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Foundation of the Mseno Dam; Analysis and the Study of Remedial Measures

1 Introduction

The curved gravity dam was constructed in the period between 1906 to 1909. The dam is located on the Nisa river in the town Jablonec nad Nisou in Northern Bohemia. In the past the main purpose of the reservoir was flood protection. Now the reservoir is used for water supply, recreation (winter and summer sports) and flood protection.

The additional geological prospecting of the site of the Mseno dam was performed in 1987 and in 1988. This prospecting was the reaction to unsatisfactoring results of the dam surveillance. The geological prospecting discovered the layers of non rock materials under the dam body. The layers of granite eluvium, alluvial granite eluvium, sandy clay etc. probably completely cover the base of the foundation. Historical drawings and design documents do not correspond to the results of geological prospecting.

It was decided to perform the more detailed numerical analysis of the dam and its foundation. The reasons for this analysis were the unsatisfactoring results of the geological prospecting, the dam survey and the stability analysis based on classical calculation methods. Consequently, the technical solution of remedial measures was supposed to be suggested the detailed analysis of the dam.

2 The Mseno dam

The construction material of the body of the Mseno dam is granite masonry. Some similar dams, approx. 90 years old, are located either in Northern Bohemia and other European countries. The type of these dams (Intze type) is characterised by the earth body adjacent to the upstream face of the dam (Fig. 1 and 2).

The dam is 420 m in length, the dam crest is 4.5 m in width, the radius of the curvature of the dam is 350 m.

The elevation of the top of the dam is 513.00 m a.s.l. The height of the dam (at the lowest point of the foundation) is approximately 20 m. The width of the dam is 15 m (the width at the toe). The elevation of the lowest part of the foundation is 492.00 m a.s.l.

The contact between the granite masonry of the dam body and the subgrade is treated with 1 m thick layer of levelling concrete.

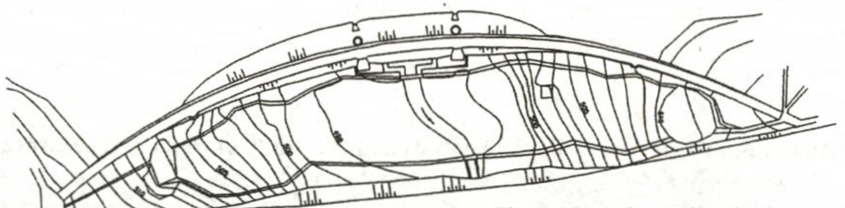


Fig. 1: Mseno dam - plan view

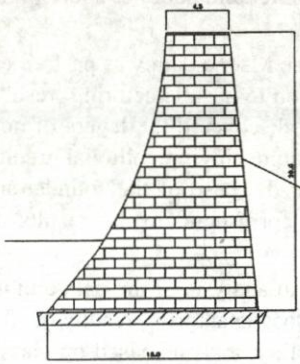


Fig. 2: Mseno dam- cross section

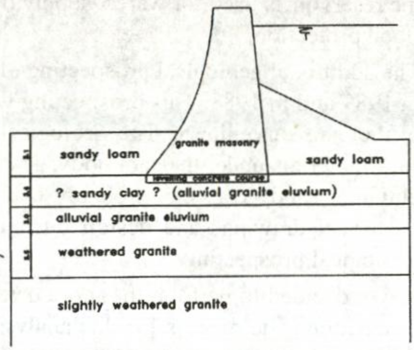


Fig. 3: Mseno dam subgrade

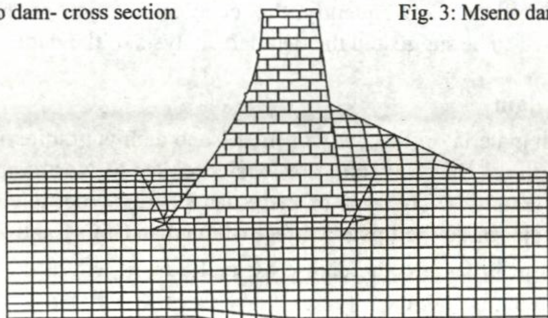


Fig. 4: Seapage analysis - FEM mesh

3 The subgrade of the dam

The archive materials (design documents, drawings) do not probably correspond to the real situation as for the subgrade of the dam. The solid rock under the dam is mentioned in old documents and drawings.

