

Earth-Fill Dam Monitored by EIS Method during Application of Nutrient Aqueous Solution used in BioSealing Method

J Pařílková¹, B Gjunsburgs², Z Zachoval¹, J Veselý¹ and Z Múnsterová¹

¹ Brno University of Technology, Faculty of Civil Engineering, Institute of Water Structures, Veverí 331/95, 602 00 Brno, Czech Republic

² Riga Technical University, Water Engineering and Technology Department, Kalku Str. 1, Riga, LV-1658, Latvia

E-mail: parilkova.j@fce.vutbr.cz

Abstract. The paper gives short information about the results of monitoring the electrical properties of an earth-fill dam during the application of a nutrient aqueous solution used in the method BioSealing. Monitoring is carried out using a Z-meter device when applying the method of electrical impedance spectrometry and, in some cases, is part of a system of monitoring seepage through the earth-fill dam of the water reservoir by its administrator. Information about the changes that take place in the body of the dam during the movement of the water level in the reservoir or after the influence of weather changes or human activity are given through the monitored changes in the electrical parameters of the soil of the dam with time.

1. Introduction

Dams of water reservoirs can be considered among the oldest building structures created by man [1], [2, 3]. Natural materials have been used for their construction – rock and soil, and artificial materials – concrete, reinforced concrete, asphalt concrete, plastics, etc. [4, 5, 6].

A typical feature of the Czech water management was the construction of fishponds and small water reservoirs, which began in the 14th century. There are approximately 25,000 of them on the territory of the Czech Republic (CR) [7]. Small water reservoirs are mostly of local significance, but are irreplaceable on their sites. Dams are usually homogeneous earth-fill ones, formed largely of local materials.

Concurrently with the construction of earth-fill dams, however, a risk of their damage arises because earth-fill dams and their basement are exposed to the effects of forces which can threaten the construction. These are particularly the effects of self-weight, water pressure, flowing water, action of ice, pounding by waves and other natural effects [8]. Therefore, such constructions are monitored and the technical condition of the construction is evaluated in terms of safety, operating reliability, causes of potential failures and their consequences. Their supervision also includes a proposal of measures, if necessary, and their subsequent implementation.

A possible measure of additional sealing earth-fill dams is the BioSealing method, which applies a nutrient aqueous solution injected into the soil, which will bring about biological-chemical-mechanical processes in the dam soil, causing the additional sealing of the dam. This paper is concerned with the monitoring of the regime of seepage water through the earth-fill dam of the Hornice water reservoir when applying a nutrient aqueous solution used in the BioSealing method.



The whole process of the additional sealing of the dam has been documented by measuring the water level in the reservoir, seepage and changes in the electrical conductance of the dam soil using the method of electrical impedance spectrometry (EIS) with time.

The aim of the monitoring system based on the EIS method was not only to document the changes that take place in the dam soil as a result of remediation using the BioSealing method, but also the effect of its hydrodynamic load and weather effects, as well as to verify the autonomous operation of the monitoring system in the specific conditions.

2. Earth-fill dam of the Hornice water reservoir

The Hornice dam and water reservoir lies in the CR, southwest of the City of Brno, north of the municipality of Hornice (Figure 1). The dam and water reservoir was approved on 31 May 1985 and originally served as an irrigation reservoir. Water from the reservoir was collected through an accumulation tank to an irrigation station located below the dam and from there it was taken for irrigating adjacent plots of land. But it does not serve this purpose anymore. At the present time it is used only for the retention and accumulation of surface water and for fish farming and duck breeding by local unions and associations. Since 2012, when property settlement was agreed on, the owner of the dam and water reservoir is Zemědělské družstvo Dešov (Farming Cooperative Dešov).

