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## **Some Problems of Reconstruction, Remedial Works and Maintenance of Dams in Slovakia**

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## **Some Problems of Reconstruction, Remedial Works and Maintenance of Dams in Slovakia**

### **1 Introduction**

Slovak territory covers an area of 49,039 km<sup>2</sup>. Crow-fly distance in the direction East-West is 428 km and the distance in the South-North direction is 195 km. The highest peak in the High Tatras is Gerlach, reaching 2655 m a.s.l., and the lowest point is the river Bodrog by Streda nad Bodrogom - 94 m a.s.l. Average precipitation total ranges from 450 mm to 2000 mm. The most significant rivers, draining the Slovak territory are:

Váh - length 367 km, basin area 11,625 km<sup>2</sup>; Nitra - 170 km, resp. 5,144 km<sup>2</sup>; Hron - 297 km, resp. 5,464 km<sup>2</sup>; Ipeľ - 248 km, resp. 5,151 km<sup>2</sup>; Hornád - 173 km, resp. 4,403 km<sup>2</sup>; Ondava - 147 km, resp. 3,355 km<sup>2</sup> and Bodrog - 15 km, resp. 7,217 km<sup>2</sup>.

Average annual surface runoff from the territory of Slovakia is  $12.6 \cdot 10^9$  m<sup>3</sup>. Geological conditions in the majority of dam sites are rather complicated, due to rich regional variability:

- region of core mountains (granites, diorites, syenites, etc.);
- region of neogene volcanites (andesites, tufs, basalts, etc.);
- region of Carpathian flysh (sandstones, slates);
- region of sedimentary rocks (sandstones, limestones, conglomerates, etc.).

These conditions, as well as not very favourable climatic conditions were decisive for the choice of prevailing types of dams. Natural conditions and economical demands of the society initiated the development of dam engineering in Slovakia already 500 years ago.

### **2 Typology and age of Slovak dams and reservoirs**

Dams and reservoirs in Slovakia may be classified according to age and significance for the society (either regional or local) into three groups:

- dams and reservoirs of historical water engineering works;
- reservoirs and dams of small water engineering works;
- reservoirs and dams listed in the ICOLD's World Register of Dams.

Basic data - number, total storage volume and flooded area of those three reservoir groups are presented in Fig. 1. From this figure, it can be seen, that the first two groups, especially the second one, are the most numerous (50 and 200, respec-

tively), however their total volume, about  $56.10^6 \text{ m}^3$ , is negligible as compared with the third group (50). The volume of 50 reservoirs in the third group represents 97 % of the total volume of all reservoirs in Slovakia  $\sim 1.89.10^9 \text{ m}^3$  (14.4 % of the average annual runoff from the territory of Slovakia). The total flooded area of Slovak reservoirs -  $212.7 \text{ km}^2$  represents about 0.4 % of the area of Slovakia.

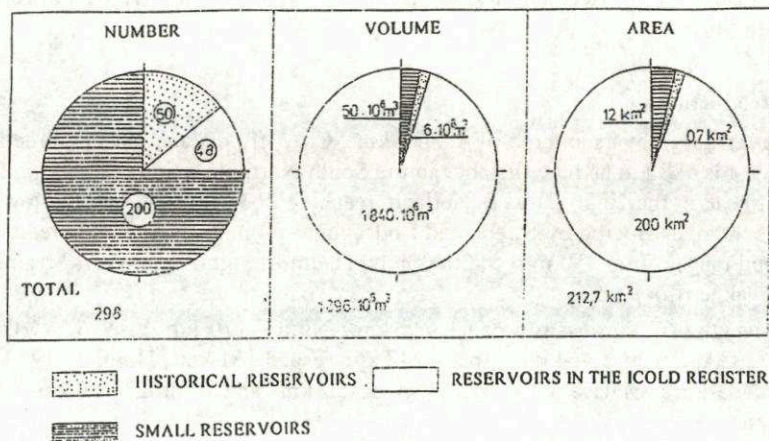


Fig. 1: Main parameters of reservoirs in Slovakia

In Fig. 2, there is given the time history of dams and reservoirs in Slovakia. It can be seen, that the number of large dams, registered in the ICOLD is 50. Six of them are historical dams.

