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High embankment dams in ravine-like valleys

Barrages en remblai de grande hauteur, situés dans des vallées très étroites

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SYNOPSIS In ravine-like valleys an embankment dam causes a stabilising effect on the flanks because of its large dead weight. The construction of an embankment dam requires a suitable sealing element. A new kind of concrete core diaphragm wall, which is particularly suitable for these conditions, is recommended in this report. It has a bituminous slip-layer on the concrete surface, which leads to a drastic decrease of the wall friction forces. This means that concrete core diaphragm seals can be used for dams of practically every height. This report gives a description of the new construction method and the model tests for the investigation of 3d bearing behaviour of embankment dams in ravine-like valleys.

DISCUSSION OF THE PROBLEM

In designing a dam the engineer is always faced with the problem of choosing the optimal type of dam for the locality in question. This is a very complex task in which the choice criteria play an important role.

In ravine-like valleys arch dams are generally prefered. In using this type of dam, the problems lie primarily in the foundation of the dam into the steep valley flanks. In eroded valleys these flanks are often in a state of low stability and a secure transmitting of the large loads requires a lot of technical efforts. In relation to the dead weight load of an arch dam the additional loads, which are caused by the water pressure, are great. In contrast to that the embankment dam type has the advantage that an approximately ten times bigger mass is built in, which produces a stabilising effect on the valley flanks. Another advantage is that the stress is transmitted gradually over large areas into the subsoil and in relation to the previous dead weight stress, the increase in the stress caused by the water pressure is relatively small. The rocky subsoil is therefore put under gentle stress, which means that even in stress cycles lasting hundreds of years, one can expect no great changes in the rock strength. Even in case of earthquakes, embankment dams have a stabilising effect on steep valley flanks.

The problem of embankment dam construction in ravine-like valleys lies, above all, in the choice of a suitable sealing element. Natural sealing elements have been used successfully as earth cores even in high dams (Chivor - Columbia : H = 237 m, length of dam crest L = = 3o8 m, L/H = 1.3o, finished in 1975 ; Chicoasen - Mexico : H = 264 m, L = 33o m , L/H = 1.25, 1979). Its use, however, presupposes suitable sources of material. Artificial sealing elements for diaphragm seals have until now been produced as core seals in the interior of the dam, or as surface seals. Concrete, asphaltic concrete, plastic concrete, sheet steel and synthetic seals are used as material. Core seals have been constructed up to a height of just under 1oo m (Concrete : Tieton - USA , H = 97,5 m, finished in 1923 ; Asphaltic concrete : Finstertal - Austria , H = 98 m, finished 198o). Dams with surface seals have been constructed up to a heigth of 16o m (Concrete : Foz do Araia - Brazil , H = 16o m, 198o).

In order to find out if the sealing elements are applicable to ravine-like valleys, one has primarily to consider the three dimensional (3d) effects.

DAMS WITH CONCRETE CORE DIAPHRAGM WALLS

Due to the steep flanks, in ravine-like valleys one has to reckon with shearing displacements in the foundation area in the direction of the line of slope, depending on the type of fill, even when achieving the best compaction. This shift can have a negative influence on the sealing elements, especially in terrace-like terrain. In comparison with other artificial sealing elements the concrete core diaphragm wall, which was developed during a research project at the Department of Soil Mechanics, Rock Mechanics and Foundation Engineering at the University of Innsbruck, can be regarded as particularly suitable for these conditions. Figure 1 shows the schematic design and the construction method (see also Schober 1982). It can be seen that the concrete core has a bituminous slip-layer on the concrete surface, which leads to a drastic decrease of the wall friction forces. This means that concrete core seals can be used for dams of practically every height (Schober/Henzinger 1984). The fill can slide past the concrete core without negative effects on it because of this bituminous slip-layer. This new type of seal turned out to be suitable for the practical use in 1982 in the case of the 31 m high Bockhartsee-dam (5ooo qm of sealed surface

