized as abrasion-sliding.

Depending on the hydrological regime of the water reservois, i.e. the operation schedule of water levels (amplitude, fluctuations, duration of water level maintenance at a certain elevation) and wave energy of water level, various forms of bank profile destruction can be differentiated (Table III – 4, 5, 6).

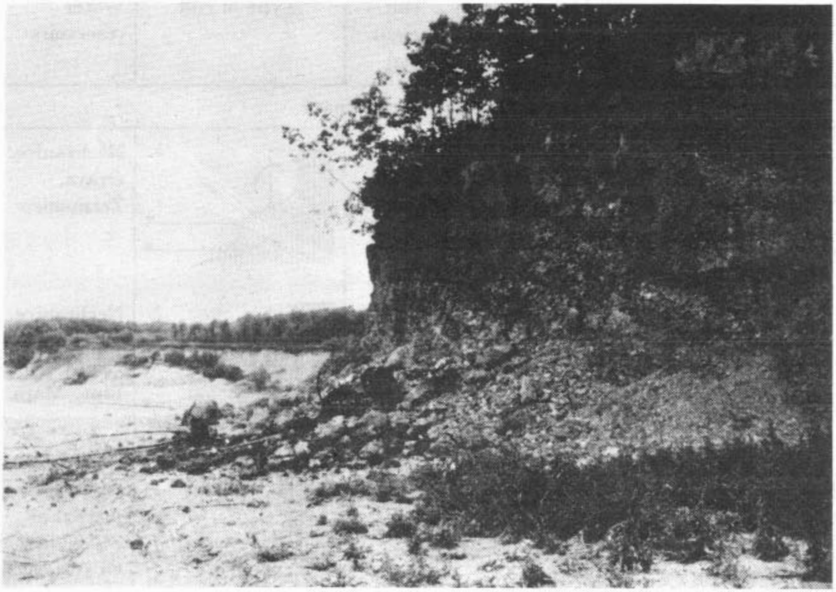
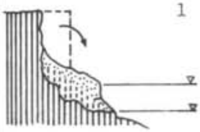
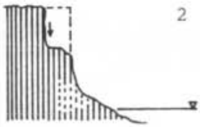
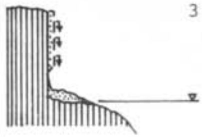
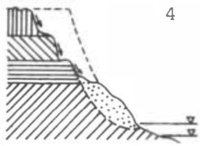
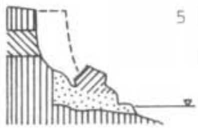
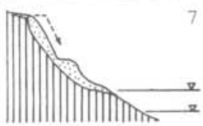


Fig. 8. Intensive abrasion in clayey sediments on the Nechranice water reservoir banks. Photo T. Spanilá.

Particularly the origin of sliding deformations can be closely interrelated with operational fluctuations of water levels. The retreat of an abrasion block pile in the case of an abrasion-sliding bank type has a temporally cyclic character, because the wave energy affects the slipped material for a certain time. The slipped soil only weakly resists the surf and is therefore readily abraded, which induces the quicker abrasion advancement towards the slope, repeated failure of stability and the new abrasion involved.

The accumulation bank type is typical of morphologically gentle sections with low abrasion block piles (below 1 m) consisting mainly of terrace gravels; sorting of the beach materials is quite common here.

Table III. Types of bank deformations on some water reservoirs in Czechoslovakia and Bulgaria

Type of bank deformation	Geodynamic processes	Lithological composition	Abrasion cliff height [m]	Type of cliff	Water reservoirs
		Tertiary – Quaternary			
Abrasion	Weathering, abrasion, slope erosion, stone fall and rockfall	Alluvial and deluvial soils, clayey sediments, slate, sand loam, sandy shale, silt rock	0.3–10.0	 1	Nechranice, Orava, Žermanice
				 2	Nechranice, Olešná, Orava, Lipt. Mara
				 3	Lipt. Mara, G. Traykov, Iskar. Kardzhali, St. Kladenets, Orava, Nechranice, Hracholusky
Sliding	Slides, landslides, weathering, abrasion, suffosion	Clays, claystones, sandy loam, sandy shale, silt rock, marl slate, loam, clay slate	5.0–20.0 and more	 4	Lipt. Mara, Šance, Iskar, Ivaylovgrad, Orava, Karolinka, Nechranice
				 5	Orava, Iskar, Kardzhali, G. Traykov, Nechranice, G. Dimitrov, St. Kladenets
				 6	Nechranice, G. Traykov, Orava, Rozkoš
	Weathering, slides, abrasion, suffosion, slope erosion	Silty loam terraces, gravel, clay, clayey sediments	0.5–1.0	 7	Jesenice, G. Traykov, Orava

