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HRB WALDBÄRENBURG: FIRST RCC DAM EXPERIENCE IN GERMANY

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SUMMARY

No RCC dams have been built in Germany to date. HRB Waldbärenburg could be the first one. This project is part of the national flood control programme of the Federal State of Saxony in Germany and will go into the approval procedure at the end of 2012.

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. An overview of the general time schedule and further steps leading to the final implementation of the project are presented in this paper.

Some challenging aspects that need to be faced during the design and construction of this 40m-high dam are the short target RCC construction period -3 months– and the relatively extreme environmental conditions at the site during winter time. A preliminary evaluation on a possible dam lay-out and construction planning has been outlined and is presented here. In addition a discussion on potential suitable materials and RCC mixes has been initiated. 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 has already been developed showing the sensitivity of various parameters in the dam design.

1. PROJECT BACKGROUND

Within the scope of the investment programme for flood prevention in the federal state of Saxony/ Germany the operation unit “Upper Valley of River Elbe” of the Dam Authority of Saxony plans the construction of 5 new storm water retention basins in the eastern part of Erzgebirge. One of these will be the storm water retention basin (in German: “HRB”) Waldbärenburg, located near by the city of Altenberg in the valley of the creek “Rote Weißeritz”.

Compared to the other storm water retention basins in the Eastern Erzgebirge the characteristics of HRB Waldbärenburg will be a gravity dam built in concrete with a stepped downstream face and a stepped spillway integrated in the dam itself. The very most of all other dams in this region are rock-fill dams with spillways beneath the dam in the valley flanks.

It is decided to build the dam of HRB Waldbärenburg in RCC mainly caused by following two reasons:

- The interference into the environment by land use is much smaller than in case of a rock-fill dam
- The interference into the environment during construction works (noise, dust, artificial light) is much shorter than in case of CVC-dam and rock-fill dam.

In case of an arising flood HRB Waldbärenburg will reduce the volume of an incoming HQ_{100} from 22,4 m³/s down to 1 m³/s.

2. MAIN DESIGN FEATURES OF THE RCC DAM

2.1. GENERAL DESIGN ASPECTS

The dam will close the creek “Rote Weißeritz” only for storm water retention – no other usage is foreseen. Therefore the basin will be a “green” one with no water inside during most of the time. Statistically it will be completely filled one time in 100 years.

The location of the dam is more than 650m above sea level with long frost periods (November to April), heavy snowfall and extreme temperatures down to –20°C and lower. But in summer temperatures may rise up to +30°C and higher.

In the subsoil there have been investigated 3 geo-technical remoulded zones: one in the contact area between the gneiss and the granite, one inside the granite in the lowest part of the valley, called granite-porphyry-vein, and the third one in the eastern flank of the valley is a zone of hydrothermal alteration of the gneiss. Beneath of these remoulded zones the subsoil/ rock is not waterproofed but interspersed by jointing.

Because free surface water as well as subsoil water in the dam area is flowing out of moor areas it is acid and therefor harmful to concrete. According to European water framework directive as well as nature preserve laws the dam must be constructed to be passed-through by all kinds of animals.

2.2. MIAN FEATURES

Caused by the single function: flood retention, the dam of HRB Waldbärenburg will get following operational equipment:

- 2 redundant reservoir outlets as 2 pipes DN 800 with valves on upstream and downstream end of the cross section,
- 1 passage tunnel H*W = 3.05m*4.25m with gates on upstream and downstream end of the tunnel,
- 1 inspection tunnel parallel to the passage tunnel,
- a stepped spillway in the centre of the dam length (width= 16m),
- a short tumbling basin with outlet river channel at the same location as the former creek bed,
- 2 bridges, one over the spillway and one over the outlet river channel,
- a crest way, only for operational traffic, and
- an operational building and maintenance yard founded on the RCC test field.

