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The influence of gypsum karst on hydrotechnical constructions in Perm region

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ABSTRACT: The presence gypsum rocks in the foundations of hydraulic structures cause engineering geological conditions that are difficult and unfavorable for safe construction. 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 has resulted in tragic consequences. Also this article deals with the pollution problem of the Kama reservoir during the mining of Polaznenskoe oil deposit. The main factor contributing to the pollution is the intensive karst processes of reservoir banks. Two methods were developed, tested and patented for controlling this pollution.

1 INTRODUCTION

The gypsum-bearing rocks characterized by high solubility take 7 million km^2 of the world. While building dams and constructing reservoirs these rocks make significant problems.

The solution of gypsum rocks in foundations of dams is the reason of additional risks during construction and exploitation of dams. The presence of soluble rocks on the water reservoir banks conduce to formation of zones with high penetration. In regions with high anthropogenic influence this fact can conduce to risk increasing of ground water and water reservoir pollution.

2 KARST PROBLEMS OF DAMS

Hydrotechnical construction in soluble rock regions can create conditions of enhanced dissolution and karst development that can threaten the structures (Milanovic, 2000). Throughout the world there are examples where the dissolution of gypsum in dam foundations has resulted in tragic consequences (James & Lupton, 1978). 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. 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 Rogunskaya, Sangtudinskaya and Nurekskaya dams on the Vahsh River in Tajikistan (Maximovich, 2005).

During construction of dams on gypsiferous rock it is necessary to carry out careful geological engineering survey including mathematical modeling for a substantiation of filtering-proof actions for gypsum protection.

3 KARST OF PERM REGION

Perm region is situated on Western Urals, Russia. Perm region occupies an area of about 160 thousand km^2.

In Perm region gypsum, anhydrites, salts, limestones, dolomites of the Paleozoic and more rarely, carbonate rocks of the Proterozoic occur at low depth under the surface or stripped over an area of more than 30 thousand km^2 (Gorbunova, 1992).

The area contains three geological structures: the east margin of the East Europe Platform, the Pre-Urals Foredeep and the folded zone of the Urals. On the Platform mainly gypsum karst and, to a lesser degree, limestone and dolomite karst occurs; in the Foredeep salt and gypsum karst occurs, and in the folded zone of the Urals there occurs dolomite and limestone karst and, more rarely marble karst. Karstic rocks are under eluvial and deluvial deposits, in river valleys they are under alluvial deposits or overlapped with non-karstic rocks of a relatively small thickness. More rarely they are stripped.

3.1 *Karst problems of the Kama dam*

The other problem is connected with the substantial activation of karst in the littoral zone.

One of the examples is the reservoir built in 1954 on the Kama-river (the tributary of the Volga). The affected area of the reservoir includes gypsiferous rocks of Sheshminskiy and Solikamskiy horizons of Ufimskiy series of Upper Permian are found in affected zone of construction.

The processes of dissolution and desalination proceed especially actively in the zone of the level fluctuation of the ground waters connected with the seasonal changes of the reservoir level which is 6-7 m. At the same time, the old karst forms get renewed and the new ones appear at a large distance from the reservoir banks.

While building and exploiting the reservoir some substantial changes of hydrodynamic and hydrochemical conditions have taken place, some problems connected with the dissolution of gypsum-bearing rocks have arisen.

The great problem of Kama dam is the gypsiferous rocks in its foundation.

Filtering-proof actions (cement barrier and drainage) provided by the project appeared were not very effective. This raised the question of consolidation of cement barrier and gelling solution was developed by the Problem laboratory of Geological Department of Moscow University. It was first domestic experience of usage of silicate solution for plugging of fractured rocks in dam foundation.

Plugging effect of this solution is reached due to gelling from colloid solution after its introduction into massive by injection, and high penetrating ability is provided with its low viscosity. After consolidation of cement barrier, filtration coefficient decreased in some times.

Post injection processes appearing under silication of water-saturated fractured gypsiferous rocks, provide safety of gypsum and efficiency of cement barrier raising in time that increases stability of dam. This is confirmed with mathematical modeling data and natural observations. Experience of injection consolidation for prevention of disaster can be used on other hydraulic engineering constructions.

3.2 *Problems of oil pollution*

The Perm region is one of the areas of oil-deposit development. A considerable number of them are located within the drainage area of the Kama River. In this area, the groundwater is poorly protected from pollution due to the intense karst development. Contaminated groundwater is discharged to the water reservoir and causes a significant pollution of water reservoir and adjacent areas. The deposit area is situated in the central part of Perm region within the Polazninskiy site of Polazninskiy karst region (predominantly of gypsum and carbonate-gypsum karst). This area encloses the left coastal side of the Kama water reservoir. 1691 karst forms are mapped within the area of 28.1 km^2, 97% of them being sinkhole. Other surface forms, such as karrs, karst trenches, hollows, gullies, dry river channels and lakes are also registered (Pecherkin, 1980). The Polaznenskoe oil deposit is an example where oil lenses were formed at the groundwater surface during its half a century development. These lenses contaminate water of the Kama water reservoir.