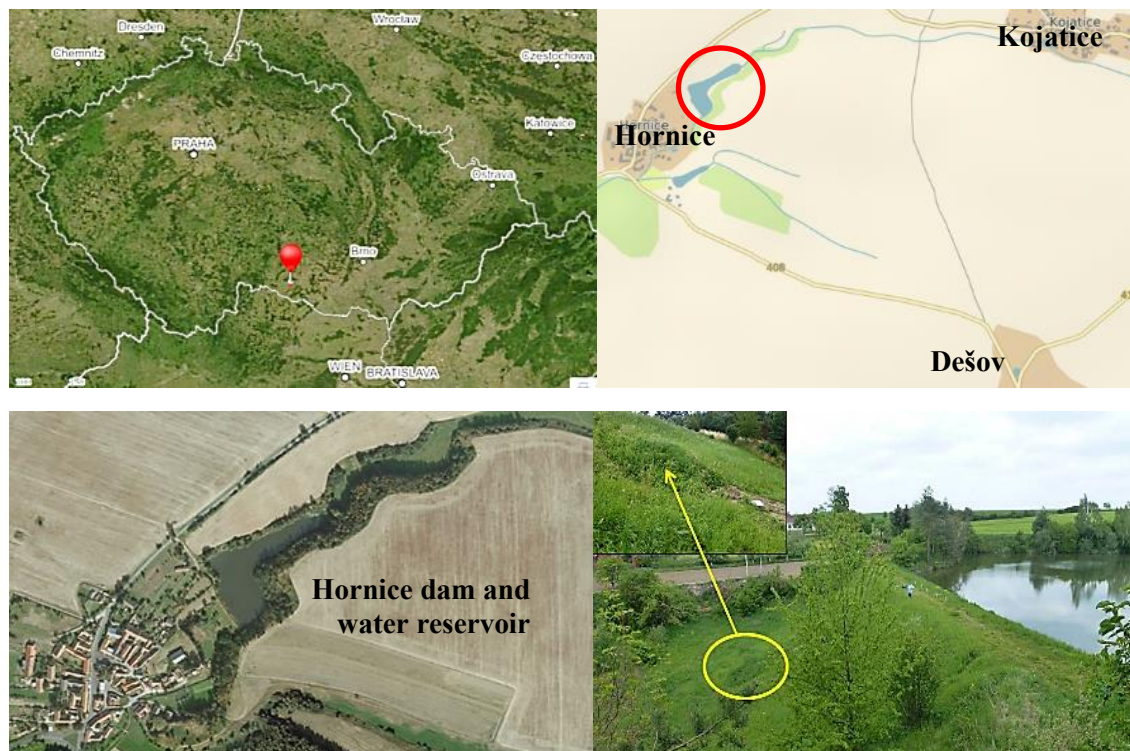


Figure 1. Situation of the location, earth-fill dam and seepage area.

The height of the dam above the original ground is 8.22 m, and the height of the dam above the base of the dam is 11.20 m [9]. A gravel road runs on the dam crest; its average width is 4.25 m (at the beginning it is 4.30 m wide, above the place of the observed seepage 3.80 m wide and at the railing securing the roughened chute 4.65 m wide). According to the project [9] the dam at its base is 46.80 m wide. The upstream face has a slope 1:2.5 and is fortified with stone packing. The downstream face of the dam has a designed slope 1:2.5 as well, but when installing the EIS monitoring system, a change in the slope was detected, which is probably a result of deformation of the downstream face due to the forming inrush area (Figure 1). The downstream face is provided with maintained grass cover.

3. Method of remediation and monitoring

Remediation of seepage of earth-fill dams is currently most often carried out using construction procedures of special foundation engineering. Sealing is carried out from the dam crest. Used are technologies of construction of a grout curtain or innovative BioSealing method and technologies [10]. There are a whole number of methods of monitoring the regime of seepage water in earth-fill dams, one of which being the EIS method ever more often used at the present time [11].

3.1. BioSealing method

The BioSealing method is based on the stimulation of the biological activity of bacteria, which occur naturally in soils (Figure 2) [12]. The number and type of these bacteria is governed by the properties of soils, such as pH value, temperature of water in soil or salt content. Their activity is stimulated using the injection of nutrients close to the place of seepage. Water flowing through soil transports nutrients towards the place of the highest seepage where the number of bacteria present and their products will rise due to nutrition. During the process the chemistry of the soil can change, as well as the transport of bacteria and the capture of fine particles transported by the flowing water.