(continued)

Table III (*continued*)

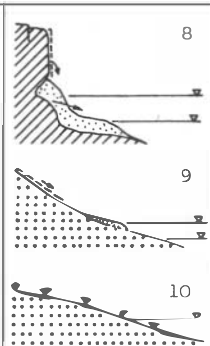
Type of bank deformation	Geodynamic processes	Lithological composition	Abrasion cliff height [m]	Type of cliff	Water reservoirs
Tertiary – Quaternary					
Accumulation	Accumulation, bog formation, shore material accumulation, biogenic effects (vegetation)	Clayey-sandy formations, marls	0.1–1.0		St. Kladenets, Ivaylovgrad, Lipt. Mara, Olešná, Orava

Fig. 9. Tumbling of individual blocks, dropping and breaking off of weathered clayey formations on the Nechranice waterwork. Photo T. Spanilá.

The discussed examples of geodynamic processes and bank deformations of clayey rocks point to the following regularities:

1. The abrasion in clayey sediments is the more intensive, the more frequent the occurrence of other geodynamic processes.

2. The synergy of abrasion with other geodynamic processes depends particularly on the effect of the technogenic factors.

3. The fluctuation of intensity of the development of abrasive and sliding deformations closely depends on the operational regime (time schedule of water levels) in the reservoir. The abrasion activity very often varies cyclically. A short-term suppresion of the development of abrasive and sliding deformations does not always indicate the disappearance of a long-term process of bank deformation.

4. The regularities of the formation of abrasion-type banks of water reservoirs in Czechoslovakia and Bulgaria point first of all at the occurrence of abrasive and sliding deformations, and then to tumbling, bestrewing, and block falling.

5. It is insufficient and inadequate to evaluate the bank deformation, for prognostic purposes, only from the viewpoint of the occurrence of abrasion deformations. A more comprehensive investigation is always necessary. Therefore, a method of investigating the entire complex of geodynamic processes in situ has been suggested and developed. On the basis of studying all factors involved, actual conditions, and direct observations of the bank retreat on various water reservoirs, operating from one to 30 years in the territories of Czechoslovakia and Bulgaria, information and data on direct correlation of the occurrence of geodynamic processes and the destruction of the bank profile have been accumulated. These data can be used for evaluating the types, forms, and extents of bank deformations on similar waterworks in both countries.

IN MEMORIAM

Ing. Ginka Simeonova passed away suddenly in March 1990. Nearly 40 years of her activity were devoted namely to problems of reforming seashores deformations and shores of water reservoirs. She developed her own method of forecasting the shores deformations and her efforts were aimed at a comprehensive solution of problems related to shore conditions

the CR to deal with problems of reforming water reservoirs shores.

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DEFORMACE BŘEHŮ NĚKTERÝCH VODNÍCH NÁDRŽÍ V BULHARSKU A ČESKOSLOVENSKU

Tamara Spanilá a Ginka Simeonová

Racionální využití vodních nádrží v souladu s ochranou životního prostředí vyžaduje nejen zajištění jejich funkcí bez rizik, ale také odborné posouzení zátopové oblasti nádrže a stabilitních poměrů břehové zóny.

Především břehy budované jílovitými horninami jsou porušovány geodynamickými procesy. Rozbor faktorů a podmínek deformace břehů na některých vodních nádržích v Bulharsku a Československu ukazují na dominantní roli technogenních a regionálně geologických podmínek při přetváření břehů.

Z výčtu geodynamických procesů se na přetváření břehů vodních nádrží podílejí především abraze a sesuvy. Byla navržena genetická klasifikace typů břehů studovaných vodních nádrží, která vychází z údajů o vzniku a intenzitě geodynamických jevů při vytváření břehového pásma.