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Groundwater flow in the subsoil of selected slovakian dams

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Abstract: Four dams selected for this study were built in various geological conditions around Slovakia: Liptovská Mara and Starina are in flysch; Málinec is in core mountains, and Turček is in neovolcanites. Their subsoils are sealed with grouted curtains. In most cases it was impossible to meet the criteria required by water pressure tests during construction. However, as the reservoirs were filled the changes in groundwater and seepage flow in their subsoil were carefully monitored. It was found that even at the conditions mentioned losses through seepage were negligible and hydraulic effects have not endangered the dam´s stability. The several anomalies recorded could only be explained on the basis of data gained from the uplift measurement systems and from special monitoring devices in the grout curtains and the ungrouted parts beneath the bottoms of the curtains.

Key words: dams, stability, seepage, sealing, drainage

Introduction

Slovakian dams are mostes built in the geological conditions of the Carpathian flysch. Their subsoil is typically sealed with grout curtains. Four dams built by Váhostav Žilina (Fig. 1.) of 50 our dams that are registered in ICOLD (International Commission On Large Dams) were selected for this paper.

Slovakian construction organisations had had some difficulties in the beginning but afterwards they managed to deal with the grouting of sealing curtains in flysch rocks having a variable ratio of sandstone and claystone layers. In many cases problems connected with the grouting quality-control emerged. Water pressure tests were to be used for such purposes. However, it was shown that their results did not always give reliable information.

In a limited way, with some risks, reservoirs were gradually filled, even if the grout thickness criteria were not met and the grouting process was continued. In such cases, special attention was paid to the measurement of all changes developing during the reservoir filling. These included deformations, water levels and groundwater flow velocities, uplift conditions, and drainage system affluents.

Based on the analysis of groundwater and seepage regimes in the dam bodies and in their subsoils, it was shown that the sealing elements safely fulfilled their functions, despite of the fact that the prescribed criteria for water pressure tests were not fully met.

Several interesting examples about groundwater flow in the subsoil of the selected dams influenced by the seepage from reservoirs were chosen. First, some remarks about the grouting criteria and seepage control methods will be presented.

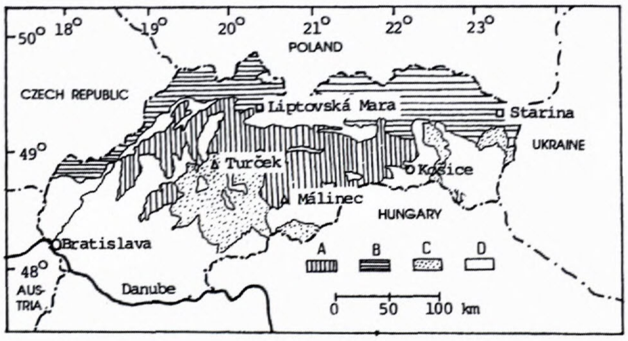

Figure 1: Generalized geologic map of Slovakia (Matula, 1969):

A - core mountains, B - Carpathian flysch, C - Neogenous depresions, and selected dams: □ - soil, Δ - rockfill

Grouting criteria

The state of the art about grouting criteria based on water pressure tests is depicted in figure 2 as a function of losses (Q) and corresponding pressures (p).

The older Jähde´s and Lugeon´s criteria were impossible to meet under our conditions. This is why Verfel´s criteria were used since 1983. They were initially set for pressures of 0.3 MPa. They are considered to be very progressive even now, since they permit higher losses in deeper layers (h) in which the more permeable medium cannot endanger the dam stability. Figure 2 shows criterial functions Kutzner (1985) used in America and Russia. In accordance with their tendencies, Verfel´s criteria can simply be transformed to the different pressures at which water pressure tests are held (figure 2 shows a particular example of a transformation for the pressure of p = 0.6 MPa). Values obtained in this way are usually recom-

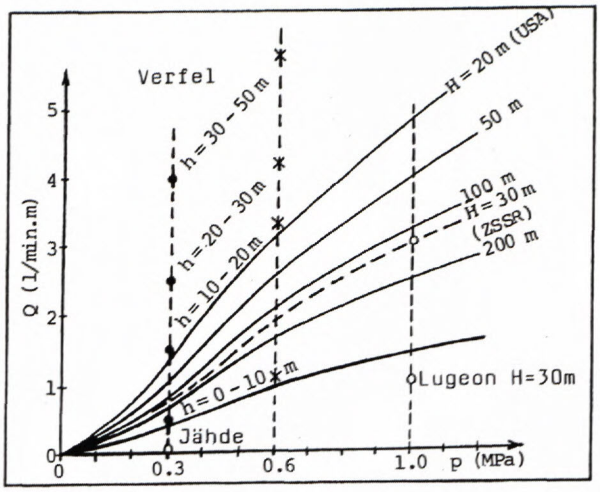

Figure 2. Grouting criteria review elaborated according to Verfel (1983) and Kutzner (1985): Q - water loss, p - water pressure, h - depth under the injection gallery bottom, H - height of the dam, o - Verfel's criteria for p = 0.3 MPa, x - adjusted Verfel's criteria for p = 0.6 MPa.

mended as maximum values and their eventual non-fulfillment should be judged individually.

The results of the water pressure tests were thoroughly analized by a large group of engineers involved in our dam construction. They came to the conclusion that water pressure tests are not very reliable for grout curtain control. Water flows out from a limited part of the borehole undoubtedly through the most permeable layer but the layer does not have to be continuous throughout the barrier width. Water can leak, for example, only to the air side but the water side of the curtain can well be as convenient. The unreliability of the water pressure tests is even clearer when the grout curtain effectiveness is monitored during the dam is in operation.

Seepage monitoring methods

Apart from the well-known methods by the means of which level, discharge and pressure regimes are monitored, one-borehole tracer methods (Halevy et. al. 1967) are also widely used in Slovakia. Based on electrolyte solutions, the vertical motion or dilution process monitoring groundwater flow, filtration velocities as well as permeability coefficients of porous or fissure media can be determined. Water flow directions, water velocities and other characteristics are sometimes determined with the multiple borehole method. Correlations between the results gained by tracer and other methods, such as pumping and recharging tests, directly measurable water affluents from drainage systems, grain-size and other analysis are also useful for practical purposes.

