THE EXPERIENCE OF THE DAM CONSTRUCTION ON GYPSUM-BEARING ROCKS (IN THE TERRITORY OF THE FORMER USSR)

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Abstract: The article is devoted to the experience of dam construction, at the base of which there are gypsum-bearing rocks. In the world there are about 70 similar dams, of which about 15 - on the territory of the former USSR. The description of the Kama hydroelectric power station (HPP), the Mingechaur HPP, the Yerevan HPP, the Baypazinsk HPP are given.

Key words: gypsum karst, dam, the Kama HPP, the Mingechaur HPP, the Yerevan HPP, the Baypazinsk HPP

The presence of soluble rocks, such as gypsum and rock-salt, in the foundations of hydraulic structures cause engineering geological conditions that are difficult and unfavorable for safe construction (Cooper, 2013; Ford, 1989).
On the globe, karstic rocks are widely developed and occupy a tenth of the land area (51 million km^2).

In the former USSR, the total area of gypsum-bearing rock extends to about 5 million km^2 (Gorbunova, 1977). Hydrotechnical construction in such soluble rock regions can create conditions of enhanced dissolution and karst development that can threaten the structures. Throughout the world there are examples where the dissolution of gypsum in dam foundations have resulted in tragic consequences. The failure of the St. Francis dam in California, USA, is one catastrophic example where 400 people perished as a result. Numerous problems are associated with dams on gypsum, these include settlement, cracking and seepage with the constant threat of failure or expensive remediation. For example, in the vicinity of Basel, on the Birs River, the dissolution of gypsum beds in the dam foundation caused settlement and cracking. Settlement was also observed on the San Fernando, Olive Hills, and Rattlesnake dams in California. Loss of water from reservoirs on gypsiferous rocks is common and seepages through the dam foundations were recorded on the Osa River (Angara basin), in Oklahoma and New Mexico (USA). Seepage and gypsum dissolution causes cavities to form and these features have been found in the foundations of the Hondo, Maximilian, and Red Rock dams, along with a dam in the Caverly valley, Oklahoma. Gypsum also occurs in the foundations of the San Loran dam in Catalonia, Poecos dam in Peru, and a number of dams in Iraq (James 1978; James, 1980).

In a number of cases, the presence of gypsiferous rocks resulted in the rejection of the dam site for construction, an example being the Saint Baume dam in Provence, which was found to be on gypsiferous marls. Surveys for the Rian dam in the vicinity of Alter Stolberg, south of Harz, stopped after gypsum was discovered in the foundation zone. Gypsum has been proved in the foundations of more than 50 dams and rock salt, which is more soluble, has been found in the foundations of others including the Rogunsk and Nureksk dams on the Vahsh River in Tajikistan (Maximovich, 2006; Milanovic. 2000; Molokov, 1981).

In the world, there are about 70 (operating, unfinished, destroyed) dams on gypsum-bearing rocks, of which 15 – on the territory of Russia and the former CIS countries (Table 1). In the territory under consideration, the Cambrian and Lower Permian gypsum-bearing formations occupy the largest area.

***Table** 1 – Dams on gypsum-bearing grounds in the territory of Russia and the former CIS countries*

The name of the dam	Country	Operate (+)/ doesn't operate
The Kama dam	Russia	+
The Mingechaur dam	Azerbaijan	+
The Erevan dam	Armenia	+
The Tbilisi dam	Georgia	+
The Baipazinsk dam	Tajikistan	+
The Nureksk dam	Tajikistan	+
The Sangtuda dam	Tajikistan	
The Farhad dam	Uzbekistan	+
The Bratsk dam	Russia	+
The dam on the Osa River	Russia	+
The Rogunsk dam	Tajikistan	the construction is underway
The Irganay dam	Russia	not completed
The Lower-Kafirnigan dam	Tajikistan	not built
The dam on the Iren' river	Russia	not built
The Cheboksary dam	Russia	not built

Consider the experience of building some of them and the methods used to protect them from destruction.

The Kama hydroelectric power station (HPP) on the Kama River (Russia). The karstic gypsum-anhydrite and limestone-dolomite rocks include in the zone of influence of the structure. The karst processes were activated after the creation of the reservoir (fig. 1) (Maximovich, 2006; 2009).