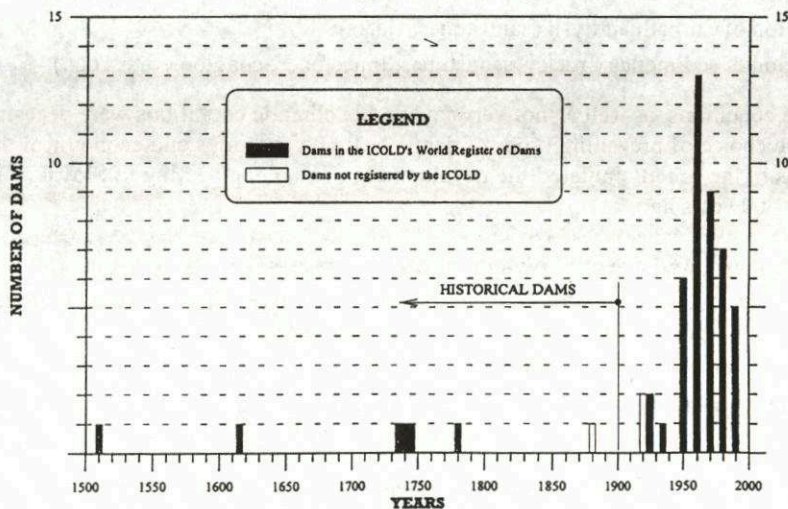


Fig. 2: Time history of Slovak dams' number

The purposes of Slovak reservoir utilization are given in the Fig. 3. According to the purposes, Slovak reservoirs can be divided into two groups:

- single-purpose reservoirs (11 hydropower reservoirs and 8 for the drinking water supply);
- multi-purpose reservoirs (31 reservoirs, used for hydropower production, irrigation, water supply, flood control, etc.)

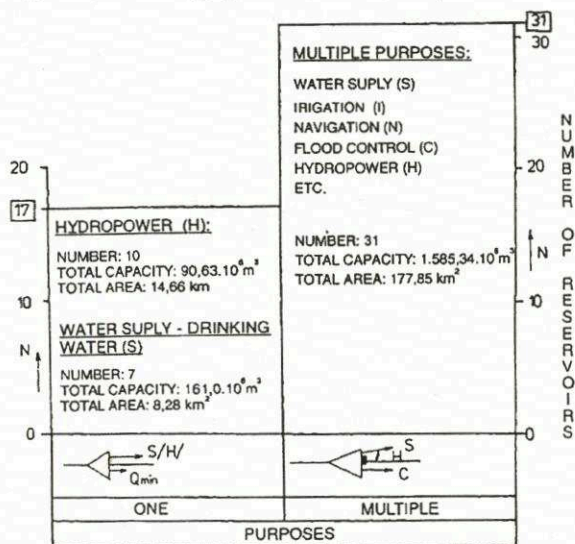


Fig. 3: Purposes of reservoir utilization in Slovakia

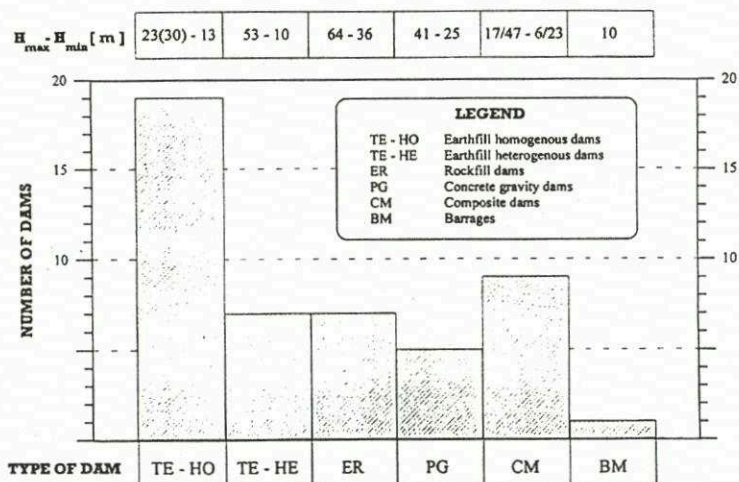


Fig. 4: Typology of Slovak dams

Generally, the types of dams in Slovakia are determined by natural, i.e. geological and climatic conditions, which are rather complicated. Within the flysch areas alternate the layers with various properties, concerning permeability and bearing power, as well as tectonically disturbed volcanites or metamorphosed rocks. All these aspects, together with climatic and economic conditions, influenced the choice and realization of the most common types of dams, i.e. earthfill and rockfill dams. Their share in the total number of large dams is 76 %, and would be still greater, if we would include also the other two groups - 50 historical dams and 200 dams of local importance. The last group of dams are exclusively earthfill dams - see Fig. 4. From the group of historical dams, the Rozgrund dam - 30 m high and extraordinary slim, is admired as unique. It was built in 1744. A particular group of dams involves composite dams and weirs.