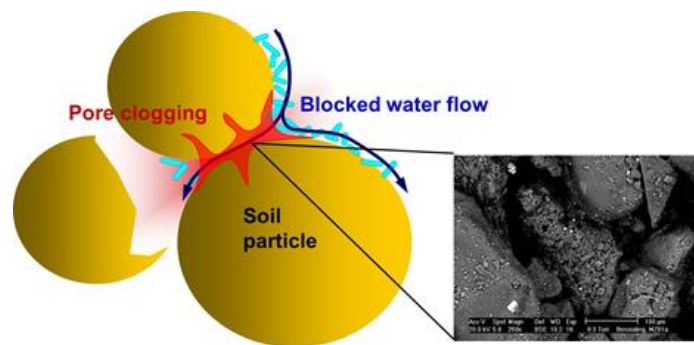


Figure 2. Principle of BioSealing - a combination of microbiological and biochemical processes.

Bacteria produce slime that surrounds particles and the soil is thus sealed. Approximately 8 weeks after the injection of nutrients, the bacterial activity begins to decrease and returns to the original state. The fine particles captured in the bacterial slime, however, form a solid seal which remain even after the death of the bacteria. The conditions under which it is possible to apply the technology are described by Liao [13].

3.2. Electrical impedance spectrometry method

Electrical impedance spectrometry (EIS) is an indirect method of measurement recording, through the measured electrical impedance Z [Ω] monitored by a harmonic alternating electrical signal of a certain frequency, processes that take place in soil and that relate to a change in soil water saturation or to a change in the electrical conductance of water.

Ideally, the measured variables are the frequency-independent soil resistance R [Ω], which is primarily dependent on water content in soil pores and the frequency-dependent reactance X [Ω], which depends on the structure of soil (grain size, density, etc.). Electrical impedance is determined using the equation

$$Z = R + jX. \quad (1)$$

Measurement was conducted using two active EIS probes. One (EIS10) was installed from the dam crest, being 10 m long and containing 22 sensors, with the first sensor being placed at a level of 1 m beneath the dam crest, and the second (EIS3) probe was 3 m long, containing 16 sensors, with the first sensor being placed beneath the dam crest on the downstream face in the area of the forming inrush area at a depth of 3.03 m beneath the dam crest, with the first electrode being 0.03 m beneath the

surface. The probe 10 m long was installed in the dam crest 0.15 m from the upper edge of the downstream face of the dam; the installation was made using a Pagani rig (Figure 3) and the first electrode is at a depth of 1.0 m.



Figure 3. Detailed view of the EIS3 probe, installation of the EIS10 probe using a Pagani rig.

The probes are divided, with the conductive part (electrode) being made of a stainless steel tube of 0.025 m in outer diameter, 0.002 m in wall thickness and 0.05 m in length; the non-conductive part is made of a polyamide tube of 0.025 m in outer diameter. The probes of the EIS method are installed as pair probes in a two-terminal connection (the driving electrical circuit is not separated from the measuring electric circuit), with the spacing between the rods (Figure 4) respecting the field possibilities and the condition of not exceeding the spacing 2 m for the reasons of transmission of the generated driving signal (limiting the effect of the geoelectromagnetic field of the Earth). The transmission of the signal is ensured by the conductors passing through the tubes and then through corrugated cable protection hose pipes in the dam soil.



Figure 4. Detailed view of the position of the installed rods and the measuring system.

4. Measurement, observation and results

The application of the nutrient aqueous solution used in the BioSealing method on the earth-fill dam of the Hornice water reservoir took place in a period between 9 May 2016 and 3 June 2016, when a total volume of 205 l of the Nutrolase-based nutrient aqueous solution in dosing 5 l of Nutrolase to 200 l of water was injected into 5 boreholes (BH1, BH2, BH3, BH4 and BH5) daily except Saturdays and Sundays. At the same time, the water level in the reservoir was increased by gating the emergency spillway until 6 June 2016. The water level in the reservoir was kept at an approximately constant level until 28 June 2016. On 29 June 2016, the gate was lowered by 0.10 m.