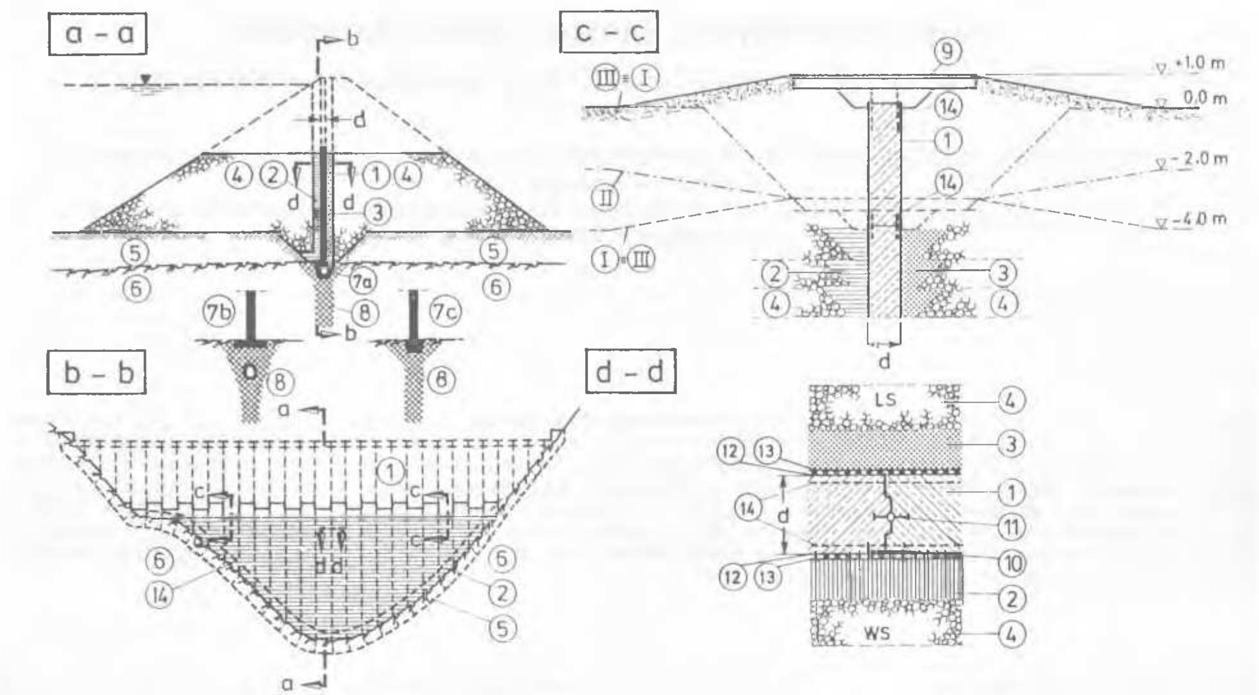


Fig. 1 Schematic design of a concrete core wall.

c-c vehicle passage. d-d joint design. 1 concrete core wall. 2 fine grained zone. 3 drainage zone. 4 shell bodies. 5 rock overburden. 6 bedrock. 7a/7b grouting and inspection gallery. 7c cut-off wall. 8 grout curtain. 9 transportable bridge . 1o water stop on the surface. 11 interior water stop. 12 bituminous slip-layer . 13 fabric protection layer. 14 skin reinforcement. I,II,III phase of vehicle passage. WS/LS upstream side / downstream side.

area) , which was built by the Salzburger Hydroelectric Company (SAFE). This dam caused no problems in the construction phase or when it was under water loading. Schober/Lercher will report on it in 1985. Figure 2 shows a construction picture of the above mentioned dam. In Figure 3 we can see the application of the bituminous slip-layer in areas of approx. 3 qm.

Fig. 2 Construction site of the Bockhartsee - dam (1982)

Fig. 3 Application of the bitumious slip-layer.

MODEL TESTS FOR THE ASSESSMENT OF THE 3D - BEARING EFFECTS.