The rocks of the base of the HPP have an uneven vertical plastering. In the sulfate-carbonate stratum, as a whole, an increase in the content of calcium sulphate down the section is observed (Kuznetsov, 1947). The rocks in the section of the dam section are characterized by heterogeneous fracturing.

In the design of the Kama HPP as a protection of gypsum-bearing rocks from dissolution, it was expedient to create a waterproof canopy in the upper pool with a length of 110 m, a cementing curtain at the beginning of the draining and vertical deep drainage in its middle, but in the process of work the created curtain could not provide the design value of the head, defined in 27%. With time, the veil lost its effectiveness.

To compact the cement slurry, a gel-forming oxaloaluminosilicate solution was proposed. The use of a silicate solution for tamponizing fractured soils at the base of the dam in domestic practice was carried out for the first time (Buchatsky, 1976, Voronkevich, 1976). Tamponage effect of this solution is achieved due to the formation of a gel from a colloidal solution after its introduction into the array by injection.

The densification, begun in the end of 1974, underwent a channel part of the cement mill with a length of 465 m. Two side curtains with the length of 100 m each were created. Thus, the curtain has a U-shape. As a result, the magnitude of the pressure drops on the veil in the Shemsha and Upper Solikamsk aquifers increased significantly. This led to a decrease in the filtration pressure on the base of the hydraulic structure and, correspondingly, an increase in the stability factor of the dam on the shear (Maksimovich, 1983).

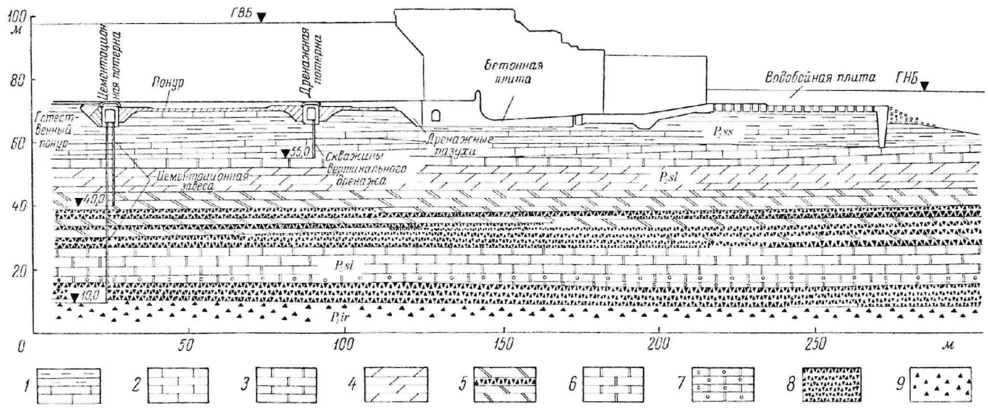

Figure 1 - Geological section of the base of the Kama HPP (Maximovich, 2006). P_2ss Sheshminsky horizon: 1 mudstone, siltstone with interbeds of limestone; P_2sol Solikamsky horizon: 2 limestones, 3 dolomites, 4 marls, 5 marls and dolomites with interlayers and gypsum lenses, 6 dolomites, 7 dolomites clay; Pir irenskiy horizon: 8 gypsum, 9 anhydrite

Thus, the example of the Kama HPP shows that careful geological studies, regime observations and a complex of engineering and geological measures to increase the rock stability allow successfully operating pressure hydraulic structures in the areas of distribution of sulfate rocks for a long time (Maksimovich & Meshcheryakova, 2017).

The Mingechaur HPP on the Kura River (Azerbaijan) (fig. 2) (Geology…, 1959). The valley of the Kura River is embedded in the deposits of the Apsheron stage, characterized by the development of weathering cracks, mainly uncovered, including crystals and veins of secondary gypsum.

In order to increase the stability of the slope, it was drained by a number of almost horizontal wells drilled from the excavation to the clay layer, and also to prevent the waterlogging of sandstones, they were shielded on both sides by a special cementing curtain on the drained area.

Fears of the possibility of development in the rocks of the base of processes of dissolution and suffusion determined the design of the anti-filtration curtain. Due to the high aggressiveness of groundwater in relation to cement, prevailing in the thickness of closed cracks, and among open - filled with loose material, a bitumen emulsion was used to install the veil. In order to prevent the latter being washed out on separate sections, the bitumen curtain is supplemented with cementitious curtain.