The most common earth dams are homogenous dams of small height. The highest of them is the Ružiná dam ( $H_{\max} = 22$  m). Heterogenous earth dams are usually sealed with clay (mostly internal core). The most interesting, as well as the highest of them are the following dams: Liptovská Mara (completed in 1976,  $H_{\max} = 52.5$  m; dam crest length  $L = 1,225$  m), Hriňová (1965,  $H_{\max} = 51$  m;  $L = 243$  m), Veľká Domaša (1966,  $H_{\max} = 35$  m;  $L = 350$  m) and Starina (1990,  $H_{\max} = 50$  m;  $L = 345$  m). The sealing is embedded into the bedrock usually with a vertical element (grout curtain, concrete membrane, cut-off wall). Rockfill dams are not numerous, however they are important due to their height. The dams Nová Bystrica ( $H = 57$  m) and Ružín I ( $H = 63$  m) belong to the highest dams in Slovakia - Fig. 5. The most common sealing element is clay (6 from 7 dams). Only on the dams of upper reservoir of the pumped storage plant Čierny Váh, asphaltic concrete surface lining was used.

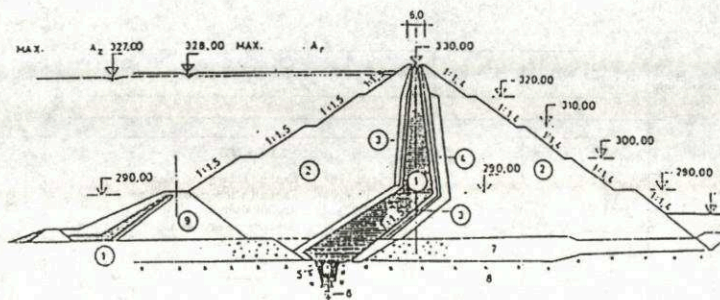


Fig. 5: Cross-section of Ružín I dam

1-clay core; 2-rockfill; 3,4-filters; 5-injection gallery; 6-grout curtain; 7-alluvial deposits

Concrete gravity dams are a significant typological group, having heights of 25 - 41 m. The bedrock of low bearing capacity (flysch) of the relieved gravity dam Orava (with internal caverns), as well as low friction of the foundation interface of the dam required to increase the stability against shearing failure by means of additional horizontal blocks. From these a grout curtain was constructed, providing

reduction of the uplift hydrostatic pressure, prolongation of the foundation interface (active friction), for the benefit of the dam stability - see Fig. 6.

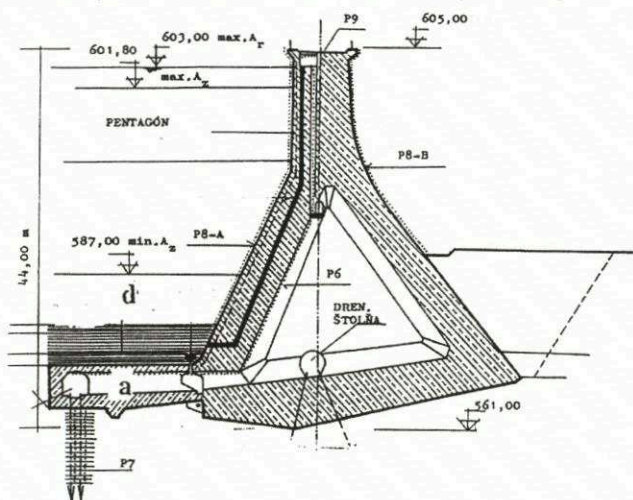


Fig. 6: Orava dam - cross-section of dam block in the middle of the valley with horizontal block (a) and clay blanket (b)

A relatively numerous typological group involves composite dams, occurring in the broad valleys or lowland areas. Their damming structures are concrete gravity dams and peripheral dams are earthfill structures. Their height is usually 17 - 47 m in the section of the concrete dam and 6 - 23 m in the section of earth dam. The earth dams are usually rather long, i.e. Krpeľany dam is 670 m long, Kráľová 10,480 m and Kozmálovce 10,250 m long. The Čuňovo reservoir of the Gabčíkovo project has peripheral earth dams more than 50 km long, at maximum height of 9 m.