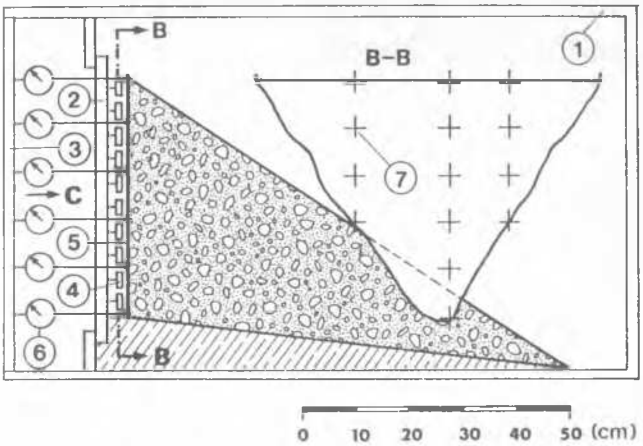
There are considerable 3d bearing effects in dams in narrow valleys.With the help of modern calculation methods (FEM) these effects can be analysed. Apart from the considerable size of the calculation, it is difficult to analyse the topographical influence realistically in case of uneven terrain. Model tests are a relatively simple way of estimating qualitatively 3d effects. During the above mentioned research project a model technique was developed, in which only the downstream shell of the diaphragm wall need to be constructed. This is acceptable because the dead weight is sufficiently simulated and the shell on the upstream side is only involved in an indirect way in the transmitting of the water pressure into the subsoil.

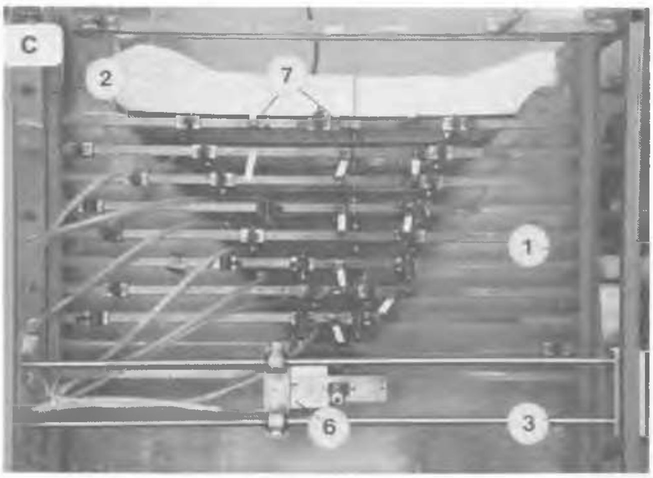
In order to show the 3d effects we always compare 3d models with 2d models. Figure 4 shows the structure of the model.

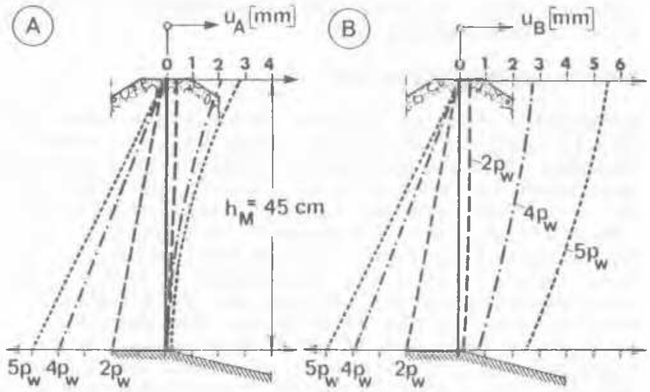
The model is based on a real embankment dam project. The height H = 22o m, crown length L = = 32o m and L/H = 1.45. Baryt sand, with a maximal grain size of 4 mm is used as material for this model. This has already proved itself suitable in past experiments (Schober/Lackinger 1979). The load device for the water pressure is made out of ten rubber flat jacks (4). These can be used to exert step by step a multiple of the hydrostatic pressure. These flat jacks press on the sealing wall, which is made out of flexible strip elements. These elements correspond with nature in stiffness. Horizontal displacements are measured at different points of the sealing wall.

