UNDERGROUND OPENINGS FILLED WITH HIGH-PRESSURE WATER OR AIR

OUVERTURES SOUTERRAINES SOUMISES A DE FORTES PRESSIONS D’EAU OU D’AIR

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Summary:
A water pressure higher than 50 kp/cm² and an air pressure higher than 40 kp/cm² have been used in the unlined tunnel and closed surge chamber of a hydroelectric power plant in Precambrian rock. The rock conditions demanded are discussed. In particular the resistance to hydraulic fracturing, but also the leakage problem through the rock mass, is mentioned. Some practical advice for the design is put forward.

Résumé:
Dans des roches Précambrienes, une pression d’eau supérieure à 50 kp/cm², et une pression d’air supérieure à 40 kp/cm² sont utilisées pour le fonctionnement de centrales hydroélectriques. Les conditions demandées sont analysées. En particulier la résistance à l’écartement des diaclases par l’eau et le problème des pertes en air est mentionné. Quelques conseils pratiques pour la réalisation sont exposés.

Introduction

A new design for hydroelectric power plants situated in Precambrian rocks has been put into practice in Norway. An example of this is the Driva Power Plant which started the production of electric power in 1973.

The main feature of the new design is an unlined headrace tunnel that slopes from a short penstock near the power house to the level of the intake at a gradient of 5 - 7°. The surge gallery is a closed, unlined chamber, filled up with compressed air, situated close to the headrace tunnel (Fig. 1).

Fig. 1. Principle of compressed air surge chamber.
A = pressure tunnel.
B = closed surge chamber.
C = sand trap.
D = steel lined shaft.
E = power house.

The maximum pressure of water on the unlined headrace tunnel at the Driva Power Plant is 51 kp/cm² and the air pressure applied to the closed surge chamber is 42 kp/cm². The loss of air has been below the limit of measurability. The low cost, the better stability by frequency regulation and lower losses of head energy have been of great benefit. At present other projects of the same type of design are planned and/or under construction.

There are many technical and geological problems involved in such constructions in valley sides. Theoretical studies have been carried out and a status report has been prepared on these subjects as a cooperative effort of several Norwegian institutes. (Report to NVE-Statskraftverkene 1973). The main engineering geological problem is the resistance of the rock to hydraulic fracturing and the leakage of air and water through the rock mass.

With earlier occurrences of high water pressure in tunnels and shafts, the security against hydraulic fracturing has been solved by rule-of-thumb based on experience regarding the necessary rock cover (DANNE et al 1964; KIESER 1960; SELMER-OLSEN 1970). Moreover, caution has been taken when clay gouges and karst phenomena occurred.

The computer program

At present the geometrical problem of rock cover is based on a calculation of the total stress by finite element plain strain analysis. The main condition imposed is that the minimum in-situ total stress must be higher than the water pressure at every point along the potential tunnel. A safety-margin equal to minimum 10 percent higher operation level is added in practice to prevent failure. The same geometrical conditions as for water pressure are also used for air pressure.

The computer program used was developed at the University of California, Berkeley, (GOODMAN, TAYLOR and BREKKE 1968) and improved and adjusted by BJORKA, BJERLYKKE and HELLAND at The University of Trondheim, The Norwegian Institute of Technology. The model used is adapted to the isostatic behavior of the crust according to its size and to the tectonic stresses, i.e. tectonic stresses are introduced, increasing linearly with the depth and no bending forces are tolerated.
Furthermore the depth of the valley in the model has to be less than one third of its height and one tenth of its length.

Figure 2 shows one half of an idealized model for a valley side sloping 40°. In the actual cases vertical cross sections of the valley are used. These cross sections have to be drawn at right angles to the contour lines. In jutting parts of a valley side more profiles must be drawn, in order to find the most unfavourable one.

The results from the computer are presented in dimensionless diagrams as shown in Fig. 3. The curves represent the minimum overburden at different heights of the operation level. The relationship between the static water pressure (increasing with the depth) equalizes the minimum principal stress. 

\[ H = \text{the height of the operation level above the bottom of the valley.} \]
\[ d = \text{the depth of the valley.} \]

For the most unfavourable values, \( K = 0.5 \) and \( \nu = 0.2 \) are used in cases where \( K_t \) and \( \nu \) are unknown.

In Norway the rock pressure measured in the Precambrian and Paleozoic rocks indicates values for tectonic stress.