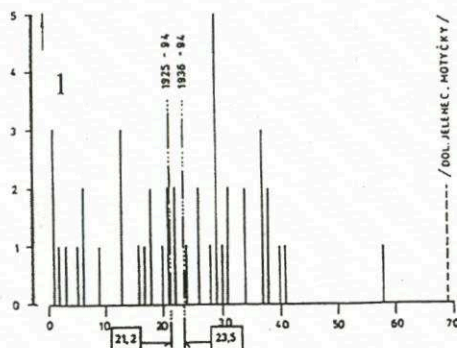


Fig. 7: Average age of dams in Slovakia  
1 - number of dams; 2 - age in years

As it can be seen from Fig. 7, average age of 50 Slovak dams in the ICOLD Register is 23.5 years. The problems of reconstruction, remedial works and maintenance of dams are determined by the age, geological and climatic conditions, operation and instrumentation of dams. The following parts of the paper submitted deal with some problems of reconstruction and maintenance of Slovak dams, divided into three groups - historical dams, small dams and large dams, registered in the ICOLD Register of Dams.



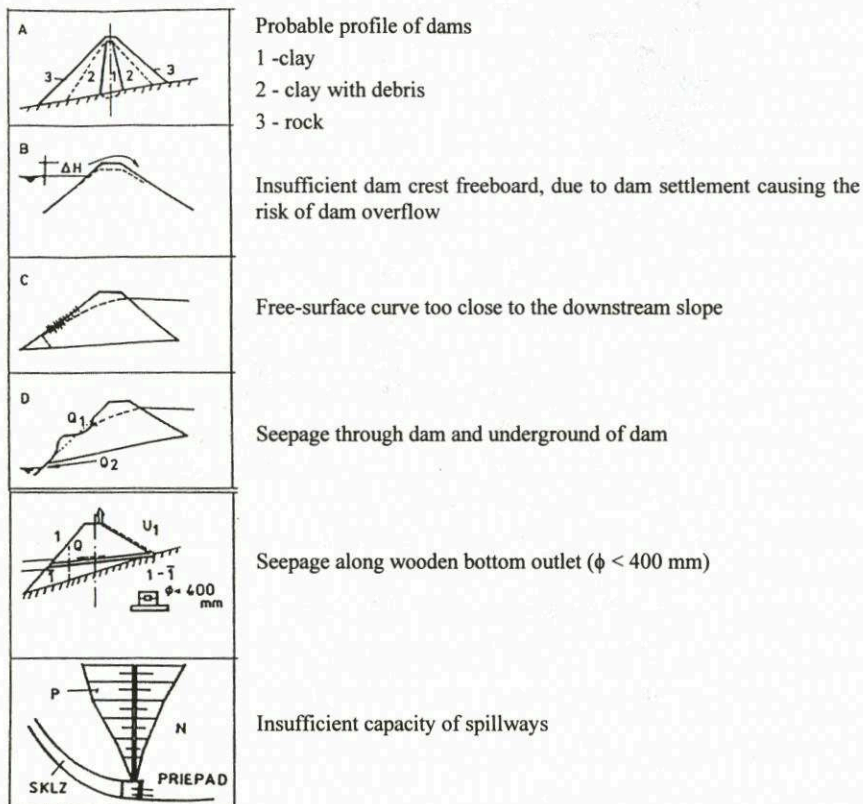


Fig. 9: The most frequent failures of historical dams

#### 4 Dams of small water works

The group of small dams is the most numerous (more than 200 dams). All these dams are earthfill dams with height  $H < 15$  m and the total volume of reservoirs  $V < 10^6$  m<sup>3</sup>. Their operation is connected with a lot of problems, despite the fact, that they are relatively "young" structures, built in last 30 - 40 years.

The most serious problems are:

- risk to downstream situated area (they are often in contact with small towns - see Fig. 10);
- imperfect project (failure in design) or failure in technology of construction;
- absence of fundamental instrumentation for the monitoring of dam safety.