Maximum height: 38.90m
Crest length: 265m
Max foot width: 26.30m
Crest width: 5.18m
Downstream slope: 1:0.8
Upstream slope: vertical
Basin retention volume: 1.6 mio.m³
RCC volume: 78 000m³
CVC volume: 9 000m³

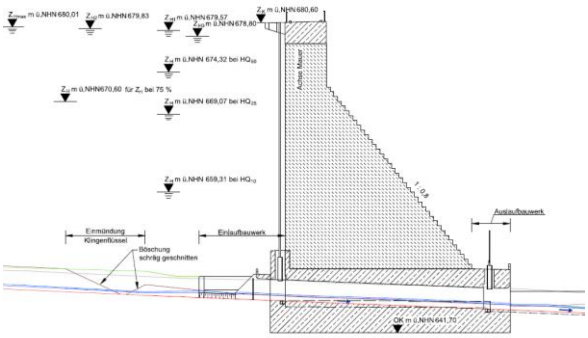

Fig. 1
Dimensions and cross section of the proposed RCC dam

The outlets, the passage tunnel and the inspection tunnel will be built in conventional reinforced concrete in one single block together before the RCC placement starts. The structures on top of the dam (crest way, spillway, bridge) as well as those on the downstream side of the dam (splitter walls, tumbling basin, outlet channel, bridge) will be built after finishing the RCC dam and also in conventional concrete.

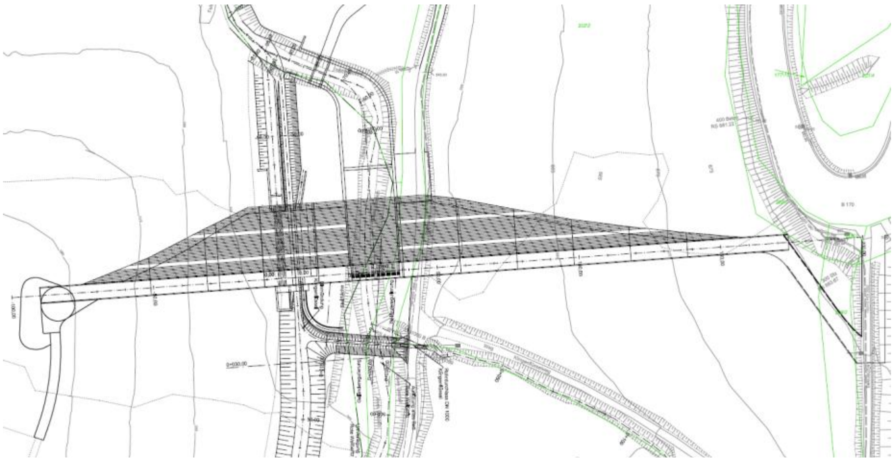

Fig. 2
Plan view of the proposed RCC dam

Because of being a dry/ green basin the RCC-dam must have special control and monitoring systems, especially for checking the leak tightness.

The above mentioned 3 geo-technical remoulded zones will be bridged and upgraded by replacing the softer soil-, gravel- and rock-areas by plain concrete in depth down to 5 m.

3. RCC DAM CONCEPT

The main aim of the RCC design and construction concept that will be used at HRB Waldbärenburg is to achieve a simple dam that can be built rapidly. It should also meet the national standards for safety on concrete dam structures. As RCC is a new technology in Germany some methodologies and specifications shall be imported from other successful international experiences.

3.1. INTRODUCTION

Following the development of RCC dams during the past thirty years, two design approaches seem to be mostly used at present around the world: lean concrete mixes or very workable mixes. The second option has been selected for this new dam. There are several reasons behind this decision, mainly:

- The simplicity of the associated construction methods,
- High workability, uniformity of fresh properties and lack of segregation,
- The good in-situ quality and durability of the hardened concrete,
- The availability of commercial fly-ash in the country, and
- Shorter construction period and economy.

The European experience is clearly inclined towards this option. Latest achievements on modern RCC dam construction show that the design and environmental criteria required for this dam will be met by the proposed structure.