The thickness of soil layers between the dam and the bedrock varies from 7 to 11 m. The main part of the non rock subgrade consists in alluvial granite eluvium. Some parts are filled by sandy clay and sandy loam (Fig. 3).

The rapid piping failure of one borehole at the bottom of the valley (downstream) occurred during the geological prospecting. The high discharge of running sand from the borehole was stopped by sand bags.

The pieces of wood, which were found in the material removed from the low parts of geological boreholes, can be considered the evidence for the presence of alluvial deposits under the dam.

4 Seepage and ground water flow analysis

The seepage analysis and the ground water flow analysis was the first step of the dam behaviour analysis. The FEM technique was applied (2D quadratic isoparametric elements).

The 2D mesh of finite elements consists in 1305 elements and 4088 nodes (Fig. 4).

Some results of seepage analysis are presented in Fig. 5. The drawing presents path lines and equipotential lines in the case of full reservoir.

Hydraulic gradients were the most important part of obtained results. Fig. 6 presents the large area of high hydraulic gradients (higher than 1.0) located near the downstream part of the dam toe. The shape of this area can be characterised by the width of 4 m and the height of 2.5 m.

5 Statical analysis - present conditions

The results of the ground water flow analysis and the results of the geological prospecting were used for statical analysis. The FEM technique was used (3D quadratic isoparametric elements).

The detailed 3D mesh (2D view) of finite elements consists in 720 elements and 5323 nodes (Fig. 7).

The following loads have been taken into consideration: hydrostatical loads, hydrodynamical loads (uplift, seepage pressure) and volume loads.

Some results in the case of full reservoir are shown by Fig. 8a and 8b. The concentration of high tensile stresses (Fig. 8a) and the concentration of high shear stresses (Fig. 8b) is presented.

6 The dam safety - present state

The high hydraulic gradients concentrated in the area adjacent to the downstream toe of the dam are considered to be the warning that the dam is not safe enough from the hydraulical point of view. The external impulse can cause the rapid piping erosion of the nonrock layers under the base of the foundation. The following restrictions were applied to reduce the dangerous effects of high hydraulic gradients:

1/ the operating water level was lowered by 2 m,

2/ it is forbidden to operate heavy vibrating machines at the downstream face of the dam (in the strip 20 m in width along the downstream face) and open any excavation at the same area.

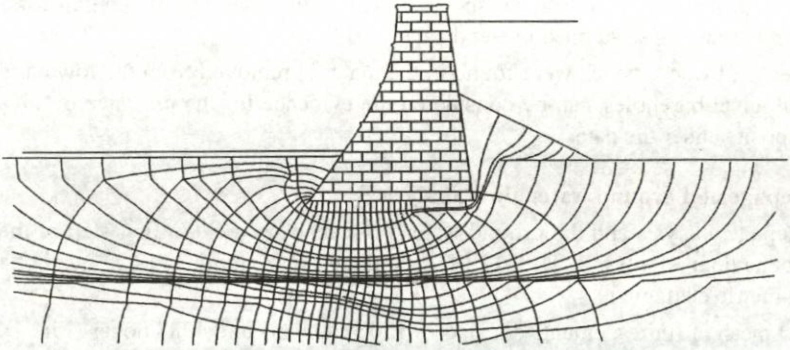


Fig. 5: Seapage analysis - equipotential lines and path lines (full reservoir)