A special measuring apparatus [15] was constructed within the project E!7614 [14], enabling fully automatic monitoring at the selected times 1 h, 7 h, 13 h and 19 h and the transmission of the measured sets through a Wi-Fi module to the user's computer. Measurement for the evaluation of the

application of the nutrient aqueous solution was carried out from 1 May 2015 to 30 June 2016 (the monitoring system still measures to the present time).

The processes caused by the application of the BioSealing technology, the fluctuation of the water level in the reservoir and the weather effects were monitored using the two EIS probes.

Two sensors were used for the measurement of the water level in the reservoir, the first one was based on the measurement of electrical impedance and the other one (ESMWLPS Water Level Sensor) was based on measurement of relative hydrostatic pressure. The patterns were supplemented by the values of visual observation and manual measurement. The main parameter documenting the application of the nutrient aqueous solution used in the BioSealing method was seepage measured by a PF500 shuttle tilt flowmeter (Figure 5). The system was also fitted with an ESP11 sensor of electrical conductance, pH and temperature.



Figure 5. Detailed view of the place of seepage with the clear water inrush and the system measuring seepage, temperature, electrical conductance and pH of seepage water.

4.1. Achieved results

The achieved values of seepage, water level, precipitation and temperature with time are given in Figure 6. The application of the nutrient aqueous solution took place in a period between 9 May 2016 and 3 June 2016. In this period, seepage through the dam body significantly dropped. On 24 May 2016, a more striking precipitation episode was recorded on the site, reflected in the patterns of practically all the parameters. On 2 June 2016, the emergency spillway was gated and the water level in the reservoir was gradually rising. Conversely, on 29 June 2016, the spillway was opened. In the period following 5 June 2016, several more significant precipitation episodes occurred, manifested in increased seepage (15 June 2016 and 20 June 2016).

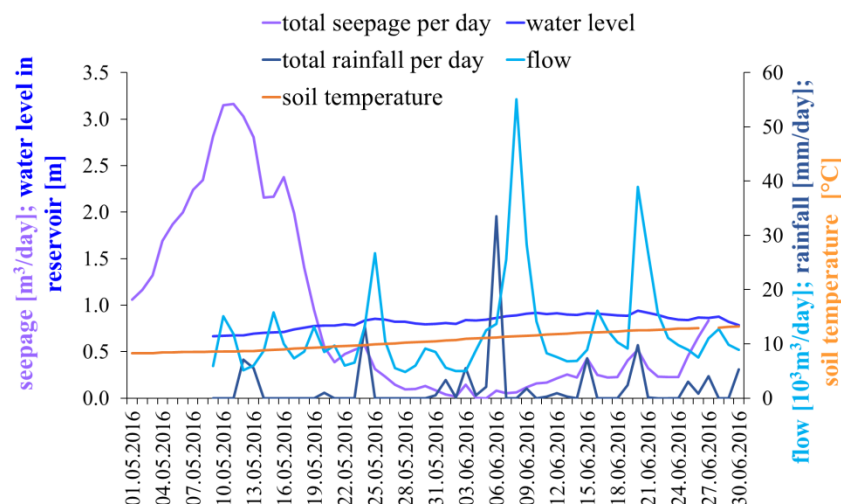


Figure 6. Monitoring of the BioSealing process.

The curves obtained from the measurement of resistance made by the EIS10 probe is given in Figure 7a, and by EIS3 probe in Figure 7b. When discussing the patterns of the measured electrical variables, an assumption was accepted that during the measurement neither significant mechanical nor chemical changes occurred in the measured profiles of the dam soil. The resistance of the Nutrolase-based nutrient aqueous solution was $150\ \Omega$. The patterns of the resistance R measured at the known levels of the dam soil in both probes shows the period of dosing – a sudden drop of the values at all levels accounts for an increase of water content in the measured profiles due to the dosing of the nutrient aqueous solution and the flushing of the dosing boreholes.

