The role of measurements of flow velocities by evaluation the safety of dams

Bedeutung von Filtergeschwindigkeits-Messungen bei der Bewertung der Talsperrensicherheit

Emília Bednárová, Marian Minárik

Abstract

Knowledge of filtration flow mode on dams is a very complex process, because it is affected by many factors - water level in the reservoir, groundwater, precipitation, time factor et al. Registering of their changes and effect on filtration flow mode is impossible without sophisticated monitoring. Besides measurements of basic parameters measurements of filtration velocities in boreholes can be used. This paper deals with the experiences obtained from these measurements.

Zusammenfassung

Die Durchsickerung eines Staudamms ist ein komplizierter Prozess, welcher von vielen Faktoren abhängt. Es sind vor allem Stauspiegel, Grundwasser, Niederschlag, Zeitfaktor u. a. Ohne perfekte Überwachung ist es nicht möglich, die Veränderungen von erwähnten Faktoren und ihren Einfluss auf die Durchsickerung festzustellen. Hier können wir außer der Messung von den Grundparametern (Spiegel, Auftrieb, Sickerung) auch Messungen von Filtergeschwindigkeiten in Bohrungen benutzen. Der vorliegende Artikel beschäftigt sich mit Erfahrungen bei diesen Messungen.

1 Brief characteristics of geophysical method for measurement of flow velocities

The principle of one borehole geophysical methods of measurement of flow velocities is based on observation of process of dilution or vertical movement of indicated solution in the borehole. Generally the indicator is sodium chloride (NaCl). Two methods are applied in practice – dilution method and method of observation of vertical flow in the borehole.

Dilution method is used in boreholes with low water column. Its principle is in observation of dilution process of indicated water in the borehole. Filtration velocity of underground water in the borehole surroundings is estimated from the dilution rate.

Observation of vertical movement of indicated water is applied in boreholes with high water column. Here the interconnection between different pressure horizons along depth of borehole is expected, as a consequence vertical movement of water originate. From the measurement of vertical movement of indicated water and its changes along the depth of borehole vertical flow is assigned. Their declines eventually increase along the depth of borehole confirm inflow

eventually outflow from the borehole. These changes and mainly their intensity are decisive for estimating of flow velocities in the borehole vicinity.

Application of geophysical methods of measurements of filtration velocities on Slovak dams has almost 50-years tradition. These methods were effectively applied on numerous significant hydraulic structures, in the phase before their construction, during their construction and also in phase of their operation. Exceptional importance has measurements of filtration velocities of groundwater in the place of hydraulic structure prior to its construction, because they allow correctly review effect of its real operation on surroundings. Such measurements were realized on dams Liptovská Mara, Veľká Domaša, Turček etc. It is possible to point out significance of geophysical measurements during construction of hydraulic structure Gabčíkovo. Using them the quality of cut-off walls, which depth exceed 60 m was controlled. Geophysical methods were successfully applied also by detection of local preferred seepage paths in the dam's body and subsoil. We illustrate some experiences on dams Veľká Domaša and Rozgrund.

2 Veľká Domaša dam

Hydraulic structure Veľká Domaša was put in the operation in 1967. Reservoir with volume 185 mil m^3 is created by earth-fill heterogeneous dam with inclined sealing **(Figure 1)**. Subsoil is formed by Carpathian flysch, in the slopes of valley tectonically disrupted, on the left side strongly weathered. On this section of dam after impoundment of reservoir preferred seepage paths occurred. Besides extreme rising of groundwater level in the left slope of dam, measurements of filtration velocities noticed potential risk of filtration failure. For that reason the grouting curtain was in this section retightened and deepened. Positive impact of treatment was proved by Lugeon tests. In following operation the treatment take effect in decreasing intensity of filtration flow and groundwater levels. **Figure1b** shows uplifts in the dam's subsoil by various load states, which shows good accordance with the water level in the reservoir, either the water level development in the boreholes. Analyse of these basic parameters, water levels and uplifts, account steady state, without negative processes.