An initial stage for transfer of technology and training period on specifics of the RCC concept will be required in this project. A preliminary investigation on potential concrete materials will be developed in advance during the tender design stage to confirm the specifications and the availability of adequate aggregate.

3.2. SIMPLE DAM LAY-OUT

A preliminary dam design has been developed in some detail leading to the final project approval by the National Dam Safety Authority. At this stage special focus has been put in those aspects that provide a simple concrete dam lay-out. The elements that could create interference with the RCC have been either removed or located in a block that will be built in advance. As has been indicated before, in this block the river diversion culvert will be provided as well as the bottom outlet and the service access. Any consolidation and foundation treatments (possibly including foundation replacement blocks) should be also completed before the RCC placement starts in the lower part of the dam.

Bearing in mind that the dam is solely a flood control structure and that most of the time there will be access to the upstream side, the idea of removing the traditional longitudinal inspection gallery has been positively discussed. The drainage of the dam will be formed through the RCC. Several collectors will be directed towards the downstream side at the respective location of the transverse joints. These drains could consist of PVC pipes placed in advance on the foundation and embedded in dental concrete at the lower part of each joint. The RCC will be then placed against them as the dam is raised.

The distribution of the instruments for monitoring the performance of the structure will be simplified as much as possible. Specific locations for the instruments and guidance of cables will be selected where the information can be recorded with minimal interference with the RCC placement. All parties involved are very much aware of the importance of achieving a placement area for the RCC as free as possible to facilitate speed of construction.

3.3. SPECIFICATION OF THE RCC MIX

The main objectives that should meet the RCC mix to be used in this dam are similar to those that would be required in a traditional concrete dam: strength, in-situ impermeability, density and durability. To that end, it is important that the fresh RCC mix does not segregate during transportation and placement, the paste should easily flow to the surface during compaction and the setting time of the mix needs to be retarded to keep the concrete fresh until the next layer is placed on top of it.

Based on previous similar experiences it has been anticipated that the total cement and fly-ash content of the RCC mix will range between 160 and 200kg/m^3. The proportion of fly-ash will be 65% to 70%. When using well-controlled cement and fly-ash materials, as it is expected to be the case in this project, the main variable affecting the mix properties is the quality of the aggregates. Special efforts will concentrate in using aggregates with optimised shape and grading, similar to those that have been successfully used in other RCC dams. Coarse and fine aggregate meeting the specifications will lead to a low water demand. In those cases a water/cement+fly-ash ratio in the order of 0.50 or less can be expected. It is important that the technical specifications of the concrete materials cover these issues clearly, including recommendations on type of plants and equipment that are more suitable to meet the required properties.

A maximum size of aggregate of 40mm will help to control segregation and the percentage of fines in the fine aggregate (fines passing 0.075mm sieve within those finer than 5mm) could be as high as 18%. Usually a fine/coarse aggregate ratio of 32% to 35% will be used. A source of limestone aggregate would be technically the preferred option in terms of thermal behaviour. If adequate crushers are used, crushed limestone aggregate also provides the amount and quality of fines that are required for a good quality RCC mix.

RCC is a zero-slump concrete. The consistency of the RCC will be measured by use of a modified VeBe consistometer. In order to meet the requirements of the fresh mix it is advisable to design the RCC mix with a Vebe time between 8 and 10 seconds.

A retarder and water-reduction admixture will be also incorporated in the mix. The target will be to keep a low water demand as mentioned above and an initial set of less than 15 to 20 hours. These parameters will be investigated along a staged trial programme that will be initiated during the design phase.

3.4. DAM CONSTRUCTION ASPECTS

The construction of this particular RCC dam will be the first experience in Germany and the short construction period will not give any allowances to learn by testing different methodologies. Therefore it is recommended that the proposed construction methods are previously approved and discussed well ahead during the construction planning stage. It is important that a preliminary construction methodology shall be included in the tender documents for information to potential Contractors. This could be the base for evaluation of proposals, in addition to any other alternative one that might be proposed during the tender period.

