LESSONS LEARNED IN CLARIFYING ANOMALIES IN THE DAM SAFETY ASSESSMENT IN SLOVAKIA

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ABSTRACT

Experiences from dam safety evaluation in Slovak geological conditions proved, that most often reasons resulting in realisation of remedial measures were seepages. Seepages through the body of dam were recorded occasionally. Generally, seepages occurred in the subsoil of dam or in its abutments. Signs of seepages were different. Sometimes there were excessive groundwater and seepage water levels, other times high filtration velocities which exceeded limit values, eventually other anomalies in the development of the filtration flow.

In order to minimize the occurrence of such anomalies, in addition to basic in situ measurements, special methods are used to assess the safety of dams. These are geophysical measurements of filtration velocities, mathematical and statistical analyses of predicted and achieved parameters of filtration flow. In the paper we present some lessons learned in this topic.

1. INTRODUCTION

The dam construction in Slovakia can be divided into two main stages. The first stage dates back to the 18th century. At that time, around 70 mostly earth-fill dams were built in our area around Banská Štiavnica, with a total volume of accumulated water of approx. 6 million m3. The main reason for their construction was the need for water for the mining industry. Of these, 22 reservoirs are currently in operation, 6 are included in ICOLD register of large dams (Veľká Vodárenská, Veľká Kolpašská, Veľká Richňava, Rozgrund, Dolná Hodrušská, Počúvadlo). The second stage of construction is the second half of the 20th century. Out of the total number of 50 dams included in ICOLD register, 44 were built during this period. The impulse for their construction was the need for water for inhabitants, industry, agriculture, energy and others, as well as flood protection. The age of these dams (without 6 historical ones) is almost 50 years. In order to ensure safety and minimize the risks of failures and accidents of these structures, it is necessary to pay attention to their monitoring. In set of basic measurements of deformations and parameters of filtration flow of groundwater and seepage water were in Slovakia included special - geophysical measurements of filtration velocities. These are performed according to need especially in dams of 1st category, usually once every 4-5 years. The results of special measurements (filtration velocities) are beneficial for assessing the filtration stability of rock environment, or for clarifying anomalies in the filtration flow. Some knowledge and lessons learned from the application of geophysical measurements of filtration velocities are presented in this paper.

2. BRIEF CHARACTERISTICS OF THE METHOD OF FILTRATION VELOCITIES MEASURMENTS

Principle of single borehole geophysical methods of measurements of filtration velocities is based on observation of process of dilution or vertical movement of indicated solution in the borehole. The indicator is generally sodium chloride (NaCl). Two methods are applied in Slovak practice – dilution method and method of observation of vertical flow in the borehole.

Dilution method is used in boreholes with low water column, where usually horizontal flow of water prevails. Sodium chloride in powder form is applied into borehole for observation of flow velocity. The salt solution is formed directly in the borehole. Its initial concentration is diluted by flowing water. Filtration velocity is calculated from the process of solution dilution.

The method of observation of vertical movement of indicated water is applied for the measurement of filtration velocities in boreholes with high water column. Here it is possible to assume the interconnection of different pressure horizons along the depth of the borehole, resulting in a vertical movement of water in the borehole. The vertical flow rates are determined by measuring the intensity of the vertical movement of the indicated water in the well and its variation in depth. Their decrease or increase after the borehole depth confirms the inflow or outflow of water from the borehole. These changes, and in particular their intensity, are decisive for determining the filtration velocities around the well.

3. GEOPHYSICAL MEASUREMENTS ON VEĽKÁ DOMAŠA DAM

It is earth-fill heterogeneous dam with inclined sealing (Fig. 1). Dam is situated on river Ondava and create reservoir with volume 185 mil. m^3. Geological composition of dam's subsoil is created by sandstones, slates and poorly agglutinated clay agglomerates sealed with grouting curtain. Hydraulic structure was put in operation in year 1967. Already in the initial stage after filling the reservoir was in the left abutment of dam (marked in Fig. 1) registered increase in underground and seepage water levels. Also geophysical measurements of filtration velocities in observation objects pointed to exceeding critical values of filtration velocities (1.2E-03 $m.s^{-1}$), which endanger the filtration stability of the rock environment. For that reason, the grouting curtain was in years 1973 -1975 in this section retightened and deepened (Fig. 1).

