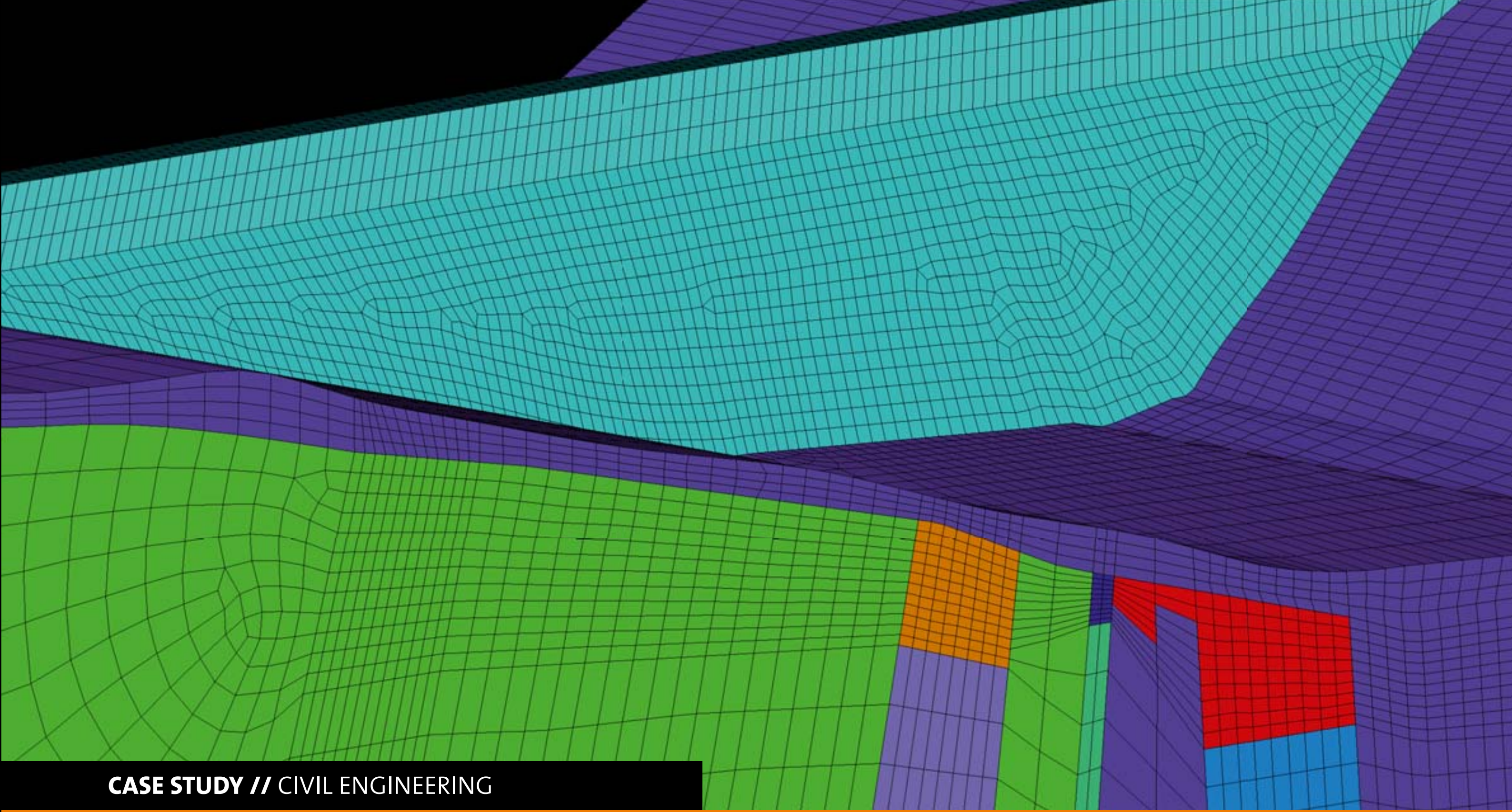

HRB WALDBÄRENBURG: FIRST RCC DAM EXPERIENCE IN GERMANY

Thermal and structural analysis with optiSLang help to plan the first Roller Compacted Concrete (RCC) dam in Germany as part of the national flood control programme of the Federal State of Saxony.

Project introduction

No RCC dams have been built in Germany to date. HRB Waldbärenburg could be the first one. The RCC dam technology has been chosen as it provides environmental advantages against other design alternatives: essential lower impacts in nature and scenery, shorter time of construction and a better ecological continuity through the dam. Some challenging aspects that need to be faced during the design and construction of the 40m-high dam are the short target RCC construction period (3 months) and the relatively extreme environmental conditions at the site during winter time. The use of a high fly-ash RCC mix concept has been proposed to reduce the heat generated in the concrete mass and to extend the setting time of the mix. A preliminary thermal and structural analysis was conducted in order to analyze the sensitivity of various parameters in the dam design.

Thermal & structural analysis

The numerical simulations were conducted with the FEM program ANSYS and optiSLang as transient thermal-mechanical coupled analyses on the 3D model of the dam structure and a connected rock section. The non-linear finite element analyses consider the evolution of temperature and mechanical resistance depending on time and location within the dam structure. The calculations were carried out as load history calculations simulating the progress of dam construction in each of the 30 cm thick layers as well as the subsequent five years of operation.

