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ГЕОТЕХНИЧЕСКИЕ ПРОБЛЕМЫ ПРОЕКТИРОВАНИЯ ЗДАНИЙ И СООРУЖЕНИЙ НА КАРСТООПАСНЫХ ТЕРРИТОРИЯХ

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Под общей редакцией доктора технических наук, профессора А. Л. ГОТМАНА

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В настоящем сборнике опубликованы доклады геотехнической конференции, посвященные решению задач проектирования оснований и фундаментов на карстоопасном основании.

Проблема включает два взаимосвязанных направления – принципы расчета и проектирования оснований и фундаментов (раздел 1) и геологические аспекты карстоопасного основания (раздел 2).

В разделе 1 представлены результаты научных исследований и разработки методов расчета фундаментов на карстоопасном основании, а также опыт проектирования фундаментов реальных объектов с учетом степени карстовой опасности площадок строительства. Рассматриваются различные виды конструктивных мероприятий противокарстовой защиты зданий и сооружений.

В разделе 2 представлены работы, посвященные особенностям инженерно-геологических изысканий на площадках с карстовой опасностью, методам оценки карстовой опасности, применению геотехнических мероприятий для сведения карстовой опасности до приемлемого минимума или полного ее исключения.

Материалы, изложенные в этих докладах, весьма полезны для инженеров-геотехников, изыскателей, проектировщиков и строителей, занимающихся проектированием зданий и сооружений на площадках с карстовой опасностью, а также для молодых ученых, аспирантов и просто всех тех, кого интересует строительная геотехническая наука.

Под общей редакцией
доктора технических наук, профессора А. Л. ГОТМАНА

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СОДЕРЖАНИЕ

Раздел 1. Проблемы проектирования оснований и фундаментов на карстоопасных территориях

3D MODELING OF KARST CONDUIT AND GROUNDWATER FLOW BELOW DAM SITE; CASE EXAMPLE VISEGRAD DAM

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ABSTRACT

Already in the first year of the exploitation of the Visegrad dam, the occurrence of submerged down streams springs was noticed. By the measurements of water quantities that appear in the springs downstream from the dam it was established that the quantity had increased from the 1.4 m^3/s (in the year 1990) to 13.92 m^3/s (in the year 2008), and 14.68 m^3/s (in the year 2009). This paper present certain investigations performed specially for needs of establishing position of karst conduit below dam site.

Key words: Karst, dam, 3D, modeling, channel, groundwater

INTRODUCTION

In respect of risk factors in dam and reservoir construction in karst, particular attention has to be paid to reservoir water tightness. An appropriate project concept, prior to exploration, can significantly reduce the risks or minimize them to acceptable levels (Zogovic D, 1980, Milanovic PT, 2000, Bruce D.A, 2003, Fazeli, 2007, Milanovic S, 2010), while the reductions of exploration work can increase them. Some of the inadequately explored reservoirs constructed in karst have never fully filled up with water. One of the good example is problem of water tightness of Visegrad dam.

The number of springs varied during the period of exploitation; occasionally some smaller springs merged into a larger one; the change of the location of the springs also occurred as well as the frequent appearance of muddled water on the surface that indicates that washing out is still in progress. In the present state there are 11 active springs. The losses began to increase constantly trough time. The filtration beneath the dam is still going on through reactivated karst channels, in the depths beneath the existing grout curtain, even beneath its already deepened section.

Since it was established that it is a highly undesirable phenomenon, the increase of which can lead a variety of damages, it has been assessed that it is necessary to perform a certain number of special-purpose investigations, in order to provide relevant data for the development and realization of the design of the rehabilitation of the dam regarding seepage.

PREVIOUS INVESTIGATIONS – DURING CONSTRUCTION AND EXPLOITATION

During the previous period of dam construction and exploitation were performed certain multidisciplinary investigations, primarily with the goal of definition of seepage. All these investigations have yielded a large body of results, a part of which is significant for the solution of the seepage problem beneath present conditions.