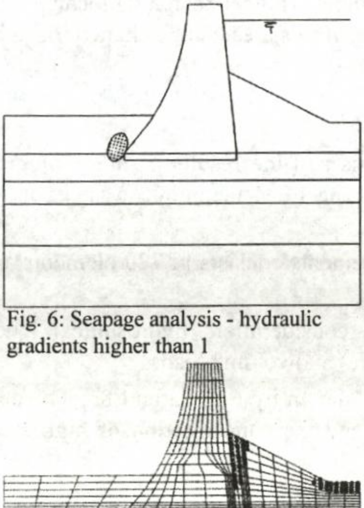


Fig. 6: Seapage analysis - hydraulic gradients higher than 1

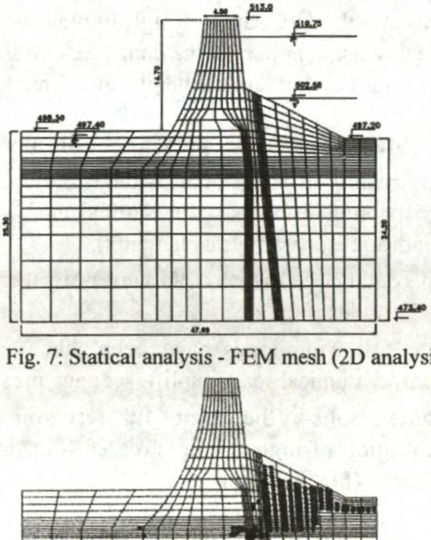


Fig. 7: Statical analysis - FEM mesh (2D analysis)

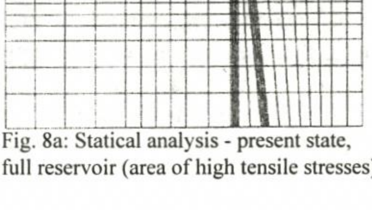


Fig. 8a: Statical analysis - present state, full reservoir (area of high tensile stresses)

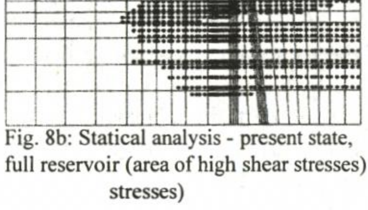


Fig. 8b: Statical analysis - present state, full reservoir (area of high shear stresses) stresses)

It is prescribed to focus the dam surveillance on the changes of the downstream land surface (to observe springs and their turbidity, terrain deformations).

The stability of the dam is not endangered now (from the statical point of view).

The present state of the Mseno dam does not require any rapid and extensive remedial measures but the results of geological prospecting and the results of FEM analysis show that safety coefficient of the dam is near to 1.0 now.

The above mentioned facts are reflected in the effort of the owner of the dam (Povodi Labe, a.s.) and the supervisor of the dam (VD TBD, a.s.) to plan and design (in 1997) and to perform (in 1998) necessary remedial measures.

7 Subgrade treatment (sealing) - alternatives of the solution

The technology based on the construction of the cut of wall has been selected to be used for the design of remedial measures. The analysed alternatives are presented in Fig. 9. All these alternatives were analysed by 2D FEM modelling. The changes of stress-strain behaviour were analysed to compare them in all alternatives and with present behaviour of the dam.

The behaviour of the dam was analysed taking future conditions into consideration:

1- the change caused by the construction of sealing element,

2- the analysis in the case of a full reservoir (after remedial measures),

3- the analysis in the case of an empty reservoir (after remedial measures).

8 Deformation of dam body - 3D effects

The three dimensional analysis of the behaviour of the dam body was performed to find an information about the relation between results of 2D modelling and the real behaviour of the dam. The analysis was performed for straight and curved dam (Fig. 10 - 3D FEM meshes).