Methodology

Due to the complexity of the interaction between material parameters and the nonlinear analysis, the FE model was built parametrically. With the help of the optimization platform optiSLang, by conducting a sensitivity analysis it became possible to calculate different variants and to analyze the dependence between the resulting values and the input variables.

The goal of this sensitivity analysis was:

- identify those input parameters which influence mainly the concrete tensile stress forced by hydration
- analyze trends, such as changes in input parameters modifying the concrete tensile stress
- provide meaningful variation ranges for the input parameters

The predictive quality of the calculation results of the sensitivity analysis exceeds clearly those of a single calculation. The evaluation of the results considers particularly the tensile stresses in the concrete due to hydration. For this, at each time step, the current main tension stresses in the dam were compared with the current concrete tensile strength.

Input data

Within the sensitivity analysis, 100 designs were calculated using the optiSLang Latin Hypercube sampling. Here, all input parameters were changed in each design to have on optimal resolution of the design space as well as minimum correlation errors in the correlation analysis, which identifies the most import input variable. optiSLang controls the process of modifying the parameter and calling ANSYS to automatically solve the 100 designs as well as the statistical post processing to identify the important parameters.

Thermal analysis and estimated stress development

In the transient thermal analysis, influences of the seasonal changes of outside air temperature (reference data from the planned site), the heat radiation, the evolution of heat hydration and the temperature of the fresh concrete were considered. The evolution of heat hydration was calculated as a function of the level of hydration. Here, the maturity function of Arrehnius et al was used. This functionality was implemented in ANSYS using ANSYS APDL programming language.

The analysis of hydration is fundamentally determined by two major time and space dependent physical processes. This is, on the one hand, the temperature evolution and, on the other hand, the evolution of concrete resistance due to hydration. During construction, the concrete is strongly heated by hydration. At the same time, the concrete is cooled by convection on the outside. Therefore, the concrete expands more inside than on the outside causing compressive stresses inside and tensile stresses on the outside. After construction, the concrete reaches its maximum temperature in the core structure (Figure 1) and, by that time, has already reached a much higher resistance than in the heating phase. As a result, the stress conditions reverse during the cooling phase in the subsequent years. Now there is tensile stress within the building structure and compressive stresses on the outside. Figure 2 shows the distribution of tensile stresses directly after the construction of the dam and after 5 years.

Conclusion

As a result of the sensitivity analysis, it became obvious that the amount of maximum tensile stress on the outside (water- and air-side) of the concrete as a result of hydration especially dependents on:

- horizontal distance between the vertical joints
- start of placing the concrete
- coefficient of thermal expansion

Thus, the major influences are structural and technological parameters. Furthermore, the results show that the maximum tensile stress on the concrete in the inner structure as a result of hydration is particularly influenced by:

- specific heat capacity of the concrete
- heat quantity of the concrete
- coefficient of thermal expansion

It mostly depends on the mixture and quality of the concrete. Only with this degree of diagnostic characterization of the thermo-mechanical analysis it is possible to truly understand the controls on the evolution of the tensile stresses and concrete tensile strength over time. With this approach, a predictive model for the evaluation and design of RCC dams is developed. By use of the predictive model, the RCC design as well as technological aspects can be optimized to provide the required safety levels.

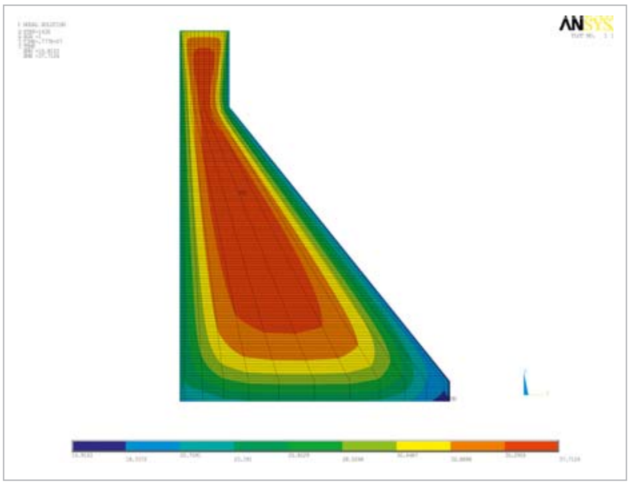

Fig. 1: Estimated temperature distribution after RCC placement

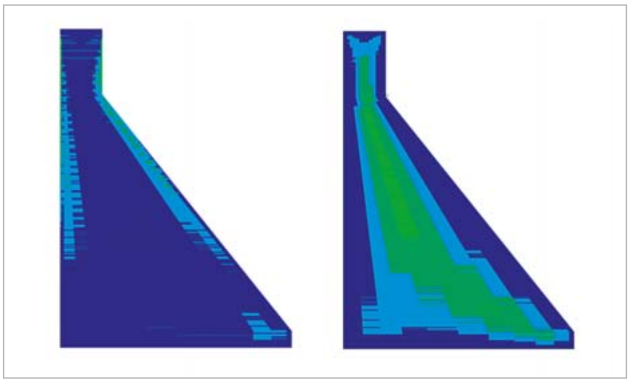

Fig. 2: Distribution of tension stresses, left: after RCC placement, right: after 5 years

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