RESULTS OF THE MODEL TESTS .

Figure 5 shows the most important results of the tests.







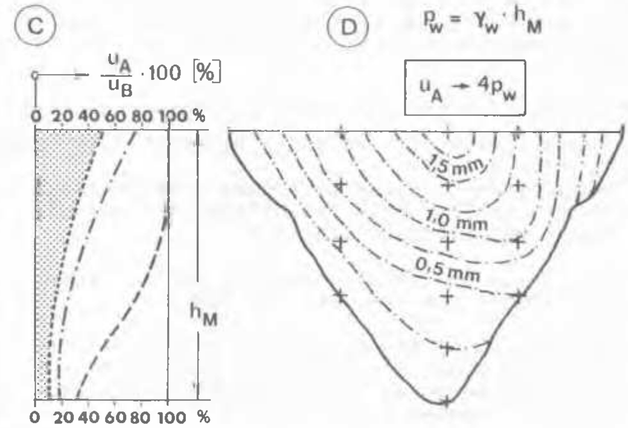


Fig. 4 Scheme and picture of the 3d-model.

B-B valley section - sectional view C
1,2,3 frame of the model, support and measuring device. 4 rubber flat jacks. 5 membrane seal. 6 measuring device for displacements. 7 measuring points.

Fig. 5 Results of the model tests.

p_w original water pressure. A wall displacements of the 3d model u_A

B wall displacements of the 2d model u_B

C 3d effects . D isolines of the wall displacements u_A under a pressure of 4 p_w.

The displacements in the 3d model (diagram A) are compared with those in the 2d model (diagram B) under a water pressure of 2-times, 4-times and 5-times the original pressure p_w .

Three sections in the 3d model and the middle section of the 6o cm wide 2d model were measured. In comparison with the middle section of the 3d model there are considerably larger displacements in the 2d model.

The 3d effects can be estimated qualitatively through the relation of the amount of the displacements. Diagram C shows that the 3d effects in this project increase from the crest to the basis, depending on the size of the displacements. In comparison with the displacements in the 2d model,there are only 48 % of the displacements at the crest and 1o % on the basis of the 3d model under a water pressure of 5-times p_w .

Diagram D shows the isolines of the horizontal displacements in the 3d model,under a water pressure of 4-times p_w .

Because of the terrain features there is a considerable, asymetrical displacement in the area of the sealing wall.

SUMMARY AND CONCLUSIONS

Embankment dams in ravine-like valleys have a stabilising effect on the steep valley flanks because of their big mass. A diaphragm concrete core wall is regarded particularly suitable as an artificial sealing element. Applicability even to high dams is achieved through bituminous slip-layers on the wall surface. Model tests with a new technique, in which only the downstream shell was set up, were carried out to estimate the 3d effects. The results have shown that the 3d bearing effects can be realized well. In the case of a real embankment dam project, the horizontal displacements due to water pressure were reduced,depending on the size of the displacements. The influence of extreme topographical features can clearly be seen in the model. The tests have proved that it is possible to estimate realistically the 3d - behaviour of the dam with the help of these measurements and a 2d stress and strain analysis.

The investigations include the following steps:

- Installation of a 2d and a 3d model according to figure 4.
  Measurements of the horzontal displacements on the sealing wall for different sizes of loads according to figure 5 .

- 2d stress and strain analysis for the cross section of the dam with the FEM .

- Conversion of the calculated displacements into the model scale for the connection with the measured displacements in the 2d model (diagram B of figure 5) .

- Search for the corresponding displacement line in the cross section of the 3d model (diagram A of figure 5) and for the correspronding isolines .

In this way one can estimate even quantitatively the displacements of the wall, which can be expected because of the water pressure,on 3d conditions.

Finally it can be said that it is possible to conclude from the corresponding isolines to the real displacements of the concrete core diaphragm wall.

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