The effect of three dimensional shape of the dam body is possible to clarify, for example, by the displacement of some reference point at the upstream edge of the crest in the centre of the valley (the displacement between full and empty reservoir):

2D analysis -	horizontal displacement:	29.2 mm upstream
	vertical displacement:	5.0 mm settlement
3D analysis -	horizontal displacement:	24.9 mm upstream
(straight dam)	vertical displacement:	4.3 mm settlement
3D analysis -	horizontal displacement:	22.6 mm upstream
(curved dam)	vertical displacement:	3.1 mm settlement.

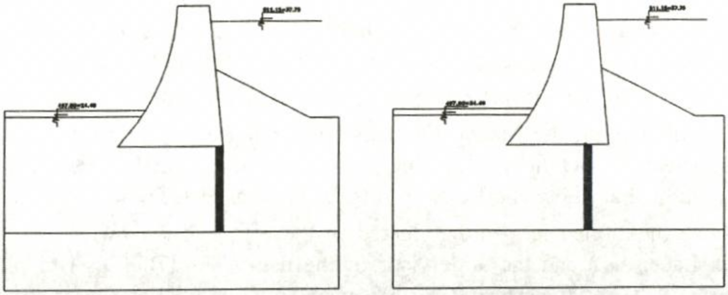
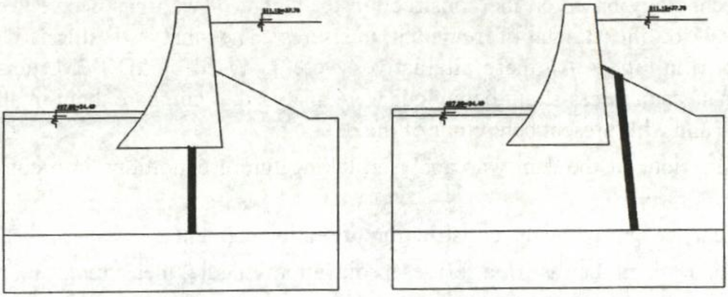


Fig. 9: Alternatives of the location of cut off wall



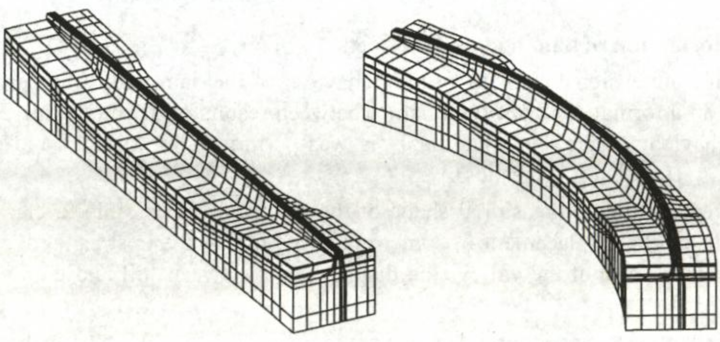


Fig. 10: Statical analysis - FEM mesh (3D analysis)

9 Statical analysis - the state after remedial measures

After the analysis of all alternatives the acceptable alternative has been selected.

Figures 11a and 11b present the results in the case of full reservoir (concentration of high compressive stresses - Fig. 11a, the concentration of high shear and tensile stresses - Fig. 11b). The cut off wall is located under the upstream toe. This alternative is considered to be dangerous for the dam.

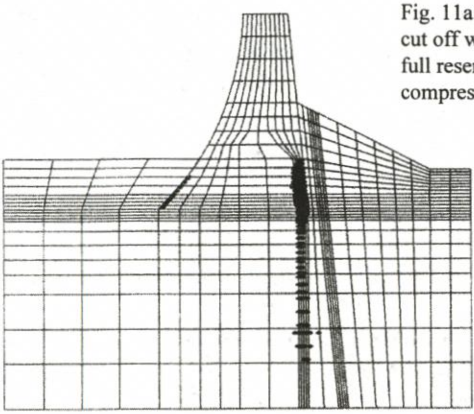
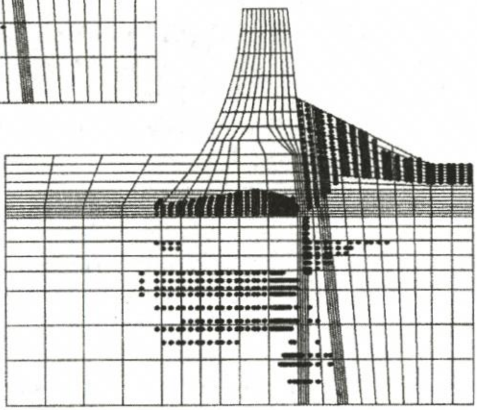