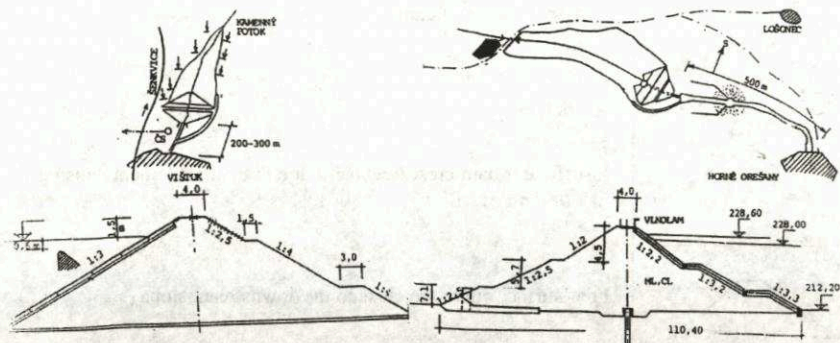
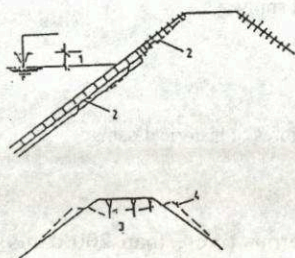


Fig. 10: Contact of small dams with the villages and small towns

The most frequent failures in behaviour of small dams in real operation are as follows:

- seepage through dam or dam underground;
- excessive settlement in the places of contact between earth dam body and concrete structures
- failure of upstream slope protection, caused by the wind waves action;
- inadequate free-board of dam crest, etc.

The typical failures of small dams are given in the Fig. 11.



- 1 - danger of dam crest overflow
- 2 - failure of dam slope protection
- 3,4 - cracks and dam crest settlement
- 5,7 - seepages

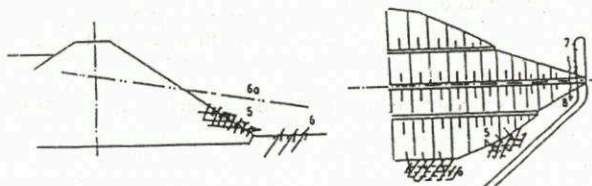


Fig. 11: The most frequent failures of small dams

## 5 Large dams, registered by the ICOLD

Safety of dams is the crucial aspect in design, monitoring (by means of measurements and observations) and operation of dams. Monitoring of dam behaviour during the construction, first filling of reservoir and real operation assists to minimize the risk factor of natural disaster. Proportionally to their importance (1st or 2nd category), the dams of this group (total number of 50) are adequately instrumented. The importance of such an instrumentation deals in:

- validation of computation model;
- prevention of failures and catastrophes (explanation of anomalies in the dam behaviour);
- information about the behaviour of new materials, used in the dam construction.

No serious failures or catastrophes occurred in the past in this category of dams in Slovakia, also thanks to measurements and observations. Some of the measurements indicate problems and anomalies in the behaviour of these dams. The most frequent problems in operation of large dams can be seen in Fig. 12.

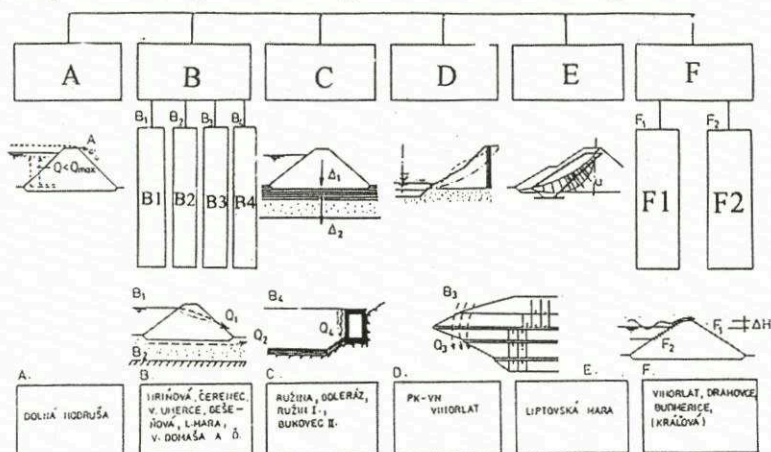


Fig. 12: The most frequent problems in the operation of dams

- |                            |                       |   |
|----------------------------|-----------------------|---|
| A-overflow of dam crest    | B-excessive seepage:  | B1-through dam body                           |
| B2-through dam underground | B3- in dam blanket    | B4-in contact with concrete structures        |
| C-excessive settlement     | D-dam slope failure   | E-unfavourable pattern of pore pressure       |
| F-impact of wind waves     | F1-dam crest overflow | F2-jeopardizing of slope protection stability |

The typical problem in the category of earthfill dams is excessive seepage through the dam body, or its underground. Excessive settlement of the dam body ( $\Delta > 1\%$ ) and high pore pressure in the clay core have occurred at some rockfill dams. Frequent problem of dams, situated in the lowland regions is the impact of wind generated waves.

