Modelling of Discrete Joints in Concrete Gravity – and Arch Dams

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This contribution deals with the treatment of discrete joints, constructed in gravity and arch dams which are discussed in the light of numerical analyses and model preparation.

A typical concrete block in a dam structure has thickness of about 20m in transversal direction and a green concrete placing height of about 3m. In general the layer height is differently treated near the rock abutment and depends additionally on the radial dimension of the concrete block and hydration heat gradient.

The joint is sealed against upstream, vertical and downstream to allow for joint grouting under pressure. The height of such grouting zones depends on the site conditions and can be up to 35m (Fig.1). Grouting pipes as well as de-aeration pipes are installed in primary and secondary concrete blocks respectively.

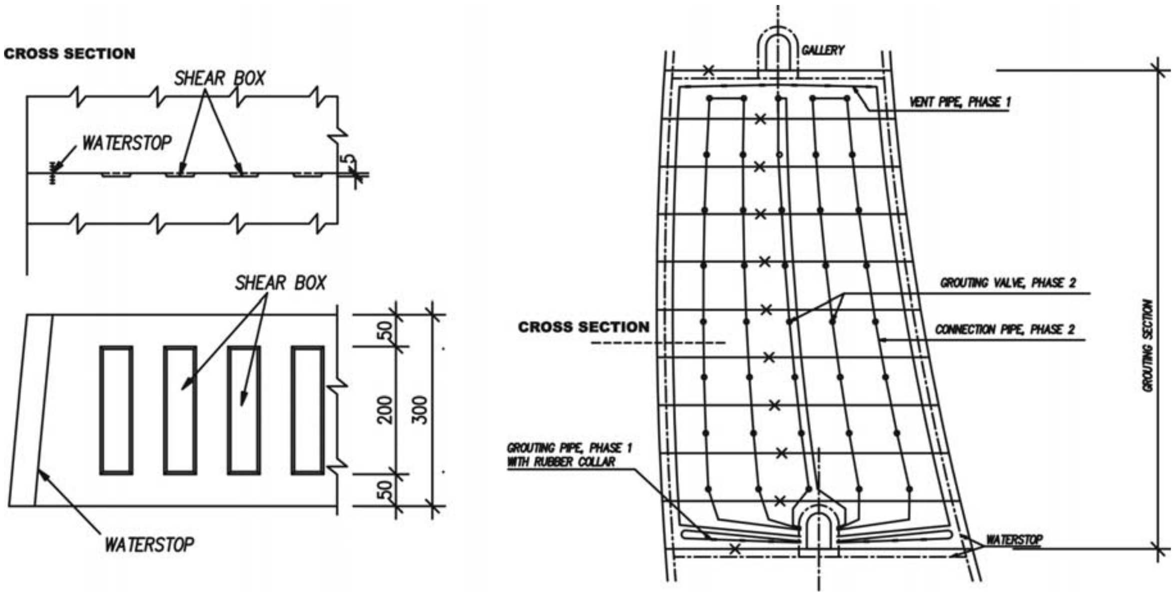

Figure 1: Cross Section block joint surface – Plane Section grouting system

After a certain time of concrete hardening and cooling the block joints are grouted under a monitored pressure. The separation of adjacent joint surfaces is carefully measured during the grouting process. Due to the grouting process it is intended to pressurize the joint and in case of an arched dam, due to the opening of the joint, the action of the entire gravity of each block is activated. After hardening of the grout the concrete blocks are “glued” together and for any subsequent loading the dam acts as a monolithic structure.

Static Dam Analysis

A common method to analyze the dams bearing behavior in detail is the finite element method. The loading sequence to be applied during the analysis and the design criteria for the structure is part of a design report and is normally approved for each structure under consideration of its specific site conditions.
In general the loading consists of dead weight, joint grouting, water load and temperature changes. According to these loading steps the final stress distribution can be calculated (Fig.2).

