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Design and Construction of the Dam Sealing Structures of Arkun CFSGD

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ABSTRACT:

Arkun Concrete Face Sand-Gravel Fill Dam (CFSGD) is one of largest sand-gravel fill dams of the world. The dam is founded on a deep alluvium layer sealed by a deep cut-off wall. The partly jointed rock foundation was treated by a classical grout curtain. The dam shows a concrete face slab for which a special joint design was developed. The connection of cut-off wall and surface slab is formed by a articulated horizontal plinth.

Since the dam is founded on a deep alluvium a 1.0 m thick and up to 70 m deep cut-off wall had to be applied. Contrary to design expectation the cut-off wall developed high compressive strength and a limited deformability. Therefore, an intensive laboratory test program was initiated in order to clarify the actual elasticity modulus and compressive strength development of the cut-off wall.
The grout curtain was extended compared to the detail design since the rock foundation shows partly vertical, open joints which could only be sealed by a large number of inclined drillings. Special attention was paid to the interface between alluvium and rock where the cut-off wall was integrated into the rock foundation.

Blocky rock structures, strong joints and coarse grained natural alluvium handicapped the drilling and sealing works, persistently. However, the monitoring results of the seepage and water pressure conditions downstream of the sealing structure confirmed its functionality.

During construction the joint design was optimized according to recent international dam construction experiences and the state of the art. A second upper copper waterstop was added. Moreover, all the joints were covered by a PVC cap filled with fly-ash.

The paper will contain an evaluation of the functionality of the sealing structure on basis of the monitoring data taken during the impoundment period. Details concerning the three different sealing structures will be provided for both design and construction aspects.

Keywords: CFSGD, CFRD, sand-gravel, grouting, cut-off wall, face slab, joints

1. INTRODUCTION

Arkun Dam and HEPP is the one of the largest concrete face sand-gravel rock fill dams of the world. Arkun Dam is located the North-east of Turkey between Erzurum and Artvin townships as shown below in Figure 1. General information of the dam and the seepage control design is explained in Haselsteiner et al. (2012).

Arkun Dam is founded on 73m depth deep alluvium material. In order to seal the underground the cut-off wall structure had to be constructed underneath the articulated plinth line of the dam. Another component of the main sealing system is the grout curtain which was applied within the rock mass according to classical approach concerning refusal criteria and grout mixes but applying higher grouting pressures. The completion of sealing system is formed by the face slab and its perimeter and face slab joints.

In the course of continuous optimization steps parts the design of the sealing system was changed during ongoing design and construction works also in order to meet the local conditions. Especially the foundation treatment consisting of grouting and the cut-off wall needed to be re-evaluated in correspondence of the actual geological conditions and information.

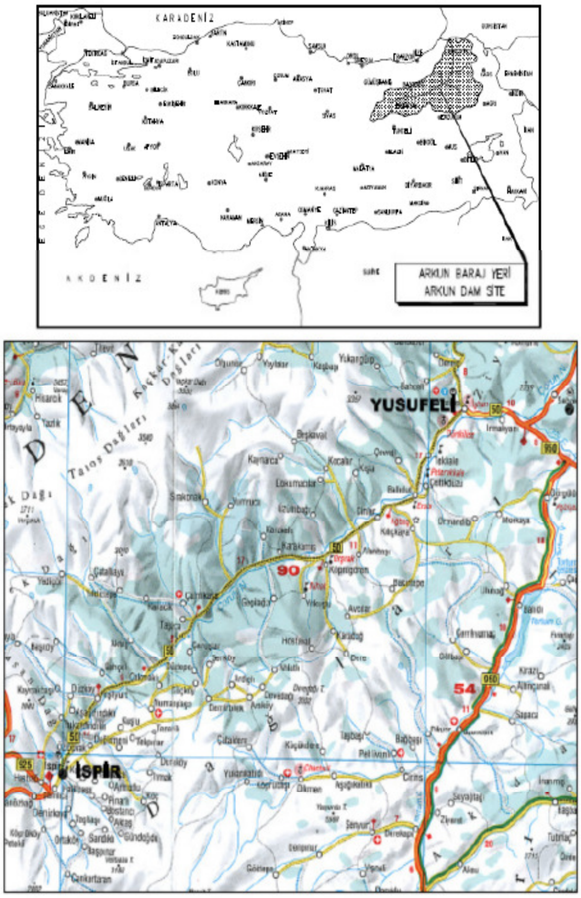

Figure 1. Location of the Arkun Dam Project

2. MAIN SEALING STRUCTURES OF ARKUN DAM

Main three components of the sealing system of the Arkun Dam can be described as below:

1. Cutoff wall structure that is integrated into the bed rock
2. Grout curtain in the rock, adjacent to the cut-off and underneath the abutment plinth line
3. Face slab with the perimeter and face slab joints

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2.1.Cutoff Wall Structure

Arkun dam has been founded on thick and blocky Çoruh River alluvium material. The maximum depth of the alluvium at the dam location reached over 70m and more which made the structure to one of the deepest of it kinds at least in Turkey. Also the alluvium blocks showed high strength so that it is very hard to penetrate or excavate it with conventional methods. Generally, the alluvium includes silt-sized grains to block size grains.