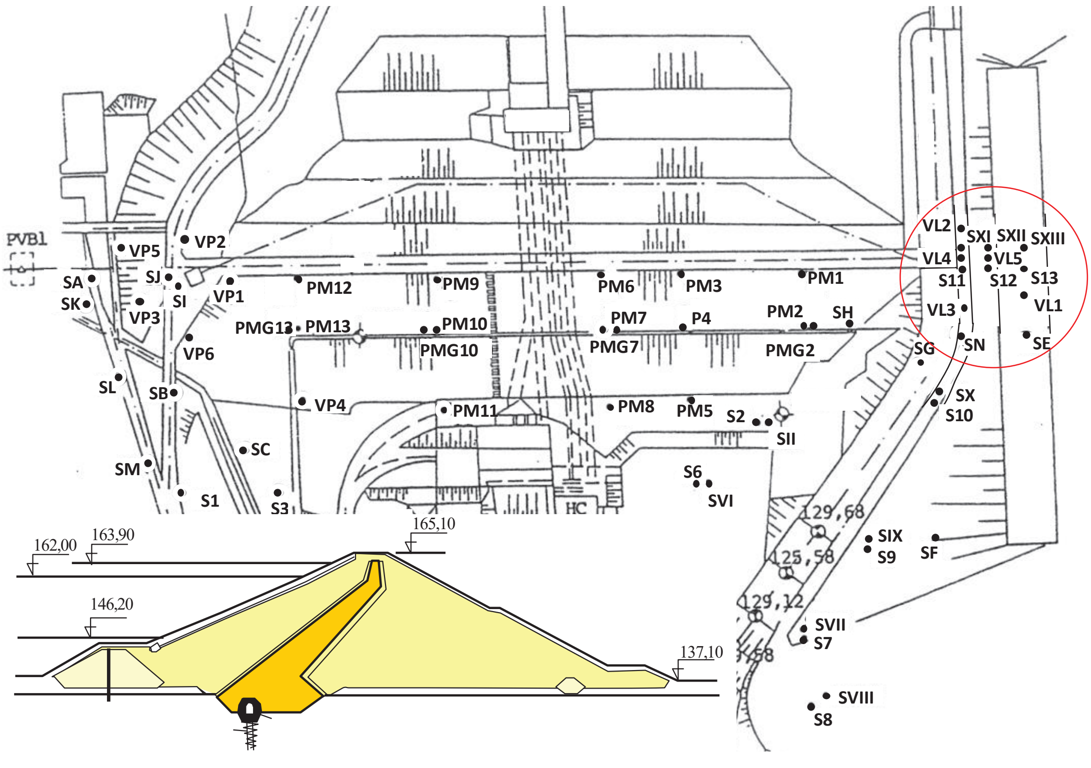

Figure 1 : The situation and cross-section of the Veľká Domaša dam showing local sealing of the grouting curtain

The effect of the retightening after 30 years was mentioned in the contribution to the ICOLD Symposium in Sofia (Bednárová et. al., 2008). Now we present findings on the results of measurements of the maximum filtration velocities apart 40 years (Fig. 2). The figure shows that the effect of sealing the grouting curtain on the intensity of the filtration flow in the examined area of the dam has a positive effect. Exceeding or reaching a critical filtration velocity of 1.2 E-03 $m.s^{-1}$ has not been yet here recorded (Fig. 3).

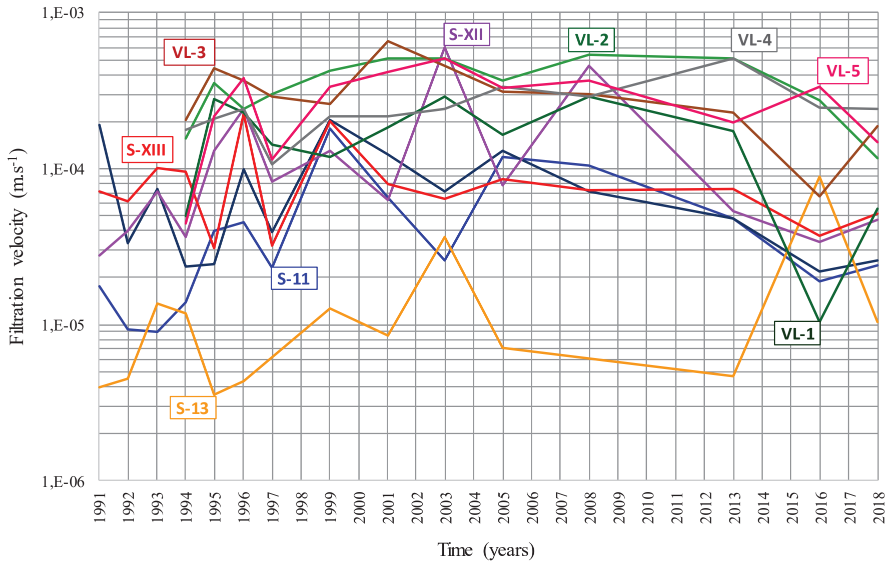

Figure 2 : Trend in the development of maximum filtration velocities in the area of left abutment