For the one-borehole method a perforated tube with an inner diameter of 60 to 150 mm and with a filter is placed at the required depth of the borehole. The results of the measurement are representative for the small surrounding area of the borehole given by several multiples of its diameter. Almost in every case the borehole does interconnect various pressure horizons and so vertical water flow takes place. Less intensive vertical water flow develops due to heterogenous temperature distribution or because the borehole does not follow an equipotential line.

Vertical flow measurement

In order to measure vertical water flow in a borehole, a set of equipment schematicly shown in figure 3 can be used. An immersion probe connected to battery powered measurement equipment, placed together with an electronic tracer jet control (NaCl solution) on the surface, is inserted into the borehole.

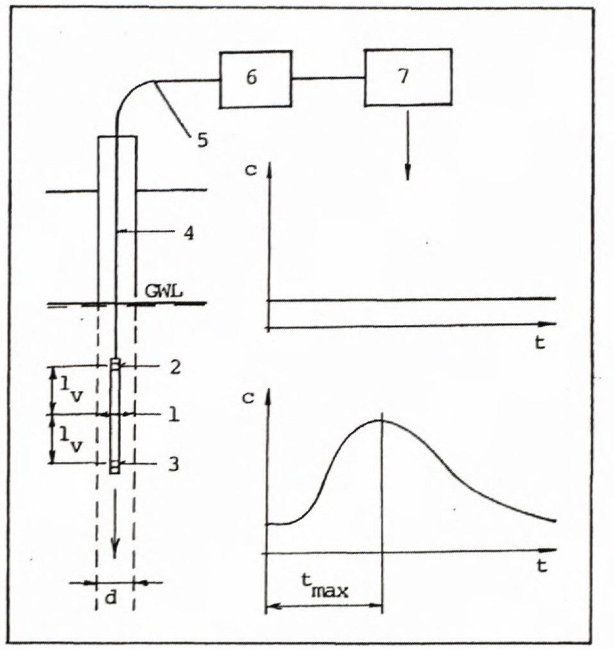

Figure 3. Diagram of equipment used for vertical water flow measurement in a borehole: d - perforated tube inner diameter, l_v - gauge distance, c - concentration, t - time, 1-3 immersion probe (1 - indicator jet, 2 - gauge for upward flow, 3 - gauge for downward flow), 4 - connection cable and solution supply, 5 - tracer jet control, 6 - computer transducer, 7 - portable computer.

The concentration dependencies can be watched directly on the computer screen and the time in which the maximum concentration takes place (t_{max}) can be determined. Estimation of the vertical velocity average value requires a laboratory calibration to set the computational time, and vertical discharge is estimated from the continuity equation:

$$q_v = v_v A = \frac{l_v}{0{,}266\, t_{max}^{1{,}474}} \frac{\pi\left(d^2 - d_s^2\right)}{4} \qquad (1)$$

where v_v is the vertical velocity, A - cross section test tube area, l_v - vertical distance, t_{max} - peak time, d - inner diameter of the tube, d_s - outer diameter of the probe.

The measurements are repeated ever an appropriate depth interval in order that all the watered part of the borehole is uniformly covered and the vertical water flow function could be graphically depicted. Individual parts of such a function can be interpreted as follows:

- If water discharge increases with water flow direction, water flows into the borehole,
- If water discharge decreases with water flow direction, water flows out of the borehole
- Medium around the borehole with constant vertical discharge is relatively impermeable.

The filtration velocity in the surrounding medium (approximately in the horizontal direction) can be calculated from the vertical water flow measurement in a borehole based on the following equation:

$$v_f = \frac{\Delta q_v}{\overline{\alpha}\, d\, \Delta h} \qquad (2)$$

where Δq_v is the increase or the decrease of the water discharge in the part of the borehole with the height of Δh, α-borehole drainage influence coefficient for vertical flow (aproximately $\alpha \cong 20$), and d - tube inner diameter.

The filtration velocity calculations according to the formula (2) are made with personal computers, the results being graphically interpreted as depth dependencies. The average filtration velocity value for each borehole is given by the formula:

$$\overline{v}_f = \frac{\sum v_f\, \Delta h}{\sum \Delta h} \qquad (3)$$

and usually is depicted as a vector in the situation. The permeability coefficient is given by Darcy´s law.

A more intensive vertical flow in a borehole can better be measured with adjusted hydrometric wings.

Dilution method

The dilution method is used in boreholes with low water column. The tracer is usually sodium chloride introduced into the water as a powder. An immersion electrode probe, together with simple battery conductometric equipment, is used to monitor the dilution process. The filtration velocity is calculated by the formula:

$$v_f = \frac{\pi\, d}{4\, \alpha\, t} \ln \frac{c_o - c_p}{c - c_p} \qquad (4)$$

where d is the observation tube inner diameter, α - borehole drainage influence coefficient for the dilution method ($\alpha \cong 2$), c_o - initial concentration, c - concentration at time t, c_p - the natural concentration. The average filtration velocity values are again calculated by the formula (3), permeability coefficients being calculated from Darcy´s law.

Formula (4) assumes that solution dilution is caused by water flowing perpendicularly to the borehole axis. If there is some water flow in the direction of the borehole, the basic assumptions of the evaluation formula validity are not met and such results cannot be used. In order to eliminate the vertical flow there are devices such as inflatable seals, which protect the measured part of the borehole against a vertical flow influence (Drost, 1970), which occurs at some work sites.

Correlation of results

At one location, the permeability coefficient was estimated from Darcy´s law by means of the tracer method (k_T) for each borehole. Apart from these results, permeability coefficients from pumping tests (k_P) and from grain-size analysis from Beyer-Schweiger (k_B) and Carman-Kozeny (k_C) formulas were estimated.

Statistical analysis results for the area tested are shown in figure 4. Note that the permeability coefficients k_C are generally lower than k_B. The median and average values from the vertical flow tracer method are lower. The pumping tests ($k_P = 4{,}6 \cdot 10^{-3}$ m/s), vertical flow tracer measurement median ($k_T = 5{,}1 \cdot 10^{-3}$ m/s) and Beyer-Schweiger estimated median ($k_B = 3{,}7 \cdot 10^{-3}$ m/s) give similar results.