Fig. 11a: Statical analysis
cut off wall under the upstream toe,
full reservoir (area of high
compressive stresses)

Fig. 11b: Statical analysis
cut off wall under the upstream
toe full reservoir (area of high
shear and tensile stresses)



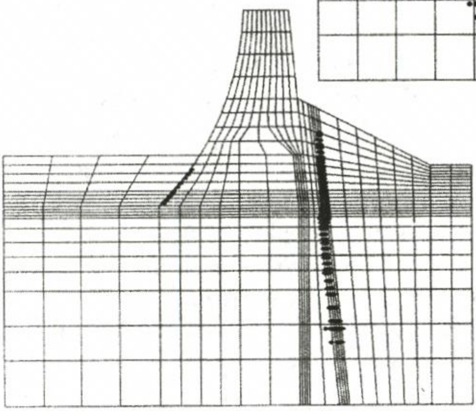


Fig. 12a: Statical analysis
cut off wall in front of upstream face
full reservoir (area of high
compressive stresses)

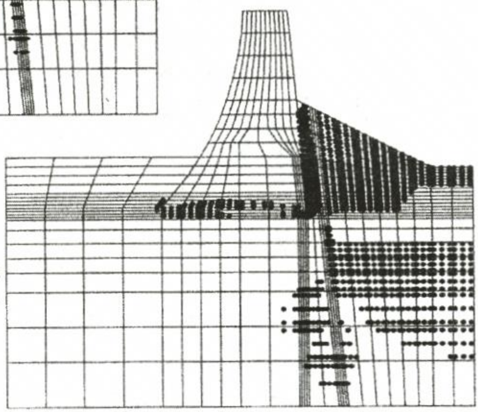


Fig. 12b: Statical analysis
cut off wall in front of upstream
face, full reservoir (area of high
shear and tensile stresses)

Figures 12a and 12b present the results for the case of full reservoir (concentration of high compressive stresses - Fig. 12a, the concentration of high shear and tensile stresses - Fig. 12b). The cut off wall is located in front of the upstream face. This alternative is considered to be convenient for the design of remedial measures. The strip between the dam and the top of the cut off wall can be sealed by flexible membrane.

10 Back analysis of the dam behaviour

The back analysis of the dam behaviour will be performed before the detailed design of remedial measures.

The supervisor of the dam (VD TBD, a.s.) is responsible for the statistical analysis of the displacement measurements of the Mseno dam. The main objective of the statistical analysis is to find the correlation between the dam movement and the water level movement and to exclude the thermal effects (May 1997).

The owner of the dam (Povodí Labe, a.s.) is responsible for the emptying of the reservoir and the simultaneous measurement of the dam displacements (September 1997).

The 2D and 3D back analysis will be performed and the mathematical model of the dam will be verified. Consequently the verified models will be used for detailed design of remedial measures.

11 Construction of remedial measures, dam surveillance

The construction of remedial measures is planed for the next year (1998).

The measurement of dam movement will be performed during the construction. The measured values will be compared to predict values calculated by verified 2D and 3D numerical models. These models will also be used for the analysis of possible differences between calculated and measured displacements.

The procedure of numerical model verification will continue during the construction period. Consequently the relationship between the movement of water level in the reservoir and the dam movement will be analysed (critical values including). These information will be used for the surveillance of Mseno dam after the construction of remedial measures.