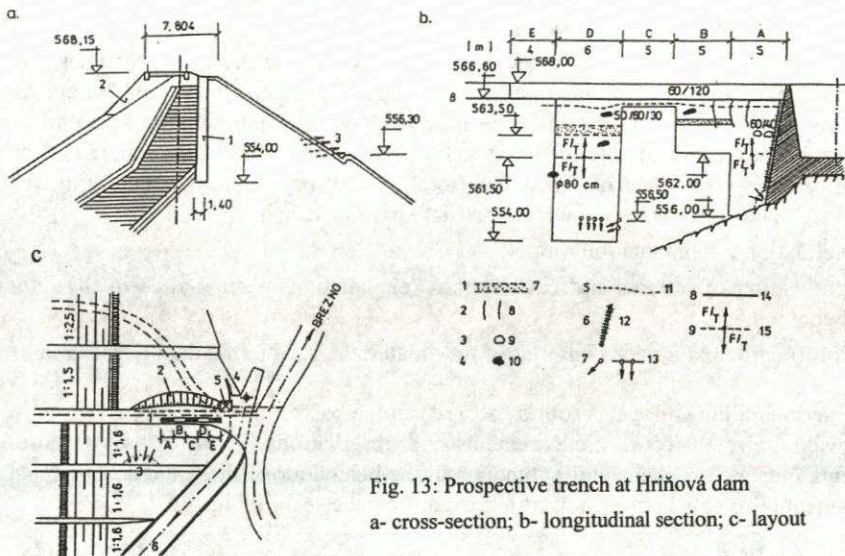


Fig. 13: Prospective trench at Hřiňová dam  
 a- cross-section; b- longitudinal section; c- layout

Long-term anomalies in the seepage regime have been typical for the operation of the Hřiňová dam. It was necessary to dig out the prospective trench (see Fig. 13) and to lower the water level in reservoir for long period, because of the risk of dam failure. Three failures are indicated in Fig. 14: P1 - P3, which occurred in the years 1966, 1968, 1971. The maximum seepage exceeded value of 100 l/s (in 1966). Earth-rockfill dam Hřiňová ( $H_{max} = 51$  m;  $L = 243$  m) with clay core creates the reservoir, which is used for the drinking water supply (total  $V = 7 \cdot 10^6$  m<sup>3</sup>).

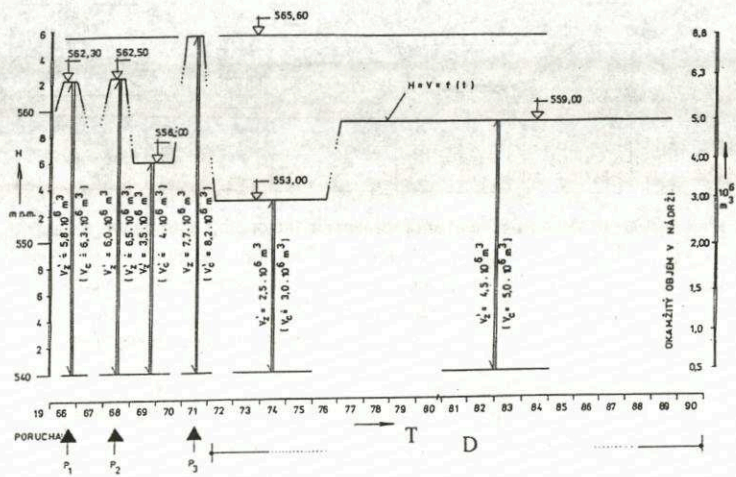


Fig. 14: Decreased volume of the Hřiňová reservoir during the dam failure  
 P1, P2, P3 - failures; D - reservoir volume; T - years

Remedial measures, realized in 1989 - 1991 at lowered water level in reservoir (559,00 m a.s.l.) consisted from:

- construction of cut-off wall and grouting of filters from the dam crest;
- grouting of clay core in the contact with rock and injection gallery.