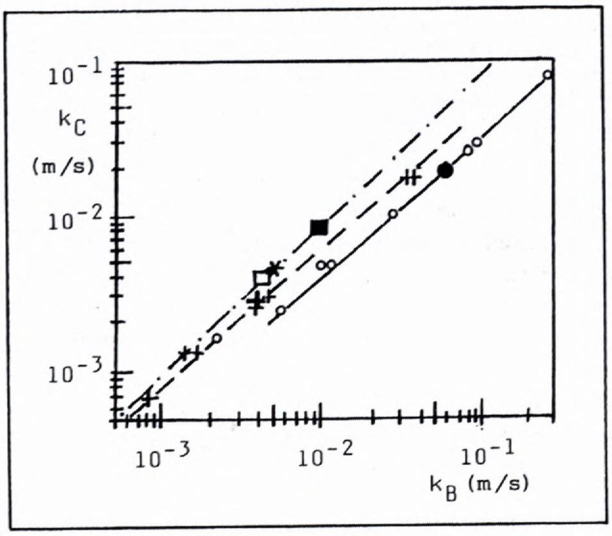

Figure 4. Correlation dependence between the permeability coefficient in the test area (k_B - Beyer-Schweiger, k_C - Carman-Kozeny) from grain-size analysis (o - average, + - median), vertical flow tracer measurements (■ - average, □ - median), and from the pumping tests (*).

The reason for the detail differences is that the grain-size analyse are based on broken samples in which careless quartering causes sandy particles to be missed. The one-borehole tracer method gives results representing a small area surrounding the borehole. However, various activities, joined with a direct or inferred supply of individual layers can take part. Pumping tests draw water from wider surroundings, thus the permeability coefficient must differ from the grain-size and one-borehole methods. However, larger differences do not occur if representative files are statistically elaborated.

Liptovská Mara

A soilfill heterogenous dam on the river Váh is 52 metres high, 1225 metres long and its subsoil is formed by Paleogene slates and sandstones. These rocks are

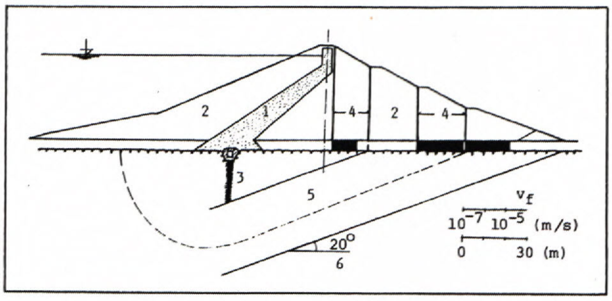

Figure 5: The Liptovská Mara dam cross-section profile: 1 - silt seal, 2 - stabilization prisms, 3 – grout curtain, 4 - observation boreholes with average filtration velocity values, 5 area of main water flow to gravelly subsoil at the air side, 6 - Paleogene layers.

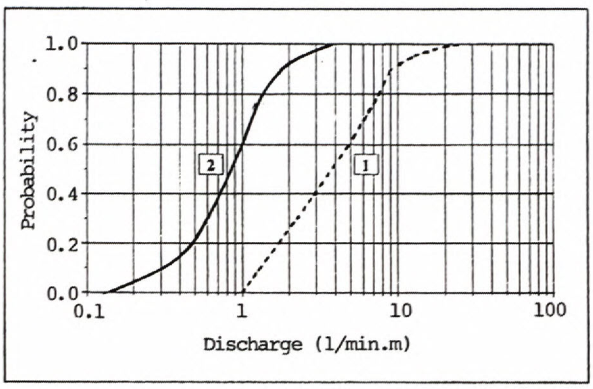

Figure 6: Empirical distribution function characterizing water pressure tests results in the subsoil of Liptovská Mara dam to the depth of 5 m: 1 - in the natural medium, 2 - after grouting

sealed by a grout curtain reaching to a depth of 10 m in the left-side bound, 20 m in the valley plain (Fig.5), 53 m in the right-side bound.

The reservoir, with a total volume of 360 mil. m^3 (the largest reservoir in Slovakia) began to fill at a time when the grout curtain had not been completed. Even after several stages of grouting the prescribed Verfel´s criteria were not achieved, whereas the worst results took place right under the pit base of the grouting gallery at the depth of 5 m (Fig. 6). Compared to the natural medium, the permeability of the curtain was five times lower, but the criterium was not met at 40 % of the levels checked.

Due to seepage during the reservoir filling, the directions of water flow changed to a direction perpendicular to the lateral dam axis; under the dam the groundwater levels increased on average by 0.8 m and did not reach the level of the bottom drainage. Seepage can only be monitored by water flow measurement in the observation boreholes, being about 0.020 m^3/s for the currently full reservoir.

In the valley part of the dam the average filtration velocity values in the gravel subsoil increase with the flow direction of seepage water (Fig. 5). Such phenomenon in the area can be interpreted as an underflow of a short grout curtain. The water loss amounts are negligible. Most important are the hydrodynamic effects upon the dam subsoil.

Therefore, the development of the filtration velocities, especially from the point of view of fine particle stability in the gravel soil pores and rocky subsoil fissures is monitored. The results shown in figure 19 imply that there have not been any dangerous conditions during the operation of the reservoir.

Starina

A soilfill heterogenous dam on the river Cirocha in eastern Slovakia is 54 m high, 345 m long, its subsoil is formed by sandstones and claystones, the grout curtain is 40 to 60 m deep (Fig. 7).

The grout curtain was built of a high quality; Verfel´s criterial values for water pressure tests were fulfilled at almost all levels monitored.

When comparing a long-term full reservoir to its condition before filling, the average groundwater level increased by 1.8 m, but in the left bound by 11 to 14 m due to seepage. The reason for this is the area morphology and the implied shape of the reservoir, water flows around the grout curtain through the side slope and flows into the dam body.

Figure 8 shows the results of the measurements from the observation borehole P-19 which is built in the area of the left-side bound of the dam. The groudwater flow was not very intensive before reservoir started to fill, it has become more intensive during the reservoir operation, but it does not reach dangerous levels. However, the groundwater and seepage flow development in the left-side bound is still being given special attention.

The dam has a very well built drainage system. It has been shown, that it very sensitively reflects rainfall and slope waters. However, the ratio of the seepage water from the reservoir is significant and relatively small (Fig.9). The total seepage amount is currently about 0.007 m^3/s.