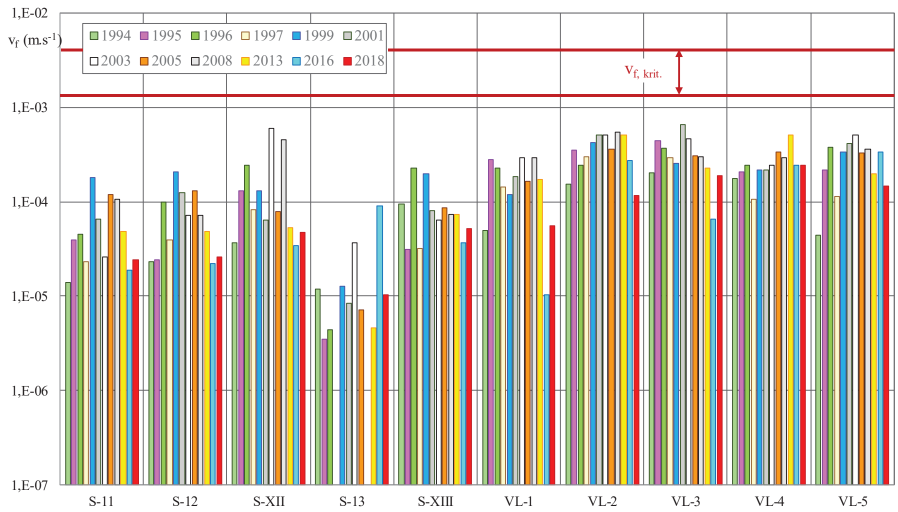

Figure 3 : Comparison of maximal filtration velocities with the critical value at the left side of dam

A comprehensive view of the evolution of the filter flow intensity in the investigated left-hand abutment can also be illustrated by the distribution functions (Fig. 4).

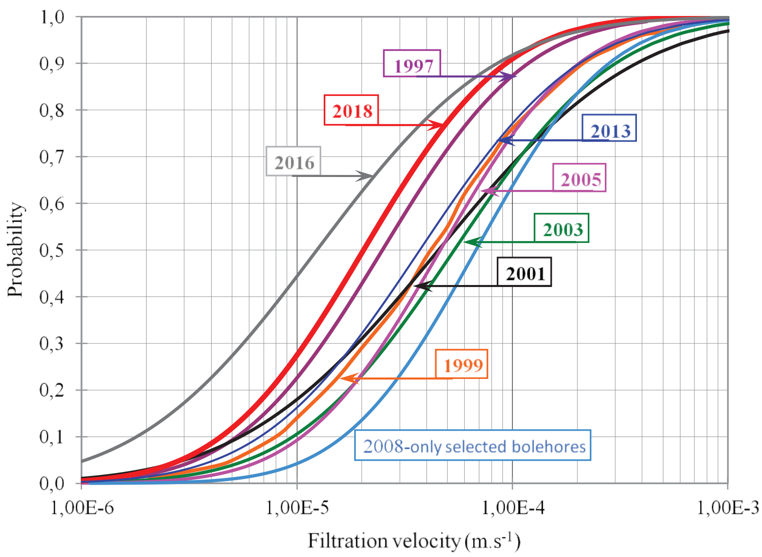

Figure 4 : Distribution functions of filtration velocities in the left abutment

4. GEOPHYSICAL MEASUREMENTS ON STARINA DAM

Starina dam is earth-fill heterogeneous dam with central sealing with total volume of created reservoir 59.9 mil. m3 (Fig. 5). The reservoir is currently the largest fresh water supply reservoir in Slovakia. The reservoir started to fill in the summer of 1987, the maximum operating level in the reservoir was reached in 1989. Since this period, indicator measurements of groundwater and seepage water flow have been regularly performed in all 31 observation objects (Fig. 5 – boreholes P and H). In the initial stage of commissioning of dam - between 1987 and 1995 - measurements were carried out annually. Later, after proving steady development of monitored parameters in most monitoring objects, the frequency of filtration velocities measurements was greater. Immediately after the dam was put into operation, it was obvious that changes in water level regime were affected both by the morphology of the area and by the existence of tectonic disturbances in the subsoil of the dam. By raising the water level in the reservoir to 340 m.a.s.l. (about 45 m above the terrain) in the area of left-hand abutment, where the bay is, the water level in observation objects (P-15, P-17, P-18 and P-19) increased by about 7 to 15 m. The existence of tectonic disturbances was also reflected in the water level rise in the observation object P-5 (by about 5 m), which is situated both in position and depth in this disturbed zone. In other observation objects the increase in the regime of groundwater and seepage water was smaller, ranging from 0.5 - 1 m. The rise in groundwater and seepage water levels in the area of left-hand abutment has raised concerns about the possible risk of the existence of preferred seepage paths and filtration velocities above critical values. However, the results of the measurements did not confirm these concerns. The trend of maximum filtration velocities (Fig. 6) suggests that the process of consolidation of the filtering regime is slowly ceasing.