The longitudinal section and cross-section of the above mentioned measures is given in the Fig. 15.

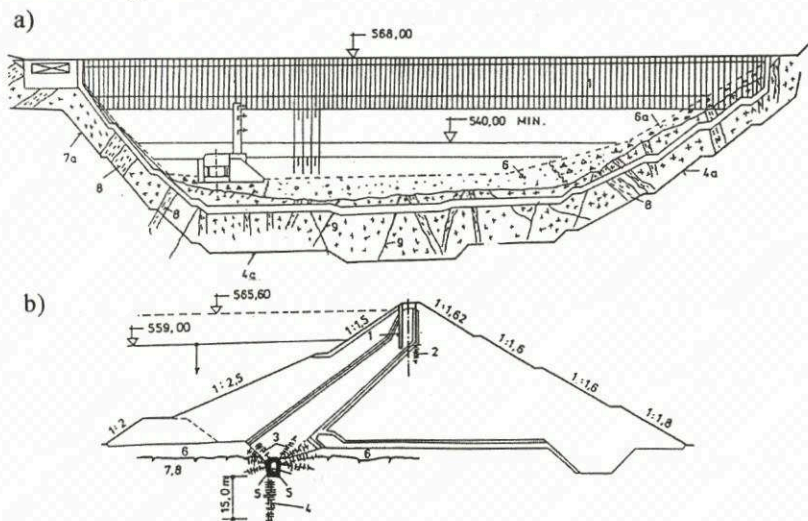


Fig. 15: Proposal of the Hriňová dam remedial measures

a- longitudinal section; b- cross-section; 1- cut-off wall; 2- grouting of filters; 3 grouting

The problem of excessive settlement of the dam body is typical for the rockfill dam Ružín I (completed in 1968,  $H_{\max} = 64$  m - the highest Slovak dam). Cross-section of this dam is given in the Fig. 5. The settlement of dam crest and clay core was more than 0,6 m after 10 years of operation and the process of dam body settlement is not finished, yet. Sealing core has been raised to the dam crest by means of cut-off wall. New calculation of design flood brought about the necessity to raise the spillways capacity. New additional spillway with diversion tunnel was constructed in 1994 - 1995.

## 6 Conclusion

The long-term analyses of problems, connected with the operation of Slovak dams showed that the safety of some historical dams and small dams is critical. The most frequent anomalies in all three studied groups of dams are excessive seepage, settlement and deformations (rockfill dams). Dams, situated in the lowland regions are attacked by the wind waves. Adequate monitoring system, proportional to the importance of dam can ensure effective operation and to minimize the risk of dam failure.

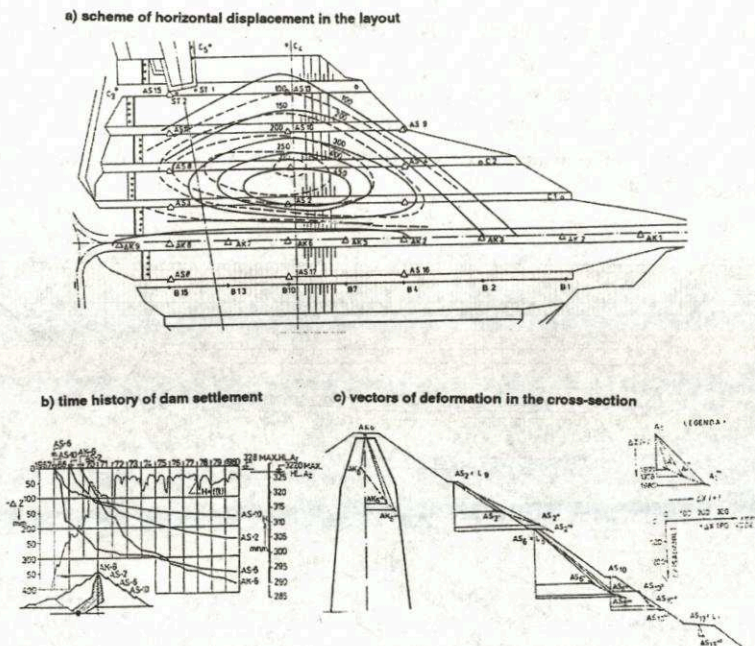


Fig. 16: Rockfill dam Ružin I

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