Based on the filtration velocities development and their comparison to limit values for the filtration stability (Fig. 19), it can be concluded that the sealing elements are effective and the influence of flow around the dam is not dangerous for its stability.

Málinec

The rockfill dam on the river Ipeľ is 55.5 m high, 620 m long (Fig.10), its subsoil is formed by paragneiss, migmatites and hybrid granodiorites with mylonitized layers, the grout curtain is 20 to 40 m deep. The cross-section profile is similar to that of the Starina dam with the only difference being that the stabilization prisms of the water, as well as the air side, are made of rock material.

As the result of having filled the reservoir and having operated the reservoir the water levels under the air side of the dam increased by 1.0 m, maximum increase being under the right-side slope at 11.2 m.

The average filtration velocity values vectors that were measured by the method of vertical water flow in boreholes and tracer solution dilution are depicted in figure 11. The first measurements were made during the initial filling of the almost empty reservoir in 1994 (vectors plotted by a dashed line), the second measure-

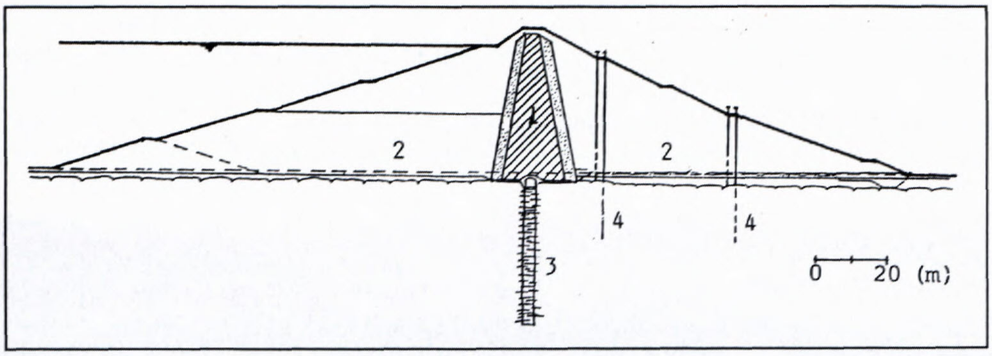

Figure 7: Starina dam cross-section profile: 1 - silt seal, 2 - stabilisation prisms, 3 – grout curtain, 4 - observation boreholes.

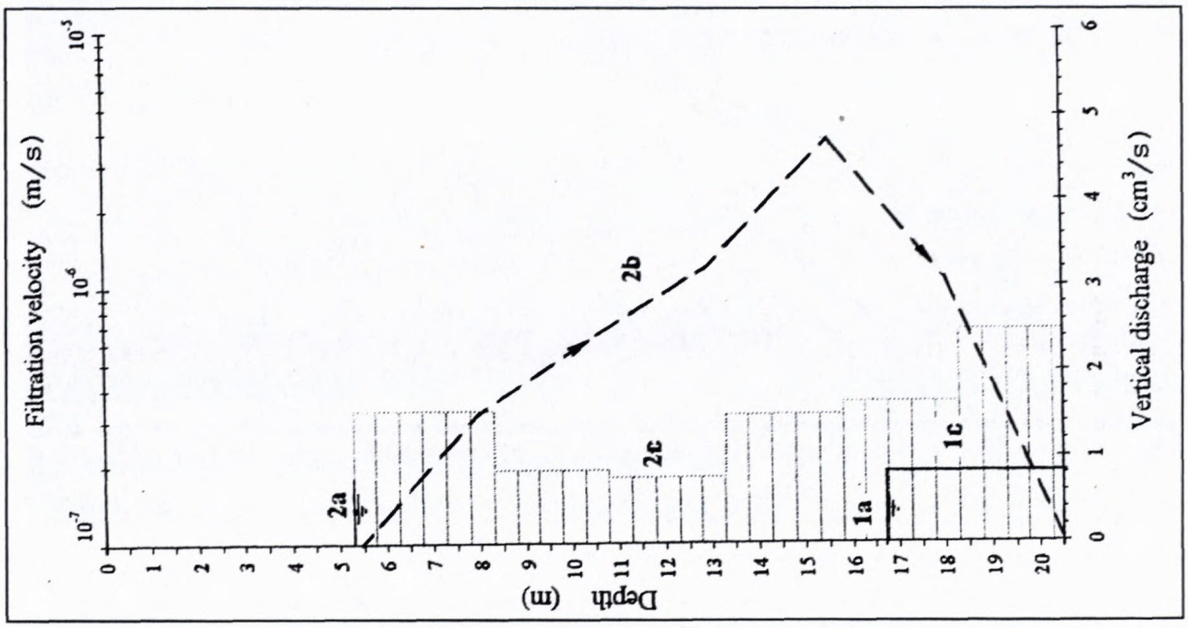

Figure 8: Results of measurements in the borehole P-19, in the left-side bound of the Starina dam: 1 - before filling the reservoir, 1a - water level, 1c - filtration velocities, 2 - for a full reservoir in 1997, 2a - water level, 2b - vertical discharges, 2c - filtration velocities.