Development of seepages in the right drain at this time indicate slightly increasing trend (**Fig.1c**). This leads to hypotheses of existence of preferred seepage path on the right side of dam. By low reliability of drainage system (left drain is not function) is this hypothesis questionable. In such situation measurements of filtration velocities take important place. Currently in some boreholes on the right and left side of dam rising tendency was documented (**Fig.1d**). From the measurements results, that in the regions of side slopes of dam filtration velocity is growing. This fact can be adjudged to long-term hydrodynamic load and low quality of geological environment in the slopes of valley. If the increasing trend will continue and filtration velocities will exceed critical values the treatment will be required.text

3 Vlčia Dolina dam

It is 25 m high concrete gravity dam, creating reservoir with volume of 172 000 m3. It was put in the operation in 1954. Subsoil is formed by hornblende schist, which was tightened by grouting curtain. For the reason that results of pressure tests were unfavorable, grouting curtain had to be retightened – first time in 1972 – 73, than later in 1986 - 87.

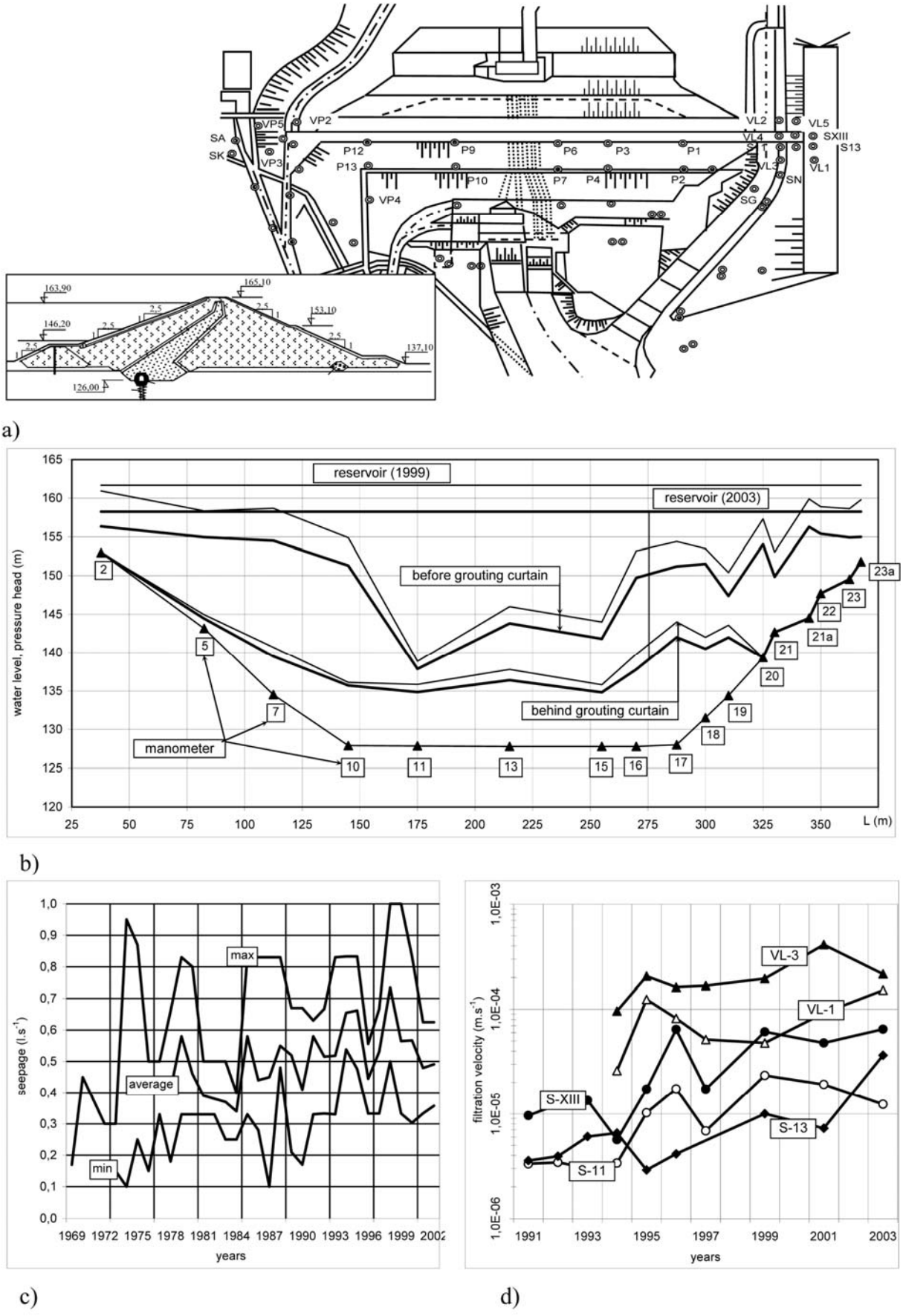


Figure 1: Development of filtration flow parameters on dam Veľká Domaša; a) situation and cross section, b) uplifts, c) seepages, d) filtration velocities

After this treatment the results of measurements of water levels, uplifts and filtration velocities recorded steady conditions. Reliability of grouting curtain validates also correlations between uplifts and water level in reservoir. On upstream side are correlation coefficients around 0.9, on downstream side of grouting