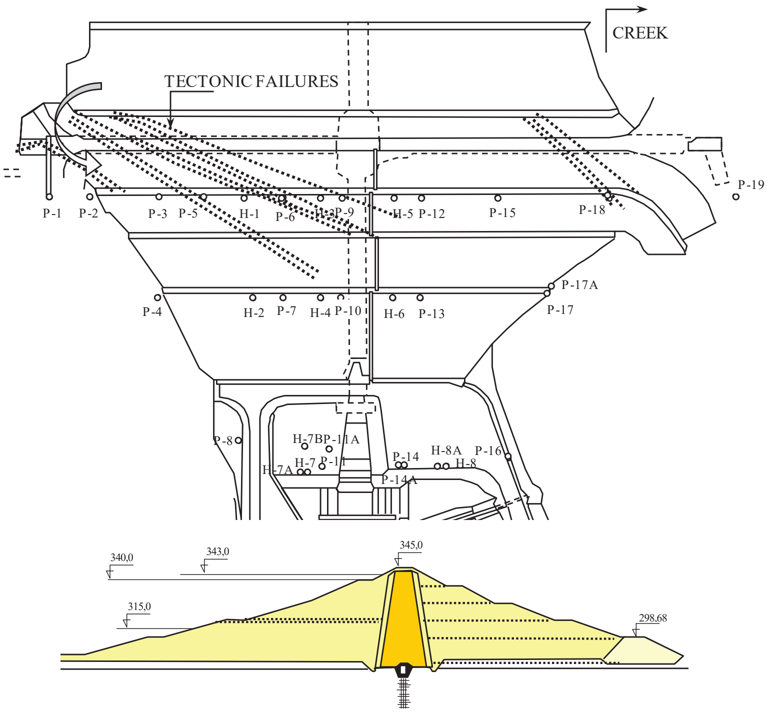

Figure 5 : The situation of observation objects and cross-section

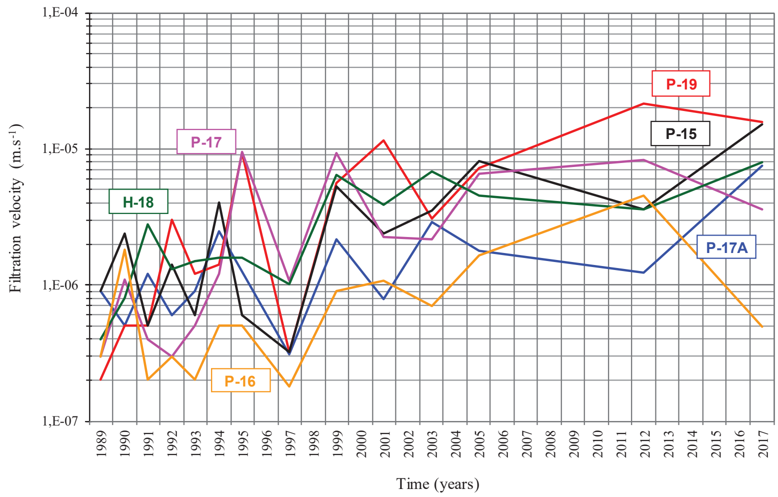

Figure 6 : Results of measurements of maximum filtration velocities in left abutment of dam

Their values are below the established threshold of critical filtration velocities (Figure 7). In other monitoring objects of the dam is the trend of filtration velocities development steady (Figure 8).