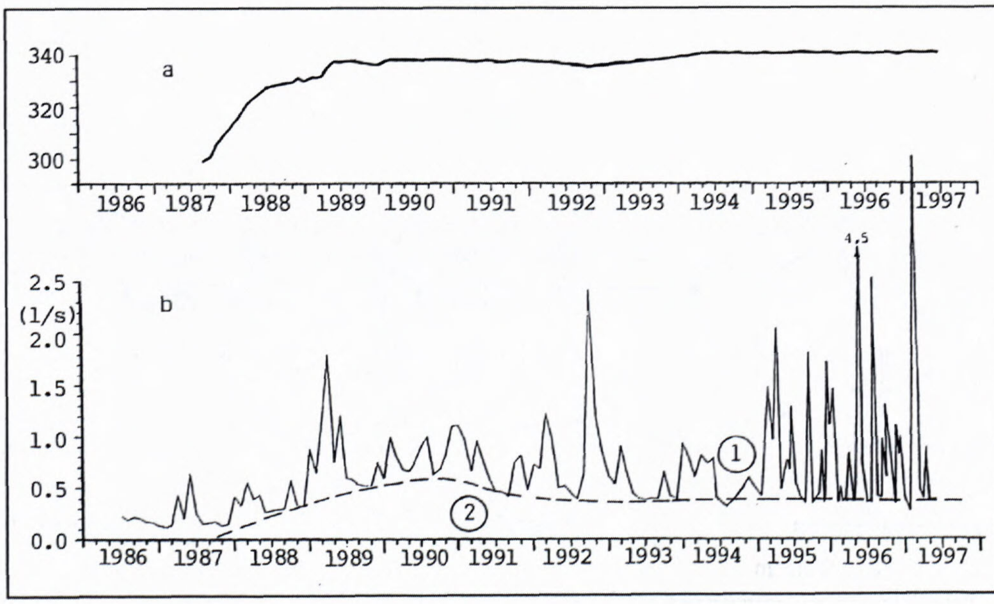

Figure 9: Time development of water levels in the reservoir (a) and amounts of water flowing out of the drain under the left side of the Starina dam (b) : 1 - rainfall, 2 - seepage from the reservoir.

ments were made in 1997 for the maximum operation water level (vectors plotted by a solid line).

Seepages caused velocity changes, together with a direction change of water flow towards the air side, especially in the valley part of the dam.

The filtration velocity changes can most readily be judged by the empirical distribution functions shown in figure 12, which were obtained from filtration velocity depth dependencies. For the almost empty reservoir the median was a value of $v_f = 1{,}02 \cdot 10^{-6}$ m/s (480 readings);

Figure 10: Málinec dam on the river Ipeľ as viewed in 1997

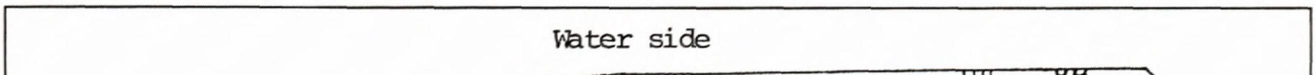

Fig. 11 Average filtration velocities vectors under the air side of the Málinec dam: dashed line for an almost empty reservoir, unbroken line for a maximum operation level.

for a full reservoir it was $v_f = 8{,}5 \cdot 10^{-6}$ m/s (683 readings). The arithmetic average values were exceeded at a probability of 22 to 30 %.

Thus, the seepage shows its presence by the higher filtration velocity values. Figure 19 implies that the biggest filtration velocity values are smaller than the limiting values providing appropriate guaranties for fine particle stability in the gravel skeleton, as well as in rock fissures at hydrodynamic loading. Further flow development can bring colmatage, but erosion cannot be excluded, therefore it remains necessary to watch the developments carefully.

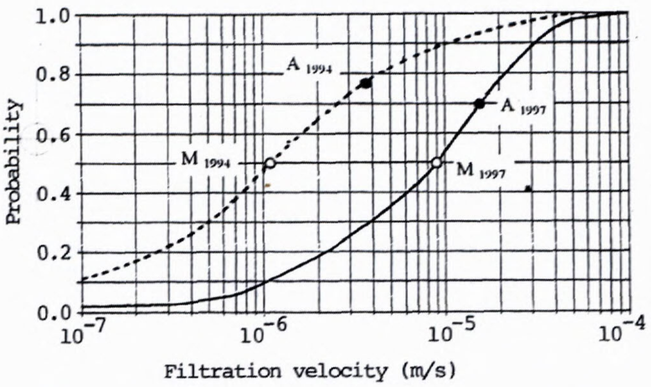

Figure 12: Filtration velocity distribution functions characterising groundwater flow for an almost empty reservoir (1994) and a full reservoir with a maximum operation level (1997): M - medians, A - arithmetic averages.

Turček dam

A rockfill dam at the junction of the Turiec and Ružová Rivers is 61 m high, 228 m long, and has a skin bitumen-concrete seal (Fig.13). Its Neogene neovolcanite subsoil is formed from pyroxene-amphibole andesites and their tuff agglomerates. The grout curtain reaches depths of 30 to 50 m.

During the investigation of grouting during hole boring, various large amounts of water flowed into the grouting gallery from various depths. Their specific values (calculated to 1 m of borehole) are depicted as empirical distribution functions in figure 14. They clearly show significantly more permeable layers at deeper levels than 30 m, with the maximum affluents sometimes reaching values of 20 l/s.m.

The fissures in the neovolcanic rock subsoil are directed mainly vertically, thus requiring that the grout barrier be emplaced the use of angled holes. In the pyroclastic rocks permeability did not go down even after having attempted several groutings. Moreover, in some layers permeability was even increased (Hulla and Chovan, 1997). Water pressure test criteria fulfillment caused serious problems in some layers. A summary of results is given in figure 15, in which different lines depict characteristics for the natural ungrouted medium and the grouted one, as well as the characteristics expressing criterial requirements. About 27 % of the checked layers did not meet the upper limit of the recommended criterium.

Despite the information mentioned above, a careful reservoir filling was started, accompanied with through measurements and analysis of the results obtained. A complex evaluation was made for the inspection water level of 757 m.a.s. (Fig. 15). This level represents an increase of 30 m compared to the empty reservoir; when compared to the maximum operation level, this level was 20 m lower.

The level increase under the air side of the dam was almost negligible, maximum 1 m. Isolines of the increased levels are depicted in figure 16.

Special observation boreholes (F-6 to F-24 - Fig. 16) were built from the grouting gallery into the layers with the worst water pressure test results. These were boreholes with a perforated tube running through the grout curtain and reaching into the ungrouted medium behind it. They were placed in such a way that they provided vertical flow measurements and further parametres for partially opened and closed heads.

Measurement results from the borehole F-13 are given in figure 17 as vertical flow depth dependencies. For a partially opened effluent valve the information was obtained, that, as a result of pressure conditions, water started to flow into the borehole from the ungrouted medium behind the curtain from the depths of 40 to 45 m, whereas the amount of water depended on how much the regulation valve in the injection gallery was opened. Having totally closed the head of the valve the vertical water flow intensity in the borehole significantly decreased, to the values close to the measurement method lower limit, since our measurement method is influenced by a sodium chloride solution density flow.

Similar results were obtained in other observation boreholes with the characteristics mentioned. These results imply that the medium under the grout curtain is both very permeable and seepage water flow in these layers was of minor amount for the inspection level of 757 m.a.s. Water levels in the observation boreholes built beneath the dam have not changed since the reservoir started to fill.