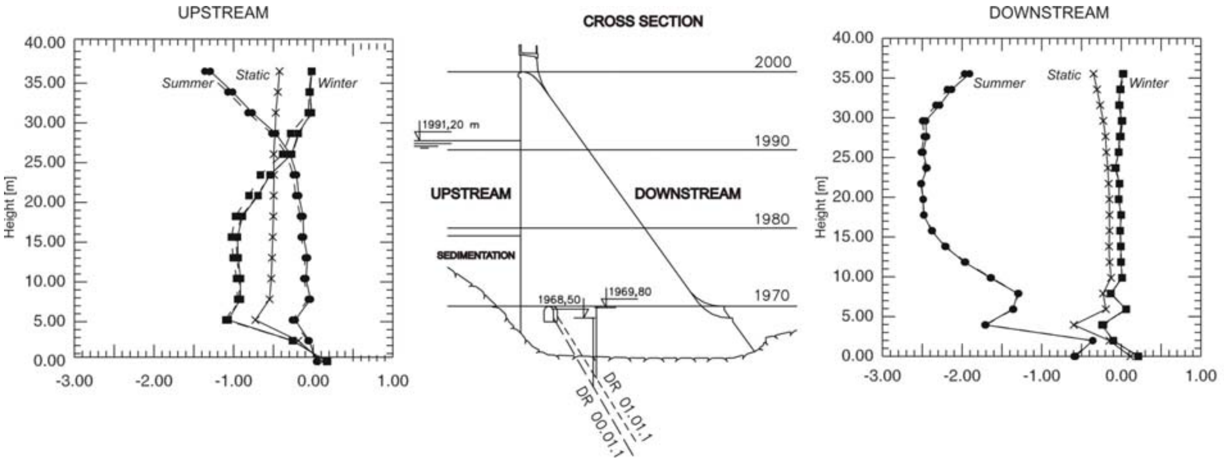

Figure 2: Hoop Stress distribution – full water pressure static, summer and winter temperatur

The calculated stress diagram presents tensile stresses in the upper part of the dam in horizontal direction, which is orthogonal to the block joints and impairs the arch action. Therefore it grew necessary to carry out the analysis under the conservative assumption of plane bearing behavior appropriately to a gravity dam. For this structure the investigation was intensified and with the help of discrete block joints the analysis was carried out. The results of this analysis show an opening of block joints. Due to the opening a redistribution of forces took place. Due to the additional movement to the downstream the block joint appears closed again.

Dynamic Dam Analysis

The general building codes do not cover outstanding structures, therefore guidelines are developed (ICOLD[1]) which for example in Austria[2] specify that dams have to pass Operational Basis Earthquakes (OBE) without considerable damages and have to survive the Maximum Credible Earthquake (MCE) without uncontrollable loss of water. The OBE corresponds to an earthquake with a return period of 200 years, the MCE is based on results of statistical analyses, research work in historical earthquakes and geological considerations.

As an example, results of the earthquake analyses of Wiederschwing Dam[3], with a height of 30m, is presented. The dynamic analysis is carried out with two discrete block joints modelled. Due to the nonlinear structural behaviour the Newmark direct time integration scheme is used. The resultant stress distribution, due to the opening of block joints, gives additional vertical tensile stresses at the up- and downstream surface of the dam (Fig.3).

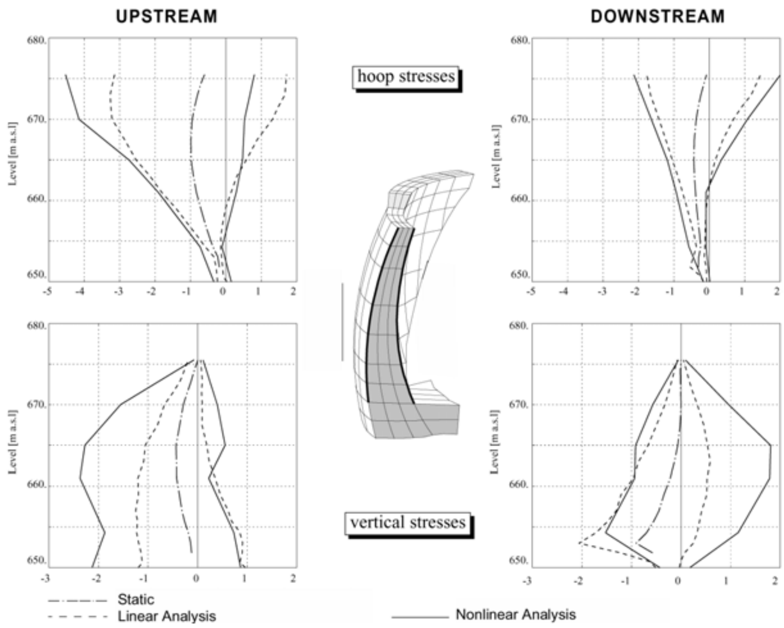

Figure 3: Stress Distribution for Static, Linear Dynamic and Nonlinear Dynamic Loading