The site with the oil lens is in the Mokhovskoe karst field. According to geomorphology, it represents an uplifted slightly wavy plain abruptly breaking to the water reservoir and slowly sloping to the gulf. The depth of the local base level increases up to 60-80 m towards the steep slope of water reservoir, in the direction of the southeast of Zabor'e village in particular (80-100 m).

The existence of karstic rocks influences the environment. There are oil minefields along the banks of the Kama reservoir. In the process of mining, oil products have polluted the ground waters and the reservoir. This phenomenon is to a large extent due to a low protection of the ground waters owing to high karst activity of the region (middle relative density is 60 karst forms on km^2, solid block cavitation is 30%).

The analysis of geological and hydro-geological information proved that oil discharge to the coast is related to the long-term operation of oil deposit. The intense karstification of the area appears to be one of the principal natural factors that provided the development of oil pollution source at the surface of fracture-karst water.

During exploitation of oil deposit the oil lens has formed. Its width is approximately 2 m. Atmospheric elements which filtrate throughout the lens pollute groundwaters.

To improve the ecological conditions the technology of mechanical and microbiological cleaning of polluted waters has been elaborated and licensed.

4 METHODS OF PROTECTION OF THE KAMA RESERVOIR FROM OIL POLLUTION

Two methods of pollution control in the Kama water reservoir were used taking into account the geological and environmental conditions at the deposit: pumping oil out the lens using special technique and the biochemical destruction of oil using the natural biodegradation on the basis of oil-degrading bacteria activation in groundwater (Maximovich, 2005a).

The special equipment for pumping oil out the lens through the boreholes was elaborated, tested and licensed. The main idea of this method is the pumping oil without taking away the water. And this aim was achieved. All technologic elements such as sensors of lens depth and capacity, possibility of operative changes of pump depth and etc. It is shown what the borehole discharge allow to pump oil in a great volumes – about 200 l/our.

The main idea of the second method is using of microorganisms. The groundwater provides a habitat for bacteria. Microorganisms in groundwater are active *in situ*, and therefore play a significant role in influencing groundwater chemistry and quality. A great number of subsurface environmental factors can influence microbial activity and therefore also the transformation of pollutants: temperature, pH, redox potential, availability of electron acceptors, salinity and hydrostatic pressure, porosity of the aquifer's rocks, chemical recalcitrance and solubility, chemical and physical adsorption and desorption on rock particles. Microorganisms found in groundwater are able to transform a large number of contaminants under the existing redox conditions. The presence of sufficient electron acceptors will be a principal factor in predicting the degradation of organic contaminants in aquifers (Elmen, 1997). Other elements like Mg, K, Ca and trace elements necessary for microbial growth are usually available in concentrations high enough to support microbial growth.

The most common pollutants of groundwater are hydrocarbons and heterocyclic compounds of oil and oil-products. There are two main biotechnological methods of oil polluted natural habitats remediation: the first, the stimulation of natural microbial hydrocarbon-oxidizing populations by nutrient supplies (especially nitrogen and phosphor), and the second - the introduction of active hydrocarbon-oxidizing bacteria (and nutrient supplies) into polluted environments (McNabb & Dunlap, 1975).

Authors in consort with V. Hmurchik try to combine these approaches to achieve the cleaning up of oil-polluted karstic aquifer. The work consists of several stages: the isolation of active hydrocarbon-oxidizing bacteria from karstic groundwater and the study of their oil degrading capability; the development of bacterial preparation based on isolated aboriginal hydrocarbon-oxidizing bacteria to remediate oil polluted groundwater; the stimulation of aquifer's hydrocarbon-oxidizing micro flora by inorganic nutrients supplies; and the introduction of developed bacterial preparation into aquifer to achieve complete oil removal (Maximovich & Hmurchik, 2009). It must be noted that the introduction of actively metabolizing hydrocarbon-oxidizing bacteria into polluted environments is essentially actual in regions of cold and temperate climate, where warm season is not long.

5 CONCLUSIONS

Our investigation demonstrates what thorough elaboration of specific works (before starting of constructions) is necessary to make in gypsum karst regions with high anthropogenic influence. If these specific works aren't thought over this fact lead to negative consequences and great expenses for its liquidation.

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