The limited amount of water flow under the down end of the grout curtain is also indicated by the pressure conditions. Having closed the regulation valves water pressure values in these layers rapidly approached those found close to the reservoir level.

Worries about a lowered effectiveness as a result of unfulfilled water pressure tests criteria resulted in the creation a relatively dense system of uplift measurement boreholes enabling us to monitor the development of uplift in various layers at the water side of the curtain, inside the curtain and at the air side of the curtain.

Figure 18 shows results of uplift profile measurements. The profile is built in one of the valley blocks of the grouting gallery. Data obtained from the medium deep boreholes are especially interesting. They can be interpreted in such a way, that the water part of the grout curtain is more permeable (the hydraulic gradientbeing very small), but the air part is very effective with a high hydraulic gradient. High grout curtain effective-

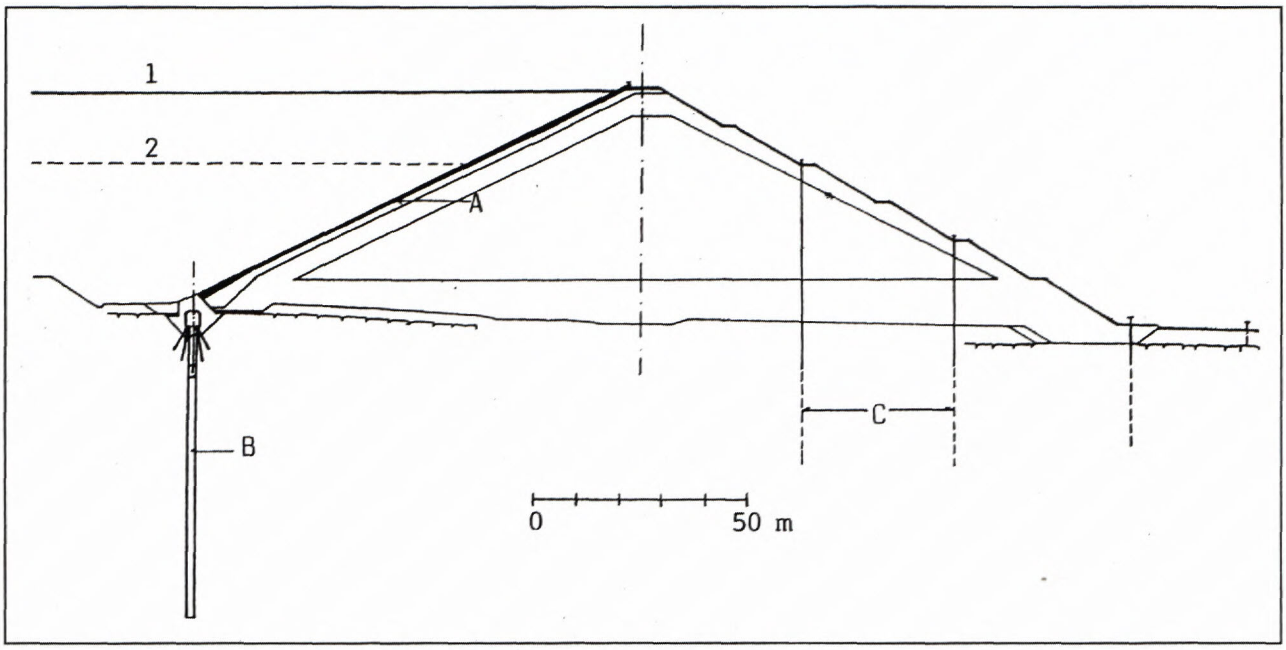

Figure 13: Cross section-profile of the Turček dam: A - bitumen-concrete skin sealing, B – grout curtain, C – observation boreholes, 1 - maximum level in the reservoir, 2 - inspection level.

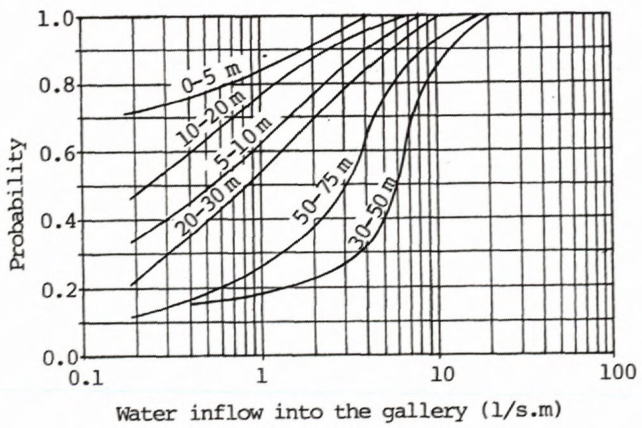

Figure 14: Distribution functions for water affluents to the grouting gallery from various depths of grouting boreholes under the Turček dam.

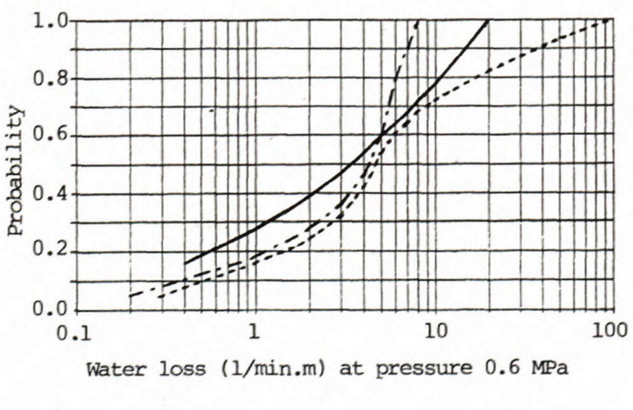

Figure 15: Results of water pressure tests in the Turček dam subsoil: - - - - in the natural medium; —— in the grout curtain, —-—- grouting criteria.

ness can even be seen in the higher and deeper layers where relatively high hydraulic gradients were observed.

Having thoroughly checked all the data obtained from the uplift measurement objects a layer, where the courtain would prove not to be closed in all, was not found.