The proposed construction methodology for HRBW will be based on the assumption of continuous RCC placement from the start at the lowest foundation level up to the dam crest. During this period the work at the site shall be arranged without interruptions, 24 hours/day, 7 days/week. Continuity leads to speed of construction and a better in-situ quality is achieved as the potential discontinuities between layers are eliminated. On this base, the RCC placement of the 155 layers in the dam should be planned at an average rate of 2 layers/day. Some unplanned interruptions may occur as for example: plant breakdown, environmental conditions, correction of inadequate procedures or any other unplanned issues. Therefore a total construction time of 90 days has been estimated for the RCC. To meet these targets with enough margin of safety, the capacity of the concrete production plants shall be at least 120m^3/hour. With such output and assuming an accumulated utilisation factor of 65% of the construction chain, the layers with maximum volume (ca. 1 500 m^3/layer) shall be placed in a maximum time of 15 to 20 hours, thus in fresh conditions and within the initial set time defined above.

Following the experience in similar RCC dams, the most adequate system to introduce the RCC in a dam of this size is to use a kind of telescopic and swinging conveyor as those that are commercially available in the local and international market. Trucks will distribute the concrete along the placement area to the point of spreading and compaction. The RCC shall be placed in horizontal layers of 300-mm thickness after compaction. Spreading and compaction will be arranged in adjacent lanes parallel to the dam axis. The same construction sequence will be used in each new layer.

In order to provide continuity to the placement, the formation of transverse joints is made by introducing a galvanised steel plate or simply a hard plastic sheet in the fresh RCC at the location of the joint. This activity is done after the RCC has been fully compacted by the rollers to avoid any interference. When this operation is made in the same section in every layer, the material that has been inserted and left in place acts as crack inducer and forces the crack to be formed at this location. The sealing of the joints is made as in conventional concrete dams with a water-stop bridging the joint plane embedded in concrete at the upstream face. For a dam of this height a single waterstop should be enough guarantee of impermeability at the transverse joints. A drain is provided downstream of the waterstop to collect any potential seepage.

The intended RCC mix can be consolidated around waterstops, drains or any other embedded element by traditional immersion vibration. The same procedure will be specified against rock abutment and formwork. As has been already tested in other dams, if the mix is well designed and the construction procedures are well trained, the immersion vibration of RCC does not require any additional grout to be added at the placement. This leads to an extremely simple RCC dam design concept and a very efficient construction.

4. THERMAL & STRUCTURAL ANALYSIS

The numerical simulations were conducted with the FEM program ANSYS ® 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.

4.1. 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 [1], 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:

- to identify those input parameters which influence mainly the concrete tensile stress forced by hydration,
- to analyze trends, such as changes in input parameters, modifying the concrete tensile stress,
- to 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. Here, the quotients were generated between the current F_Assess_S1 stresses and the current concrete tensile strength corresponding to (Eq. 1) each finite element:

$$F\_Assess\_S1 = \sigma_1(t) / f_t(t) \qquad \text{(Gl 1)}$$

with: $\sigma_1(t)$ – main tensile stress
$f_t(t)$ – current concrete tensile strength

4.2. INPUT DATA

In Table 1, the main input data of the thermal-mechanical sensitivity analysis are documented. Within the sensitivity analysis, 100 designs were calculated using the optiSLang® Latin Hypercube [1] 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.

Input parameter	Parameter type	Variation	
		MIN	MAX
Start date of RCC	discrete	1.4. / 1.5. / 1.6. / 1.7. / 1.8.	
Initial temperature of Fresh concrete	continuous	10°C	20°C
Thermal quantity of concrete	continuous	17000 J/kg	28000 J/kg
Initial thermal conductivity of concrete	continuous	1.4 $W \cdot m^{-1} \cdot K^{-1}$	2.4 $W \cdot m^{-1} \cdot K^{-1}$
Initial special heat conductivity of concrete	continuous	750 $J \cdot kg^{-1} \cdot K^{-1}$	1250 $J \cdot kg^{-1} \cdot K^{-1}$
Density of concrete	continuous	2100 $kg.m^{-3}$	2500 $kg.m^{-3}$
Initial heat coefficient of concrete expansion	continuous	0.000014 K^{-1}	0.000020 K^{-1}
Concrete quality (1-ax. Compressive resistance)	continuous	15 MPa	25 MPa
Distance of joints (resp. block size)	continuous	15 m	30 m
heat transfer coefficient	continuous	20 $W \cdot m^{-2} \cdot K^{-1}$	45 $W \cdot m^{-2} \cdot K^{-1}$