curtain around 0.5. Steady state also confirms the development of water level and so measured values of filtration velocities **(Fig. 2)**. From distribution function is evident, that intensity of filtration flow is extraordinary stable (**Fig. 2b**). Presently obtained results achieve that maximal filtration velocities are deeply below the critical value in term of filtration stability.

In given conditions the measurements of filtration velocities provide certainty, confirming the safety of hydraulic structure operation. During the processing of filtration velocities distribution functions plays significant role. These functions provide information about the probability of occurrence of particular filtration velocity, about the value of median and allow from this value consequently calculate seepage, where drainage system failed etc.

4 Rozgrund dam

Rozgrund dam, which is more than 250 years old, is a part of historically valued system of reservoirs. The dam was constructed in 1744, in 1749 was first time increased and in the second half of 18th century was for the second time increased [1]. With its parameters belongs also nowadays to the jewels of dams construction. Its height is 30,2 m, with steep slopes - upstream from 1:1.25 to 1:1.75 and downstream from 1:1.24 to 1:1.74.

In compliance with preserved historical plans for construction of earth dams in 18th century, these were designed as heterogeneous dams with core sealing or as zoned dam.

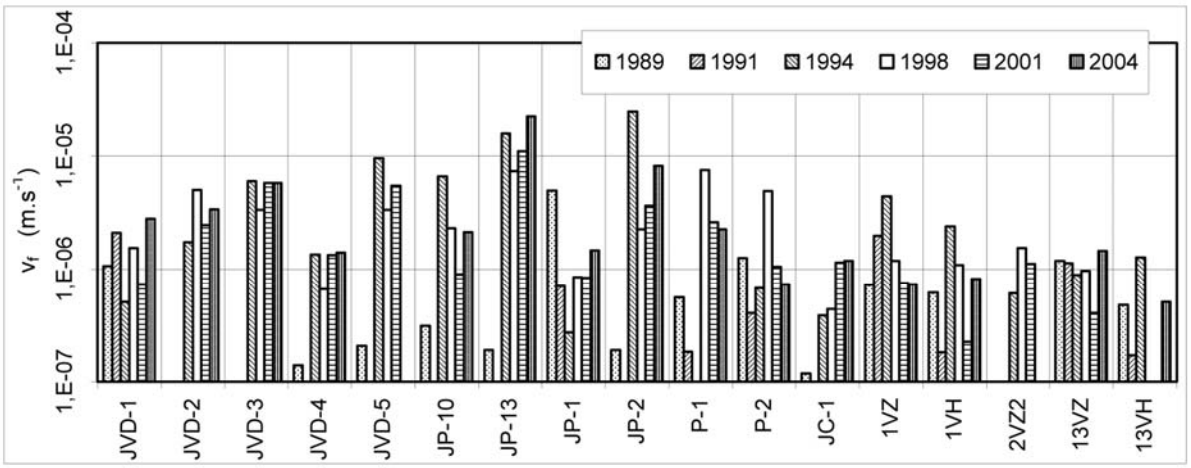
Dam’s body is created by loam materials with fractions; the subsoil is composed of andesite. From the view of observation of filtration regime is dam equipped with monitoring system consisting of 14 boreholes **(Fig. 3)**.