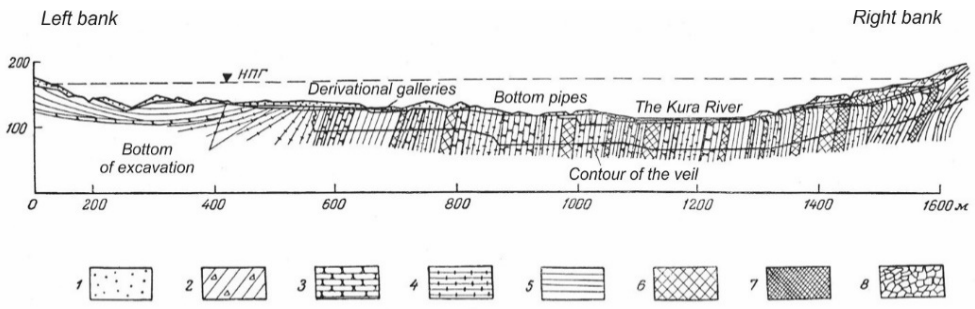

Figure 2 - Geological section along the axis of the Mingechaur HPP (Geology…, 1959) Quaternary deposits: 1 - alluvial loams, gravel pebbles and sand, deluvial and proluvial-deluvial loams; 2 - fragments of bedrock with loamy aggregate (landslide soils). Absheron deposits: 3 - silty sandstone; 4 - sandstone-clayey silt; 5 - silty clay; 6 - intermittency of powerful words of sandstones, clays, aleurites; 7 - intermittency of low-power layers of sandstones, clays, silts; 8 - tectonic breccia

The Yerevan HPP on the Hrazdan River (Armenia) with gypsum-bearing clays at the base (fig. 3). In deeper horizons there are gypsum strata with a thickness of up to 10-15 m. The total thickness of the gypsum-bearing strata is 300 m. On the site of the dam, the upper layers of the gypsum-bearing strata lie directly in the riverbed.

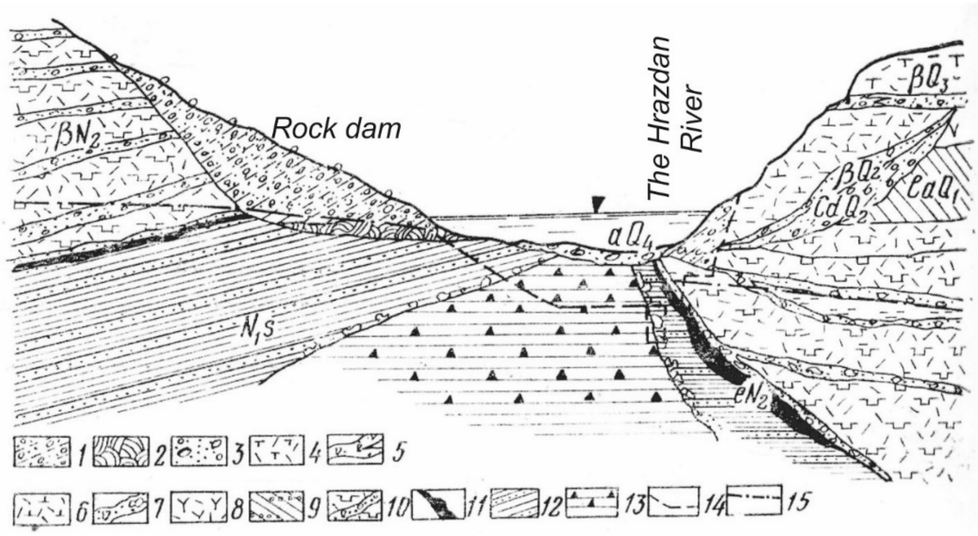

Figure 3 - Geological section of the Yerevan Dam section (Lykoshin, 1992)
1 - fragments of basalts with loam and sandy loam; 2 ancient landslide formations; 3 - boulder-pebble deposits of the riverbed. Hrazdan; 4, 6, 8, 10 - basalts; 5- boulder-pebble deposits with fragments of basalts; 7 - basalt slags; 9 - lacustrine-alluvial deposits; 11 - clays red-brown; 12 - clays calcareous, partially gypsum; 13 - clays calcareous, strongly plastered; 14 - sole of a concrete pile tooth; 15 - groundwater level before the construction of a hydroelectric power station

As protective measures, a curtain at the base of the dam is arranged by the shock-mechanical method (the Ikos-Feder method). At the base of the dam, a deep borobeton tooth is created, mating with the frontal and airborne cement curtains in the fissile basalts of the right bank. Within the layer of gypsum slabs, which in the underworld of the valley has a thickness of 6 m and steeply falls deep into the right bank, the concrete-pile tooth reached a depth of 30-40 m. After 40 years of operation, no deformations of the dam and associated structures were recorded (Geology…, 1959; Lykoshin, 1992).