From performed detailed geological mapping of the dam site (in the 1:50 to 1:1000 scale), through more than 4470 m of drilling, as well as a lot of number of tracer tests which is indicative of groundwater circulation, and constant monitoring of 58 piezometers in dam abutment, was not enough to established conditions of karstic network reactivation.

Water seepage beneath the dam was systematically monitored from the year 1991 to the year 2009. Measured values are shown in the graph on Fig. 1.

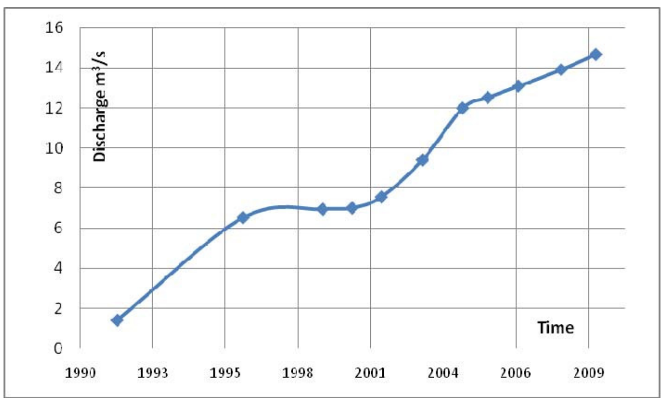


Fig. 1. Water seepage measurements through time

MAIN RESULTS OF NEW SPECIAL INVESTIGATIONS

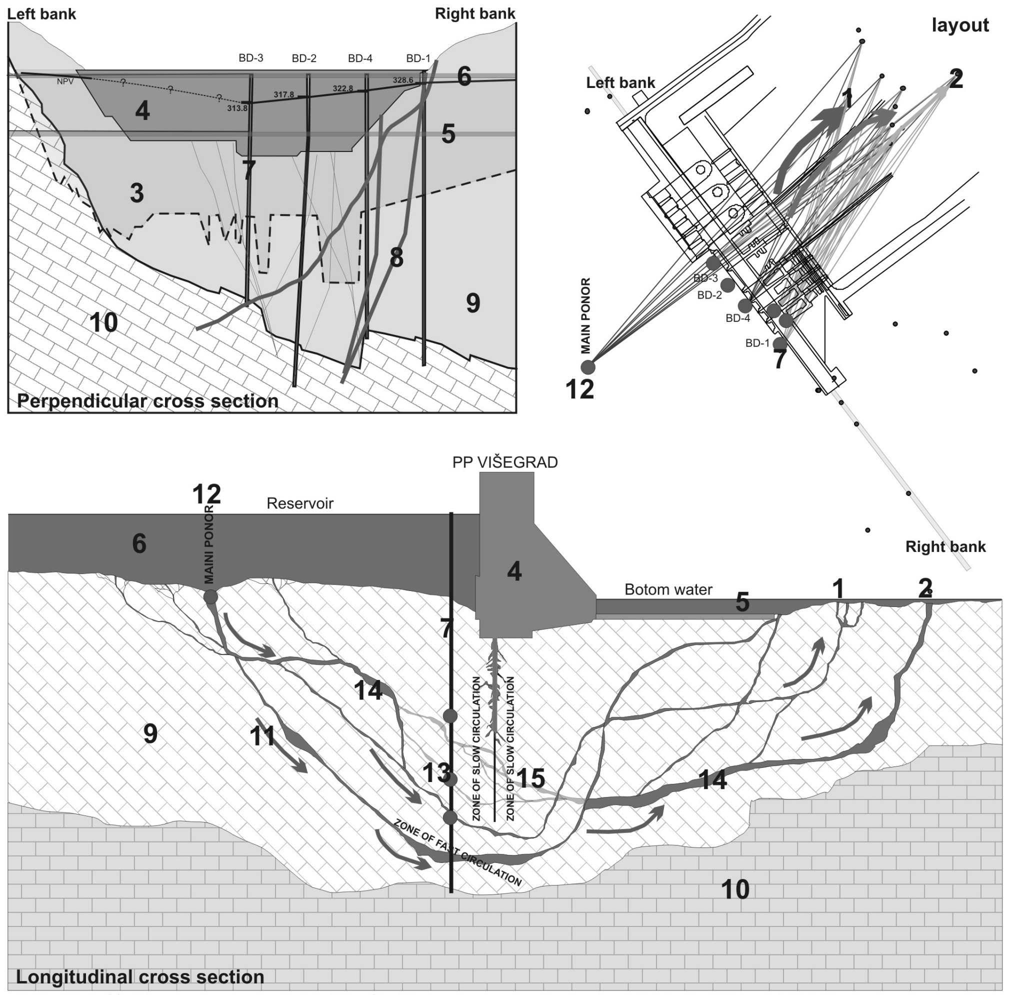
In order to define the positions of channels along which the groundwater circulate under dam site, in the year 2009 were performed the special-purpose investigations.