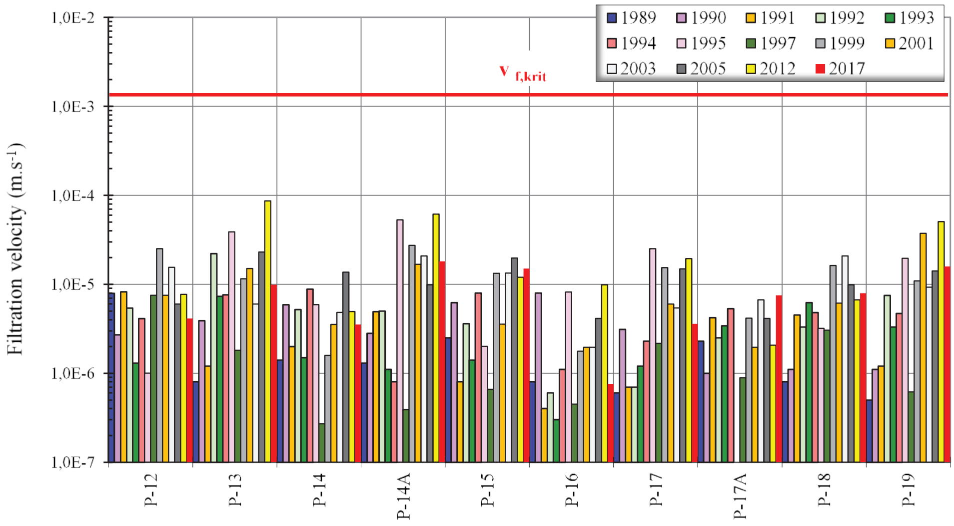

Figure 7 : Comparison of maximal filtration velocities with the critical value at the left side of dam

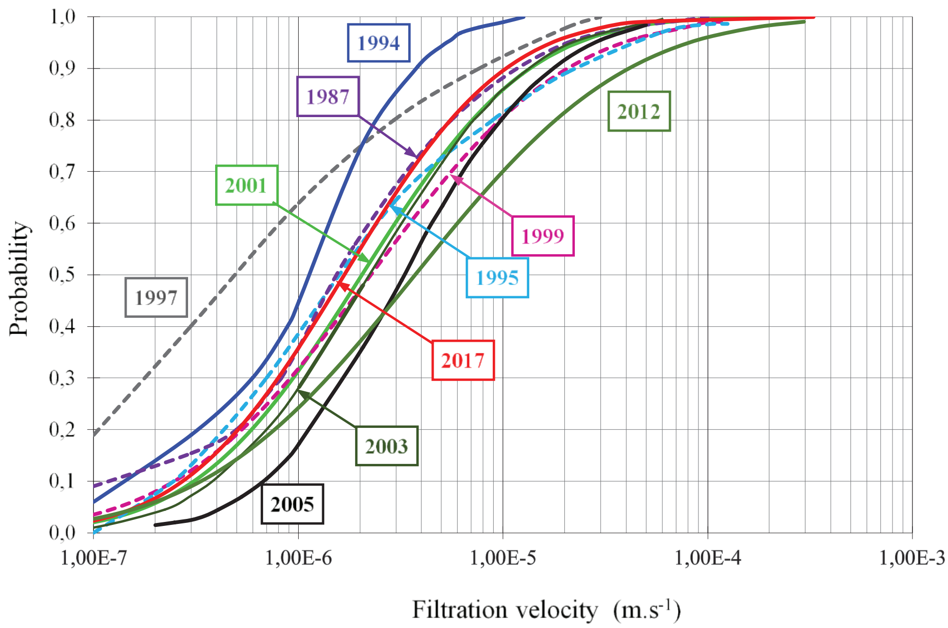

Figure 8 : Distribution functions of filtration velocities on the Starina dam

5. CONCLUSIONS

The statistics of failures and accidents of dams points out that overflowing or seepages are their most often reasons. Problematic of seepages is closely related with wide variability of properties of materials contained by the body and subsoil of dam. That fact considerably complicates not only designing, but also reviewing the safety of dams. Here the monitoring plays important role. Because of fact, that within frequent risks of dam's failure belong piping, control of filtration flow and its development is by observation of dam's safety very essential. Without correct recognising of intensity of filtration flow is reviewing of hydraulic criteria problematic. Basic parameters – water levels, uplifts, seepage or pore water pressures are for this reviewing not sufficed.

From above mentioned results, that exist several considerable reasons, why knowledge of filtration velocity by operation of hydraulic structure is essential. Experiences gained from application of measurements of filtration velocities in Slovakia indicate, that by these measurements it is possible to gather information about:

- maximal intensity of filtration flow and trends of its development, what is essential by reviewing of filtration stability,
- potential existence of local preferred seepage paths and its position,

- complex view on filtration flow in the sub regions of dam and its subsoil,
- possible calculation of seepage through dam's body and subsoil where drainage is not working,
- effect of extreme hydrodynamic stress on filtration flow mode and comparison with presumption of project,
- potential hidden risks of filtration regime development (piping), which need not appear on changes of water levels, uplifts or seepages,
- expected and in situ achieved values of intensity of filtration flow.

In addition, values of filtration rates can be used by optimizing of remedial works. Their understanding together with variability of geological conditions can be used as control system by numerical modelling, by inverse models.

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