Joint Opening at the Dam Base

To attribute for discontinuities at the dam base the behaviour of Schlegeis arch dam, a large dam with a height of 131m, was intensively investigated[5]. For the dam an upstream sealing element was constructed to reduce the uplift water pressure. However, due to loading of the dam joints in the rock foundation open and lead to water pressure uplift.

The opening of a base joint is simulated with a numerical model. Based on these results the abutment stability analysis is carried out. As a consequence of the discussions in the dam community and the endeavour to make results available for comparison reasons of such essential behaviour a benchmark workshop was devoted especially to analyze with different numerical procedures the ‘same problem’. Within the range of plausible different assumptions based on engineering judgement the results were in good accordance.

The results of the analyses are published in the ICOLD proceedings and can also be retrieved from the IALAD[4] network work package 2 and 3 respectively.

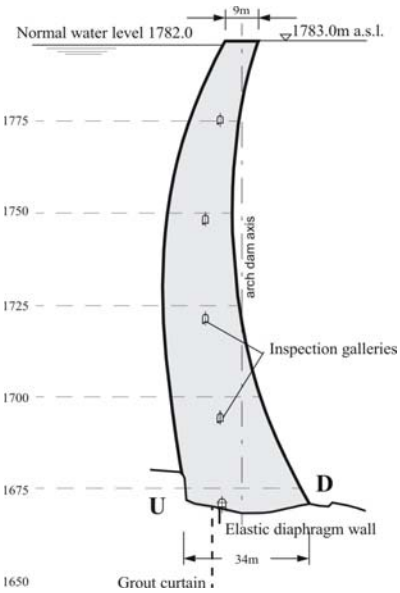

Figure 4: Schlegeis Dam Cross Section

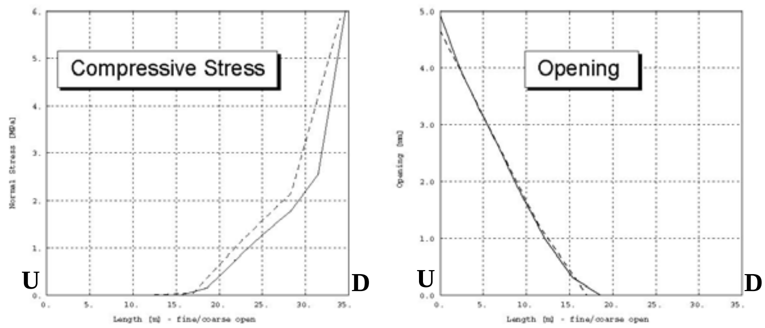

Figure 5: Abutment Stress Distribution and Joint Opening

Conclusions

Due to the fact that commercial programs are not able to allow for modeling of the entire construction sequence, special adaptation and modification with pre- and post-processing routines are necessary to been written. Though commercial programs have a quality control upon their programs, due to established (assumed with engineering judgment) boundary conditions gained results by different employed programs might vary significantly. To account for this circumstances especially for the dam engineering community benchmark workshop are established under the auspices of ICOLD, which is a valuable source of procedures.
Though many problems in conjunction with joints are able to be solved, under certain circumstances the possible numerical behavior of block joints is not satisfying to the necessary extent. An algorithm to allow only orthogonal joint opening without shear deformation would be helpful under an ultimate shear resistance. Such an algorithm would be helpful for further investigations, especially for dynamic loading conditions to account for high vertical tensile stresses in the concrete column.

References

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5. Zenz G., Aigner E., 'Uplift Pressure and Stress Analysis of an Arch Dam and Foundation - Comparison of Results', Vth Intern. ICOLD Benchmark Workshop, Denver, Colorado, 1999.