Detailed investigations of the narrow area around the dam site started with the geodetical survey of the dam and the appurtenant structures, as well as of the surrounding terrain, and by formation of the geodetic location plan in the 1:1000 scale, together with making maps of bottom topography of reservoir and downstream. Also, geological investigations of the dam site started with new, high-quality detailed geological mapping of the terrain. Parallel with these investigations was performed cross-hole geo-electric scanning in the left and right dam abutment and over the reservoir, as well as reflective seismic investigations in dam galleries.

In the zone of the storage was simultaneously performed the bathyimetric recording of the bottom of the part of the storage near the dam and of. By self-potential measurement of reservoir bottom sinkhole of great size and capacity was detected further investigated with underwater video equipment. Immediately after the detection of the "large sinkhole" were performed its measurement and determination of water inlet velocities. The entrance is area about 15 m^2 and 5 m deeper it become channel with diameter of 2m and swallowing capacity of 9 m^3/s Fig. 2.

In the meantime were performed the works on investigation drilling and corresponding investigations in the boreholes (video endoscopy, carotage etc.). The locations of these boreholes were determined is in succession, depending on the results of all previously performed investigations Fig. 2.

Finally, after drilling of all boreholes and the completion of the corresponding investigations in all 4 boreholes were conducted cross-hole geo-electric and seismic tomography between the boreholes, as well as several times repeated tracer tests in the large sinkhole (ponor) and boreholes.



1 - location of first tracer appearance, 2 - location of last tracer appearance, 3 - grout curtain, 4 - dam Visegrad, 5 - botom water, 6 - reservoir Visegrad, 7 - investigation borehole, 8 - main fault, 9 - karstified rock, 10 - limestone with low karstification, 11 - groundwater flow direction, 12 - main ponor (sinkhole), 13 - location of tracer injection,14 - channel with active water circulation, 15 - channel with slow water circulation due to injection works

Fig. 2. Hydrogeological characteristic of potential leaking below HPP Visegrad according special investigations conducted in 2009

3D MODELING OF KARST CONDUIT

Geological investigations of the karst setting, required to address seepage beneath the dam of the Višegrad Hydropower Plant (Višegrad HPP), were focused on a rather narrow area containing a refill “sinking” zone and a drainage “discharge” zone. The basic problem was how to perform a quality analysis, or how to state the problem whose goal was to develop a model which will be an analysis of the geometry of subsurface karst conduits, integrating hydrogeological laws and basic geological characteristics.

The problem was approached from three parallel directions:

- Theoretical approach, which initially played a major role and provided guidelines for field activities,
- Detailed and highly-complex field investigations and

•	Development of a basic input 3D model, then an empirical approach and later also a mathematical approach, aimed at producing the final form of the model.