The dam has a very good drainage system built at the air side. It enables us safely to localize for all the affluents from the dam subsoil. At the inspection level the total seepage reached 0.017 m^3/s, for various estimation assumptions the values ranged between 0.006 and 0.032 m^3/s. Seepage also presents a part of the amount of water which permanently has to be let out into the river bed beneath the dam (0.070 m^3/s). Water losses are not important from the water economy point of view. More critical are the hydrodynamic effects upon solid soil particles from the point of view of the dam subsoil stability.

The maximum filtration velocity value in one borehole reached the lower velocity limit in the dam subsoil for the inspection level (Fig. 19). Thus, attention has to be paid to water flow developments during the further reservoir filling.

Flow development and filtration stability

The seepage problems which occured in the subsoil of the Slovakian dams in the past led in 1970 to the introduction of regular ground- and seepage water flow velocity measurements. These measurements were started even before the first reservoir filling.

Figure 19 shows the development of the maximum filtration velocities in the subsoil of our fill dams. These were gained by methods described in more detail in this paper. The figure also shows the limit filtration velocity value for the stability of sandy and fine particles in rock

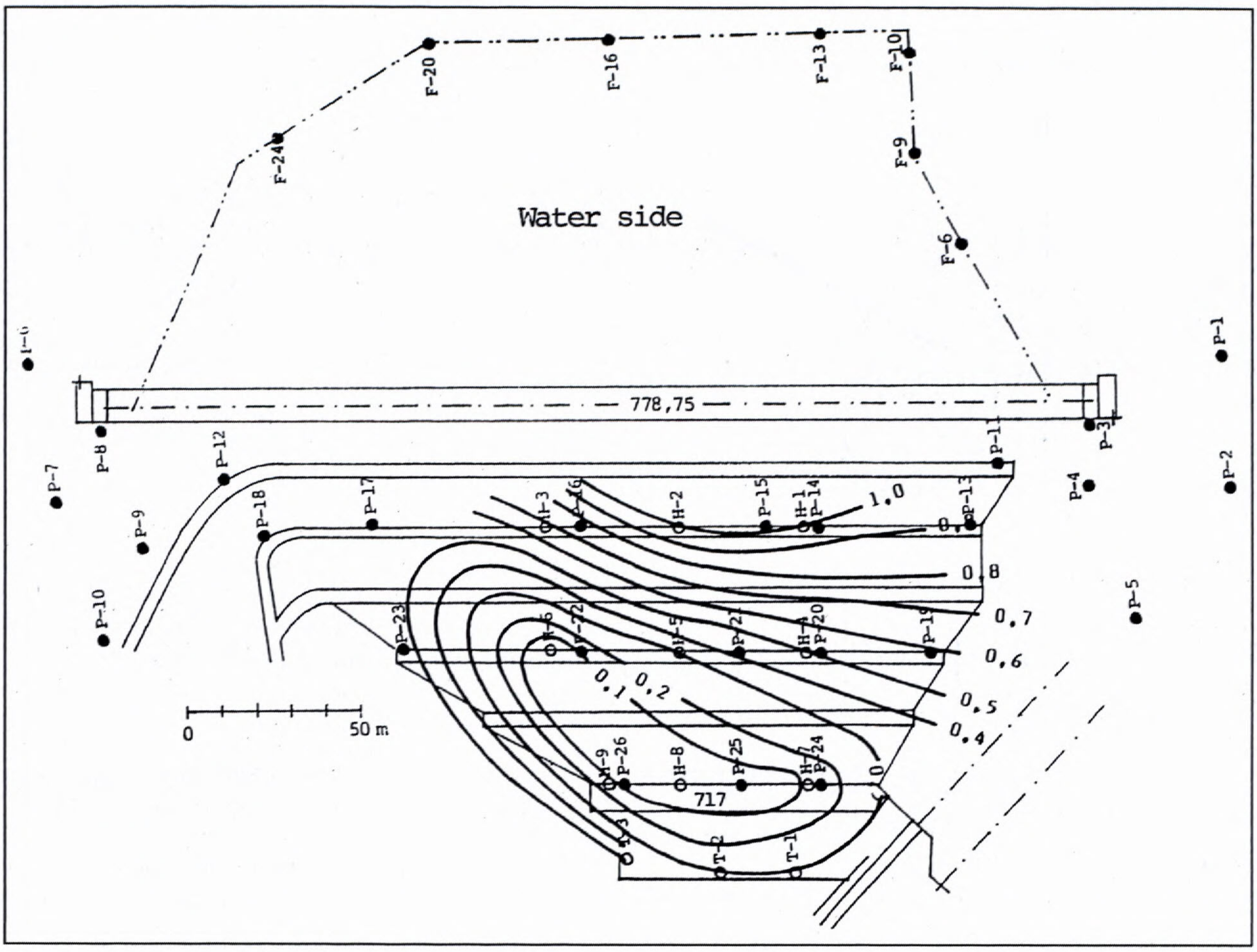

Figure 16: Isolines of increased water levels in the Turček dam body after reservoir filling to the inspection level of 757 m.a.s.

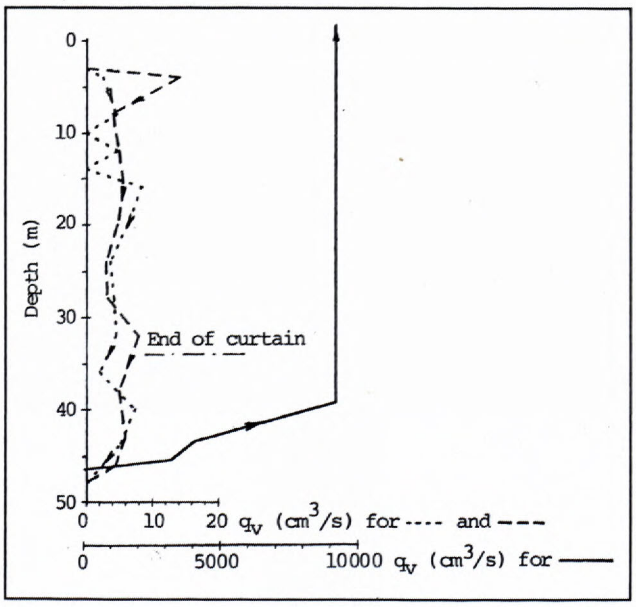

Figure 17: Vertical discharge depth dependencies in the borehole F-13, in the grouting gallery: —— - for a partially opened borehole head, - - - - - for a closed borehole head and the empty reservoir, ·········· - for a closed borehole head and the inspection level in the reservoir (757 m.a.s.), —·—·— down end of the grout curtain.

fissures (Ronžin, 1974). The maximum filtration velocity in the subsoil of the Turček dam was the closest to that value. Maximum filtration velocities in the subsoil of the other dams have significant safety reserves. An excess of the limit value in deeper layers in a small extent, does not have to mean any danger for the dam stability.