The Baypazinsk HPP on the Vakhsh River (Tajikistan). The geological structure, in which the Cretaceous, Paleogene and Quaternary deposits take part, is characterized by a significant karst of carbonate rocks and the presence of gypsum under pressure structures (fig. 4). The thickness of individual gypsum interlayers varies from a few cm to 2-3 m (Lykoshin, 1992).

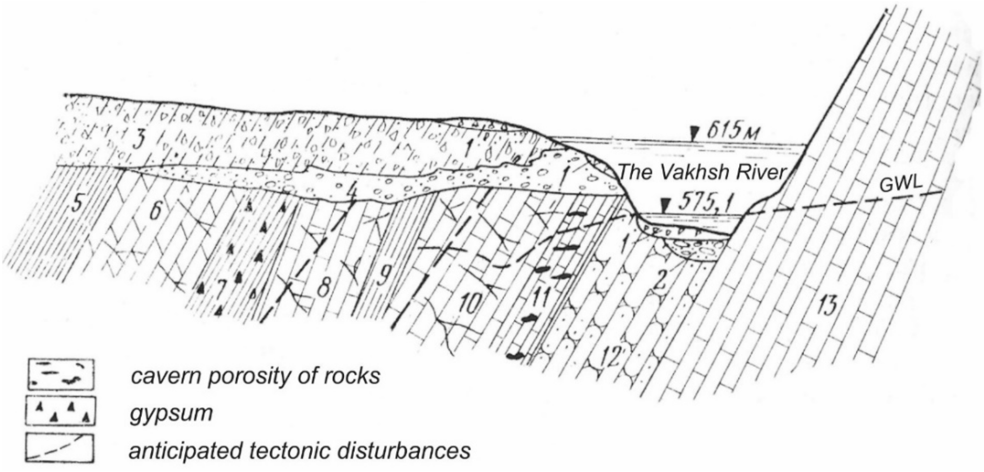

Figure 4 - Geological and lithological section of the Baipazinsk hydroelectric station (Lykoshin, 1992)
1 - bulk ground; 2 - alluvium; 3 - deluvial-proluvial deposits; 4 - proluvial-deluvial deposits; 5 - Turkestan clays; 6 - Upper Alayan; 7 - Middle Alayan; 8 - Lower Alayan; 9 - Suzak clays, Bukhara limestones: 10 - upper pack, 11 - lower pack; 12 - Adzhar sandstones; 13 - Maastricht limestones

From the side of the upper slope of the dam and in the channel of the river there is an anti-filtration screen and a drain. The same screen is made on the slopes of the left and right banks, on the section between the dam and the tunnel in order to reduce the filtration in the body, the base and bypassing the dam, as well as the proper coupling of the dam to the banks. The anti-filtration spillway devices are implemented in the form of a concrete drain before the weir, an anti-filtration curtain under the concrete threshold of the weir and mating walls, anti-filtration spurs in the areas of shore adjacencies, drainage under the drains and drainage in the rapid flow zone. Observations have shown that, due to the adopted design and silting of the reservoir, the hydrounit for filtration and deformation of structures is in favorable conditions.

The above examples show that the presence of soluble rocks and the development of karst processes in the area of pressure hydraulic structures creates serious problems in their operation, significantly increases the cost of construction and repair, and in some cases can lead to accidents and destruction of the dam, which is accompanied by human casualties. Practice shows that the cost of repair works related to the development of karst processes can be comparable with the cost of the structure (Maksimovich et al, 2017).

Note that the obvious mistakes in the exploration, design, operation and organization of observations are repeated year after year for a long time. This is largely due to the fact that by now the experience of dam construction on soluble rocks has not been generalized, there are no clear methodological approaches to the quantitative assessment of karst processes in the dam impact zone.

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