Based on the above problem statement, it was safe to assume that interactive work and integrated use of known 2D and partly-defined 3D parameters will produce an output of a three-dimensional nature.

By way of solution, evidence was needed that the method to be applied for the construction of a 3D geometrical (or physical) model and a parametric model of karst aquifer, aided by an incomplete data series, is feasible.

A 3D geological model was developed for the purposes of generating a network of potential karst conduits running from the sinkhole zone to the spring zone, or from the determined potential infiltration zone to the accurately defined karst discharge zone.

The 3D geological model was developed using ArcGIS software and its 3DAnalyst, SpatialAnalyst and NetworkAnalyst extensions. All spatial data, such as geological maps and profiles, as well as the positions of the dam, grout curtain, grout galleries and piezometers, were converted into digital form, and each spatial unit was defined by its x, y and z coordinates.

The compilation of all elements in a 3D environment produced a real, spatially oriented network of potential karst-conduit pathways, which was used as an input parameter for subsequent Fig. 3.

A 3D network of potential karst conduit pathways Fig. 3 was constructed based on the results of GIS data processing. The 3D model described the network of courses of potential karst conduits, from the sinking zone to the discharge zone (or from the identified potential zone of infiltration to the accurately defined zone of discharge of karst water).

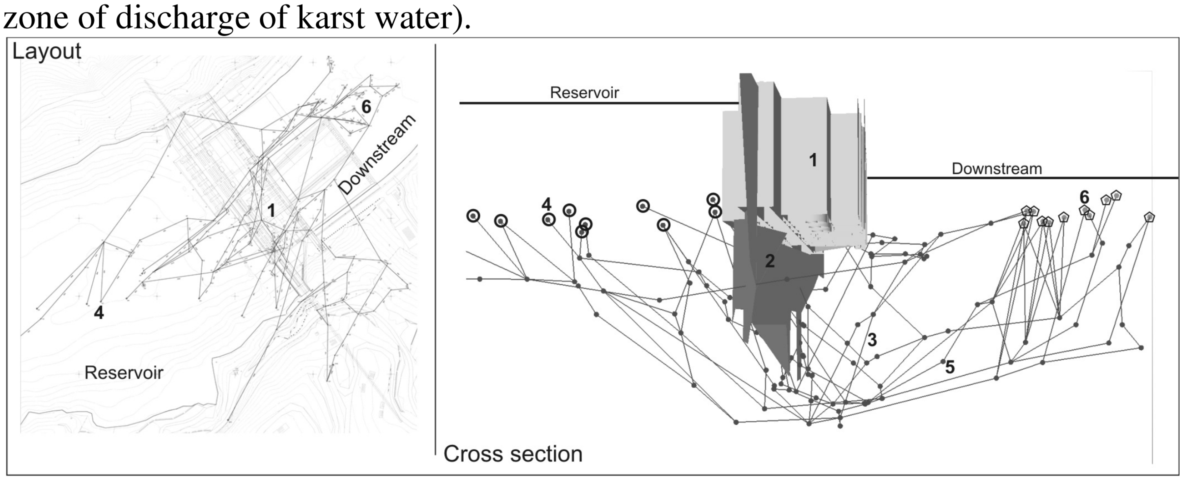


Fig. 3. Spatially-oriented 3D network of potential karst conduits: 1. Dam, 2. Grout curtain, 3. Network - karst conduits - link, 4. Node – sinking zone, 5. Network node – link bifurcation, 6. Discharge zone - springs

As required by the numerical algorithms, this network was described by means of model nodes and elements. They made up the topology of the numerical model and spatially corresponded to the geological model.

Nodes were represented via x, y and z coordinates, where potentials were computed. 1D elements were used for hydraulic calculations based on the finite element method. The lengths of these elements were defined by the corresponding nodes, and calculations were performed along them.