In results of water levels in boreholes placed on the dam crest (PS-1, PS-3 and PS-4) were in the past detected uncommonly high amplitudes of its fluctuation (**Fig.3c**). Analysis of this problem leads to hypothesis, that its source may be intensive precipitation, or also existence of preferred seepage paths. Development of water levels signified, that increase of water levels in boreholes was registered when the water level in reservoir exceeds height 702 m.

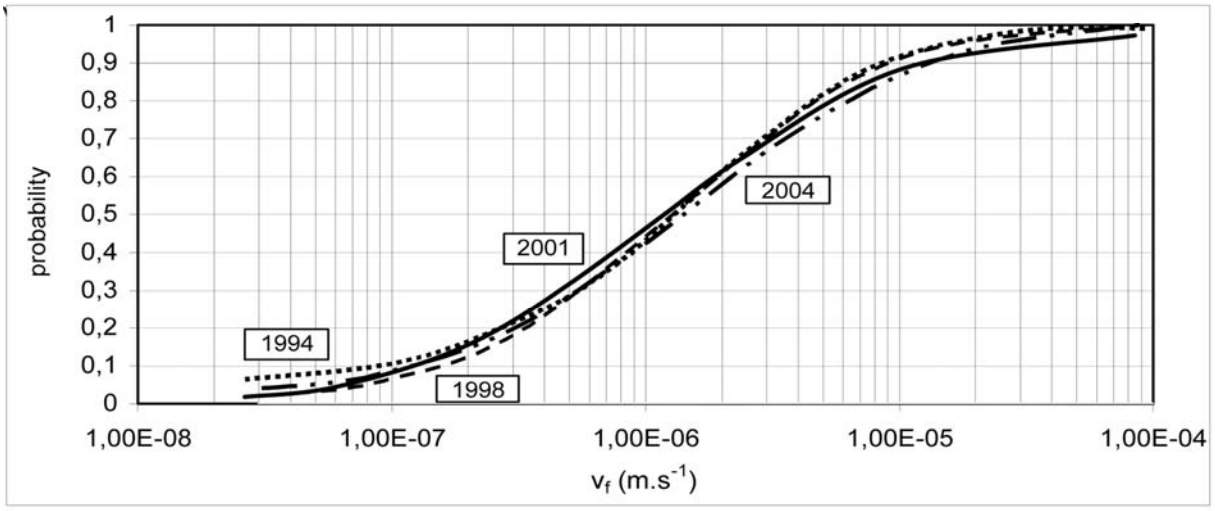
To eliminate occurrence of such phenomena, negatively affecting safety of hydraulic structure demand of execution of treatment originated. To consider real reason of existing anomaly and consequently effectively optimize design of treatment, were measurements of filtration velocities in these boreholes performed, analyzing filtration flow regime by artificial increasing of water levels to the high above level 702 m. From these measurements results, that in all measured boreholes was in the depth from 3 to 4 m under terrain recorded outflow to the surrounding area. In higher depths were not noticeable changes in filtration flow regime observed. In region of outflow of water from the boreholes the filtration velocities reach values approx. 10-3 m.s-1. Results of measurements in borehole P-4 is presented on **Figure 3d**.

From obtained results issued that more permeable region is in good accordance with level of heightening of dam in 18th century. Moreover results of engineering geological investigation confirmed in the depth around 3 - 4 m local occurrence of rock-loamy debris, with increased

amount of fractions. In given conditions were using measurements of vertical flow and filtration velocities recognized preferred seepage paths in depth, which is in good accordance with level 700 m above sea level. This knowledge results to necessity of tightening of this historically value dam to the depth approx. 4 - 5 m below its crest.



a)



b)

Figure 2: Development of filtration velocities in the subsoil of Vlčia dolina dam; a) time diagram, b) distribution functions

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.