Significant changes measured by the EIS10 probe (Figure 7a) can be observed at the level -2.2 m beneath the dam crest, when about a 98% drop of the values R occurred in the measured profile in a period between 21 May 2016 and 31 May 2016, i.e. a rise of water content. In the following period, water from the profile flows away and the values R gradually reach the original level, which they, however, did not exceed. The large fluctuation of the signal measured at the levels -1.3 m to -2.2 m is probably caused by a very variable content of air, which water transports when flowing through the soil. The higher the air content in the measured profile, the higher the values of the measured resistance R and vice versa, the higher the water content in the measured profile, the lower the values of the resistance R . Based on an engineering-geological survey performed [16], it is possible to state a more significant abundance of coarse-grained soil in the given range of the measured levels. As a consequence, it is also possible to assume a more significant dependence of the measured values of the resistance R on the soil porosity and on the given transport features.

The positive effect of the application of the BioSealing technology, i.e. the local additional sealing of soil documented by the rise of the values R (almost twice higher), is evident at the level -9.3 m, i.e. the dam base, to which reaches the active dosing of the nutrient aqueous solution according to the measurement. At the following measured level (-9.9 m), the same effect, i.e. the rise of the values R , was not observed anymore.

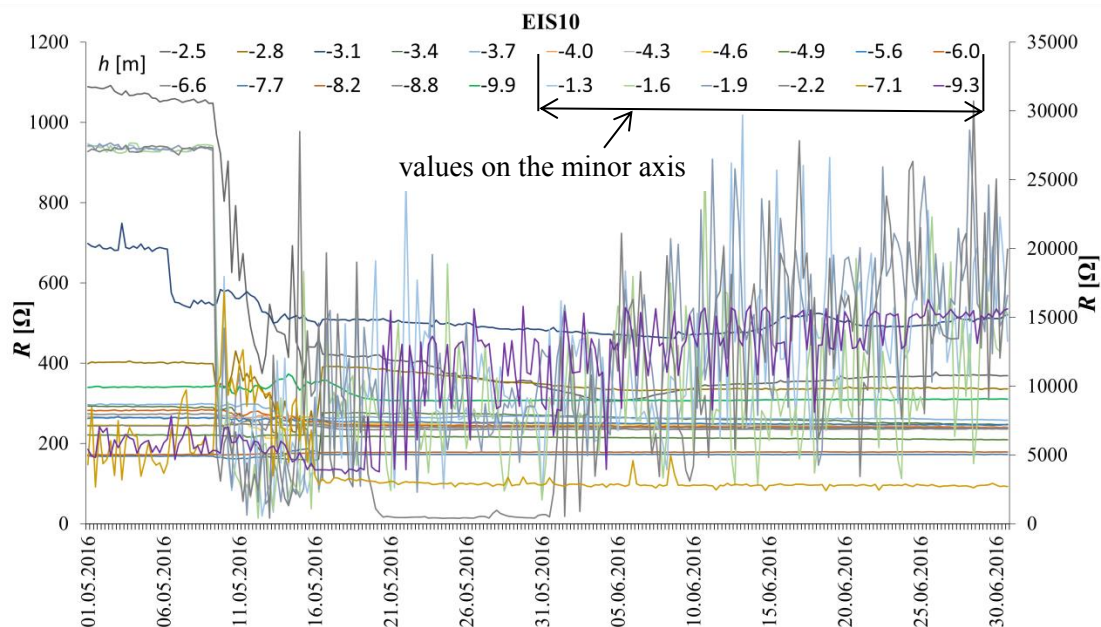


Figure 7a. BioSealing process monitored by the EIS method.

The EIS3 probe (Figure 7b), which is placed directly in the inrush area, also clearly recorded the application of the nutrient aqueous solution used in the BioSealing method. In the following period, a rise of the resistance values R can be observed at the levels -3.1 m (the surface layer of the downstream face of the dam), -3.3 m, -3.5 m and -5.9 m. In the other monitored levels, the values R remained low, which indicates a soil with higher water content.