The network was comprised of 177 nodes, linked by 226 elements. From an optimization algorithm perspective, the number of nodes, elements and free parameters is indicative of the complexity of the problem. As a result, 207 x 5 (1130) parameters were determined and at the same time more than 100 computed values were compared with measured values. It is obvious that this optimization problem required substantial processor time and a parallel genetic algorithm was therefore used to arrive at a solution.

RESULTS OF MATHEMATICAL MODELING – OVERVIEW OF GROUNDWATER FLOWS

The principal objective of the use of the mathematical model is to determine the spatial layout of principal karst conduit

s and their physical characteristics. Taking into account the satisfactory degree of congruence with the real system, the model defines all main groundwater flows, with the corresponding parameters (dimensions, resistances, potentials, velocities and discharges). This model, with its results, represents a foundation for interpretation of geological data and determination of direction of development of the dominant karst channels, i.e. water circulation paths.

By simulation on the hydraulic model with the adopted topology and flow characteristics are obtained all hydraulic parameters upon which the analysis and defining of the dominant directions of water flow beneath the dam body can be performed. The results of the mathematical calc. are shown on the Fig. 4.

The results of investigations show that the largest amount of water flows from the storage into the underground through the large sinkhole with length of circa 20 m and area of 7.1 m^2. According to the measurement results in this way into the system of underground structure flows circa 8.15 m^3/s. The remaining water that leaves the storage and infiltrates in the underground (circa 6.5 m^3/s). From the large sinkhole are formed two karst forms through which groundwater flows. The “left” direction of underground flow, i.e. the karst channel, was formed along the dominant longitudinal fault structures. Along this direction was formed a system of karst channels with two courses, that generally run towards the boundary of the dam blocks

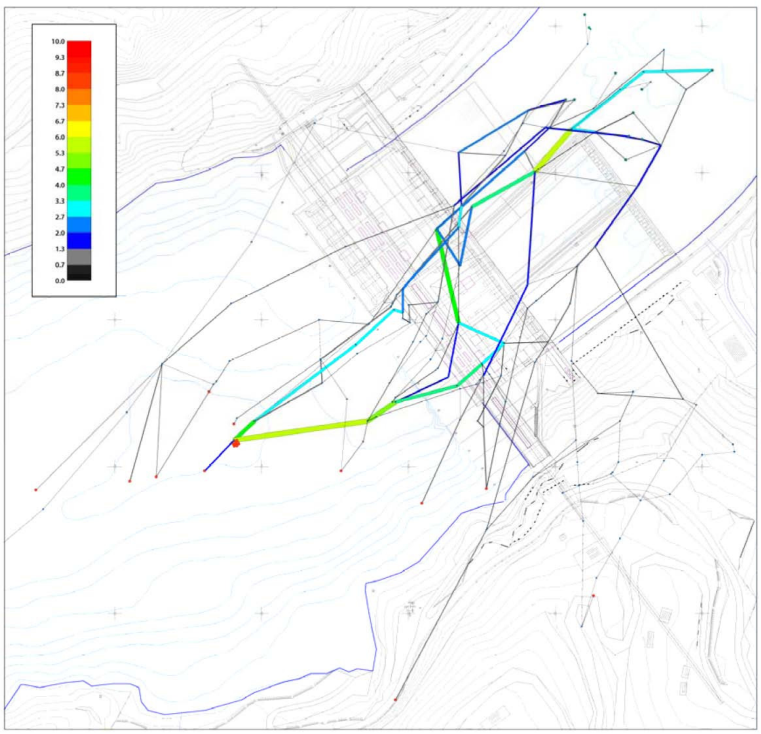


Fig. 4. Computational values of discharges along underground courses.

By the performed special-purpose investigations were defined the underground water courses and parameters necessary for development of the technical solution for the permanent rehabilitation of seepage. However, the conduction of the sealing rehabilitation works under such complex conditions is a very complex process, so it must be followed by the elaborate special-purpose monitoring from the very beginning of the process of conduction of rehabilitation works.

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