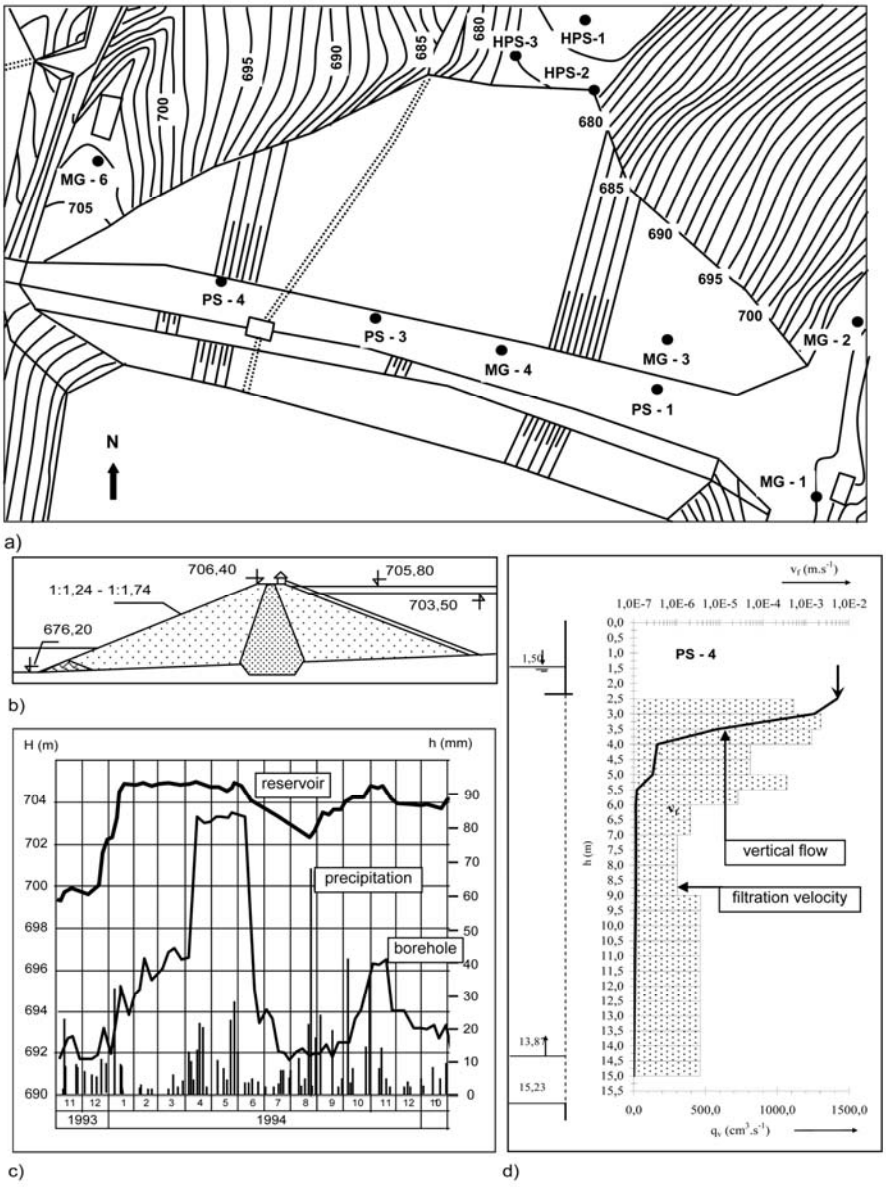


Figure 3: Anomalies in filtration flow development on Rozgrund dam; a) situation, b) cross section, c) water levels, d) vertical flow and filtration velocities

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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Authors' Names and Affiliation

Emília Bednárová, Ph.D. emilia.bednarova@stuba.sk
Marian Minárik, Ph.D. minarik@svf.stuba.sk
Department of geotechnics
Slovak university of technology
Associate professor
Radlinského 11
813 68 Bratislava
Slovakia

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