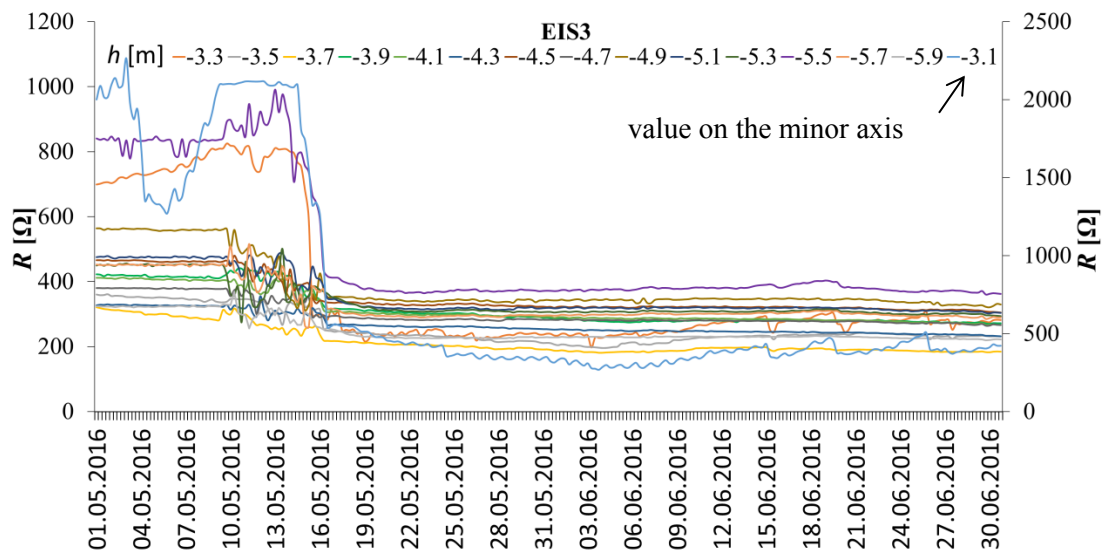


Figure 7b. BioSealing process monitored by the EIS method.

5. Summary and conclusion

The first application of the BioSealing technology in the conditions of the CR documents its potential in sealing local seepage through the bodies of earth-fill dams. In comparison with the use of traditional remedial methods for sealing seepage that takes place through earth-fill dams of water reservoirs, such as jet grouting or construction of clay-cement slurry walls, the technology of BioSealing offers lower costs in application, a relatively lower intervention to the earthen body and a lower load imposed on the environment. The method has been developed and patented by the Dutch companies Deltares and Volker Staal en Funderingen. It was used in practice when sealing seepage through soil in the North-South underground line in Amsterdam. In Austria sealing work along the Danube canals was carried out by the company Züblin Spezialtiefbau using this technology within research. These practical applications have proved the functionality and efficiency of the method, but for its transfer to the area of mass application it is necessary to verify the durability of sealing, to optimise the dosing process in relation to the parameters of the specific site, etc.

The above-given results of monitoring the process of dosing the nutrient aqueous solution (used in the BioSealing method) using the EIS method show the suitability of its application in documenting the processes which take place in soil during and subsequently after the dosing. A significant advantage is the fact that the measuring probes remain in the same position over the entire time, thus it is possible to monitor changes still at the same measured levels and to evaluate them relatively. Because it is an indirect geophysical method of measurement, it is necessary in measurement to eliminate the effect of parasitic parameters (temperature, chemistry, etc.) on the monitored variables. Measurement was carried out using a unique measuring apparatus constructed within the solution of the international project E!7614 in a EUREKA applied research programme.

Acknowledgements

This paper has been created within the project LF13019, which is part of the international project E!7614 supported by the Ministry of Education, Youth and Sports within the special-purpose support of the EUREKA programmes, the project LO1408 “AdMaS UP – Advanced Materials, Structures and Technologies” supported by the Ministry of Education, Youth and Sports under the “National Sustainability Programme I” and the specific research projects FAST-S-16-3757, “An Increase of Safety and Reliability of Selected Hydraulotechnical Constructions”, and FAST-S-15-2841, “Spillways for specific hydraulic conditions”, supported by a targeted subsidy of Brno University of Technology.