Table 1
Summary of variables varied in the thermal-mechanical sensitivity analysis

4.3. 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 [2]. 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 3) 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 4 shows the distribution of tensile stresses directly after the construction of the dam and after 5 years.

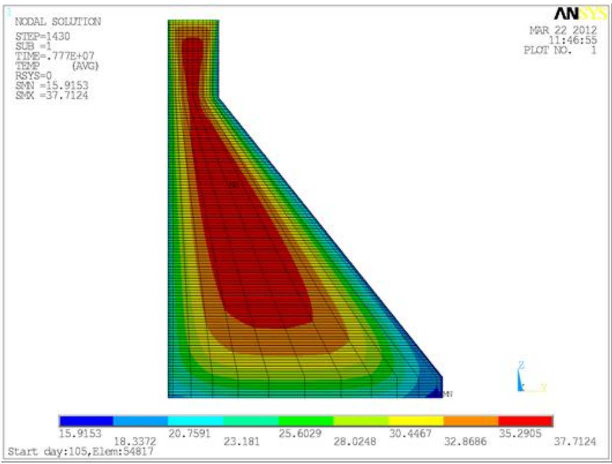

Fig. 3

Estimated temperature distribution after RCC placement (start date 1.04)

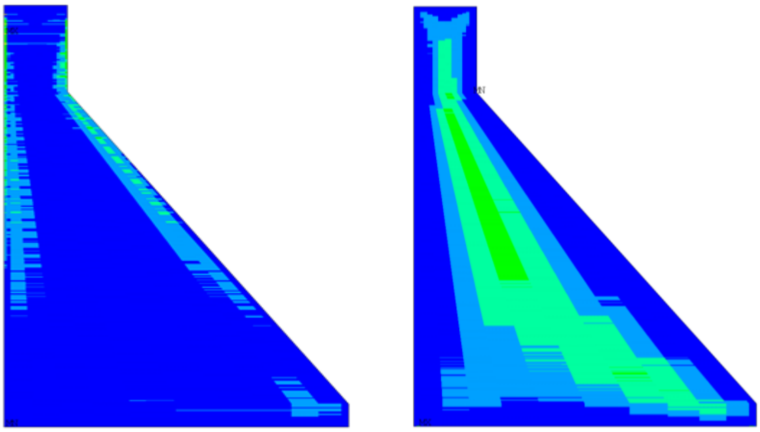

Fig. 4

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

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:

- the horizontal distance between the vertical joints,
- the start of placing the concrete, and
- the 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:

- the specific heat capacity of the concrete,
- the heat quantity of the concrete, and
- the coefficient of thermal expansion.

and 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.

5. CONCLUSIONS

Being German engineers we first of all had to have argue ourselves into designing an RCC-dam, because we haven't done it ever before. This is done positively.

Secondly we had to persuade our client of designing, approving and building a concrete dam without water in the basin most of the time and currently in Germany unknown method (RCC). This is done positively.

On third we have to assure the authorities and all involved non-government organisations as well as all involved people itself in Germany – and we have a lot of them – of building an RCC-dam at this location is the very best solution for reaching the objective: protection of human life in case of flood waters. This is currently on the way and we are awaiting the positive answer in 2013.

REFERENCES

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[2] Madaleno, A. *"Erfassung von Verformungs- und Spannungszuständen im jungen Beton infolge Temperatur". Dissertation, Bauhaus-Universität Weimar, 2002*