Conclusions

During the filling and operation of the reservoirs, water leaks into side slopes. Groundwater flow in the side slopes is mainly influenced by rainfall, so no big changes due to seepage take place.

Significantly more important is the influence of the seepage from the reservoirs upon bodies, subsoils and side slopes of the dams, as well as upon the terrain beneath the dams. In our conditions, we have shown that the water losses due to seepage from the reservoirs are from the point of view of water economy unimportant. Significant are the hydrodynamic effects directly influencing dam stability.

Sealing and drainage elements in dam bodies and subsoils are the significant technical measures to ensure the stability requirements. The analysis of the grout curtains presented has shown that, despite unfulfilled water pressure tests criteria, their effectiveness is very good.

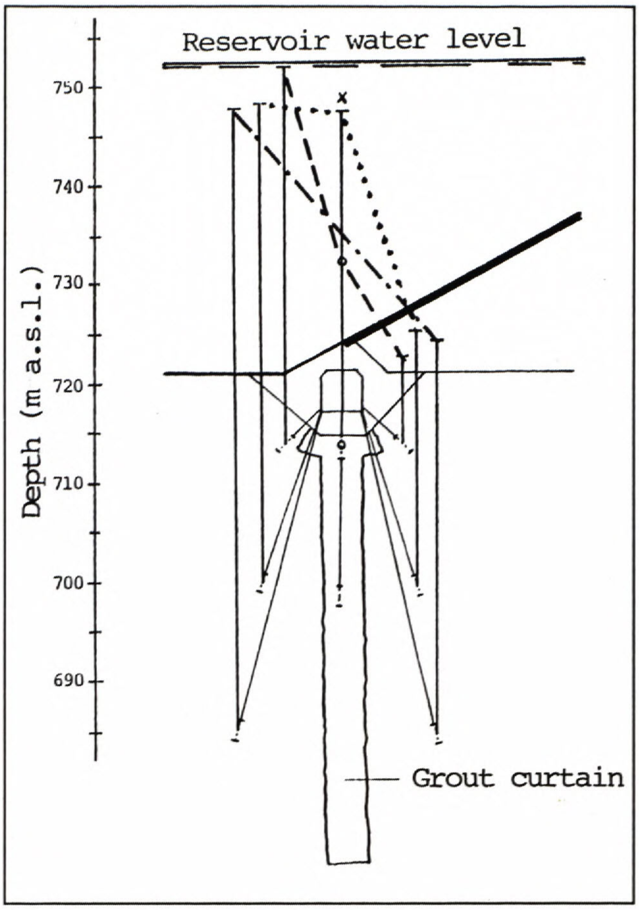

Figure 18: Uplift conditions in the valley profile of the Turček dam at the inspection level of 757 m.a.s.: - - - - - hydraulic gradient for short boreholes and gallery pit base, ········ - gradient for medium boreholes, —·—·— - gradient for deep boreholes, x - uplift under the curtain.

As a result of seepage, water levels increased by 1 to 2 m, and locally even by 14 m under the dams described and in the areas of their bounds to valley slopes when compared to the status before the reservoir filling. Filtration velocity values increased too, but on the average not more than ten times. The maximum filtration velocities are significant for the dam stability; appropriately safe values were not exceeded. Built-in drainage systems drain only a part of the seepage amounts outflow.

From the point of view of the local anomaly studies, uplift measurement systems and special boreholes enabling us to monitor water flow inside the curtain, as well as in the ungrouted medium under its bottom, are very helpful.

In sum we concluded that water seepage from reservoirs affects groundwater flow only in place of the dams analysed

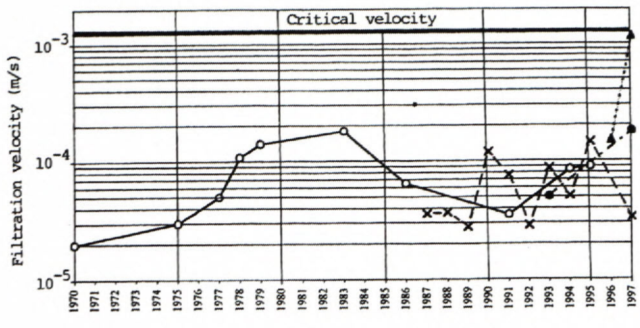

Figure 19: Time development of maximum filtration velocities in the rocky subsoil of dams: ——— - Liptovská Mara, - - - - - Starina, —·—·— - Málinec, ········ - Turček, and the limit value for fine particles stability in rock fissures (======)

and currently do not endanger their stability. In the process of dam aging, the development of their sealing elements effectiveness needs to be thoroughly monitored, since the effectiveness plays a very important role in the total dam stability and their safe and reliable operation.

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References

Drost W., 1970: Groundwater measurements at the site of the Sylvenstein dam in Bavarian Alps. Isotope Hydrology, IAEA Vienna, 421- 437.

Halevy E., 1967: Borehole dilution techniques: a critical review. Isotopes in Hydrology, IAEA, Vienna, 531-564.

Hulla J., Chovan P., 1997: Grouting curtain under the Turček dam (in Slovak). Inžinierske stavby, 45, 4-5, 171-174.

Kutzner C., 1985: Considerations on rock permeability and grouting criteria. Proc of ICOLD, Lausanne, 315-328.

Matula M., 1969: Regional engineering geology of Czechoslovak Carpathians. I. Ed. Maheľ, M., Bratislava. Vyd. Slov. Akad. Vied, 225 p.

Ronžin I., S., 1974: Some criteria for evaluation of filtration stability of water structure subsoil (in Russian). Gidrotechničeskoe stroiteľstvo, 24, 7, 24-27.

Verfel J., 1983: Grouting of rocks and diaphragm wall construction (in Czech). SNTL, Praha, 408 p.