References

- [1] Smith N 1976 *A history of dams* Citadel Press Firsth edition New York USA ISBN 978-080-6502-915
- [2] Bednářová E 2011 Nádrže a priehrady od minulosti po súčasnosť a ako ďalej (Reservoirs and dams in the past, in the present and in the way forward) *Eurostav* p 8-11 ISSN 1335-1249
- [3] Bednářová E, Lukáč M, Lukáč M, Minárik M, Bakaljarová M, Lipták B, Miščík M, Panenka P and Stoličný J 2010 *Priehradné staviteľstvo na Slovensku. Originality mílniky zaujímavosti (Dam engineering in Slovakia. Originality - Milestones - Interesting Features)* Bratislava KUSKUS Ltd 206 p ISBN 978-80-970428-0-6
- [4] Votruba V 2002 *Nejstarší přehrady doby předkřesťanské (The oldest dams of pre-Christian times)* Vydavatel Ministerstvo zemědělství České republiky ve spolupráci s Českou vědeckotechnickou vodohospodářskou společností (Publisher - Ministry of Agriculture of the Czech Republic in cooperation with the Czech Scientific and Technical Water Management Society), 29 p ISBN 8002014790 9788002014799
- [5] Broža V, Kratochvíl J, Peter P and Votruba L 1987 *Přehrady (Dams)* Praha SNTL – Nakladatelství technické literatury (Technical Literature Publishing House) 548 p
- [6] Votruba L, Broža V and Kazda I 1978 *Přehrady (Dams)*. Vyd. 1 (1st Edition) Praha Vydavatelství ČVUT (Czech Technical University Publishing House) 332 p MDT 627.81(075.8)
- [7] Blažková Š, Sedláček M and Daňhelka J 2016 Vývoj metod odvozování hydrologických podkladů pro posudky bezpečnosti malých vodních nádrží při povodních (Development of the methods of derivation of hydrological source data for the expertise of safety of small water reservoirs during floods). *XXXV. Přehradní dny 2016 (35th Dam Days 2016)* Ostrava ISBN 978-80-01-05969-2
- [8] Lukáč M and Bednářová E 2006 *Navrhovanie a prevádzka vodných stavieb Sypané přehrady a hrázde (Design and operation of hydro-engineering structures. Embankment dams)* Bratislava Vyd. Jaga group Ltd (Jaga Group Publishing House Ltd.) 183 p ISBN 80-8076-015-2
- [9] Hejtman Z 2012 Provozní a manipulační řád pro vodní nádrž „Hornice“ na p.č. 124/33 v k.ú. Hornice (The rules and regulations of operation for the water reservoir “Hornice” on plot of land 124/33 in the cadastral area Hornice). *Podrobná situace (Detailed situation)*. Vypracoval zodpovědný projektant Ing. Zdeněk Hejtman zak.č. 31/2012 č. výkresu 3 část H 3 (Prepared by the responsible designer Ing. Zdeněk Hejtman, contract no. 31/2012, drawing no. 3, part H.3)
- [10] Liao H, Zhao K, Lambert J W M and Veenbergen V 2005 River Management Bureau Changjiang Water Resources Commission Wuhan 430010 China and GeoDelft 2628 CK Delft the Netherlands *Experimental study on Biosealing technology for seepage prevention*
- [11] Pařílková J and Pařílek L 2008 Monitoring of the earth dam of a water reservoir by the method of electrical impedance spectrometry *EUREKA 2008* Brno ISBN 978-80-214-3687-9 pp 21-31
- [12] Lambert J, Veenbergen V, Van der Hoek E and Karstens S 2004 Environment BioSealing: How Micro-Organisms Become Our Little Allies in Repairing Leaks *Ingeokring Newsletter* Vol 11 No 1 pp 9-12
- [13] Liao H 2005 Experimental study on BioSealing technique for seepage prevention *MSc thesis UNESCO-IHE Institute for Water Education/GeoDelft Delft the Netherlands*
- [14] <http://www.eurekanetwork.org/project/id/7614>
- [15] Pařílková J and Radkovský K 2016 Z-meter IV – User’s Manual pp 1-19
- [16] Rupp D and Pazdírek O 2015 BioSealing – the final report of a pilot project. *EUREKA 2015*. Jaroměřice nad Rokýtnou, pp. 197-205, ISBN 978-80-214-5338-8, ISSN 2464-4595