For the construction a trench-cutter was applied. Before starting the work with the trench-cutter the geological conditions were explored by additional conventional drillings (Figure 2). The aim of it was to have a better understanding of the boundary of the bed rock and the interface between alluvium and bed rock. Contrary to the assumption in the detail design the rock boundary showed a slightly different shape so that the cutoff wall geometry needed to be adjusted.

Due to the blocky characteristics of the alluvium the works of the cutter were the hardest part since the cutter got stuck several times and the wearing of the machine parts was considerable. Figure 3 shows the cutter machine while drilling at the toe plinth line.

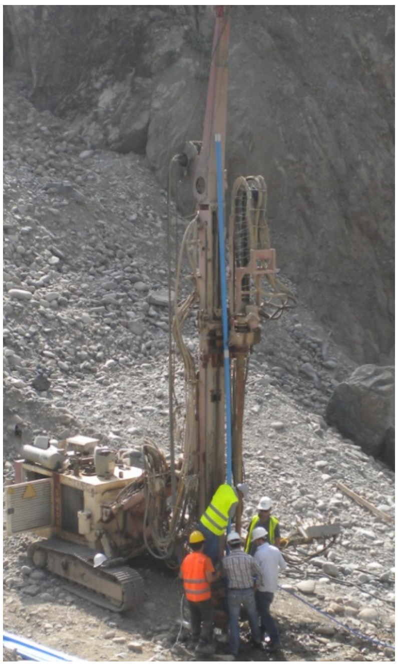

Figure 2. Exploration drilling

Figure 3. Cut off wall cutter machine

2.1.1. Construction Phases of The Cutoff Wall Structure

The cutoff wall structure was constructed in following phases:

- Preparation of the alluvium material/surface that is located under the toe plinth line
- Construction of the guide wall
- Excavation of the cutoff wall panels filling in the bentonite suspension
- Concreting of the panel blocks by tremie pipe

Before cutoff wall concrete works started a lot of plastic concrete tests had been carried out according to the Technical Specification of the detail design. A result of those tests were the determination of the engineering properties of the cutoff wall. As shown in Table 1, the Technical Specifications of the plastic cutoff wall concrete dictated quite a low amount of cement compared to the changed design as given in Table 2. Table 3 shows the engineering properties as assumed during detail design.

Table 1. Composition of the Cutoff Wall Concrete According to TechSpecs

Sand	73%	1086 kg/m3
Aggregate	19%	283 kg/m3
Filler	8%	119 kg/m3
Bentonite		60 kg/m3
Cement		120 kg/m3
Water		375 l/m3

Since test results were partly contradicting especially in regard to the elasticity modulus the amount of tests was increased and three independent laboratories were asked for performing the tests, two Turkish and one Austrian. The results of the tests were that the design was changed to a mix summarized in Table 2. Nevertheless, the engineering properties of the cutoff wall indicated a much higher elasticity modulus and higher compressive strength which was to attract stresses from the deformation of the surrounding compressible alluvium. Although, FEM-models indicated that cracking cannot be excluded and some seepage may pass through those cracks a seepage analysis showed that the consequences are tolerable.

Table 2. Composition of the cutoff wall after changing the design

Sand (kg)	950
Aggregate (kg)	238
Cement (kg)	220
Bentonite Slurry (lt)	60
Water (lt)	300

Table 3. Engineering properties of the plastic cutoff wall concrete and some test results

Permeability Value kf (m/s)	< 10^{-7}
Deformation Modulus (Mpa)	200-500
Uniaxial Compressive Stress (Mpa)	0,5-1

Permeability	5x10^{-7} cm/s
Viscosity	47 second
Modulus of Elasticity	210,7 Mpa for 29 days
Uniaxial compressive strength	1,83 M/mm^2 for 29 Days
Unit Weight	1,768 g/cm^3

As shown in Table 3 the first set of test results confirmed more or less the engineering properties predicted by the Tech Specs of the detail design. Nevertheless, during the quality control of the cutoff wall samples showed much higher compressive stresses as shown in Figure 4. Samples investigated in the universities showed quite a different development of the elasticity modulus compared to the governmental laboratory. This could be the reason that the samples for the universities were taken directly from site and the governmental laboratory prepared the plastic concrete in-house according to mix criteria.

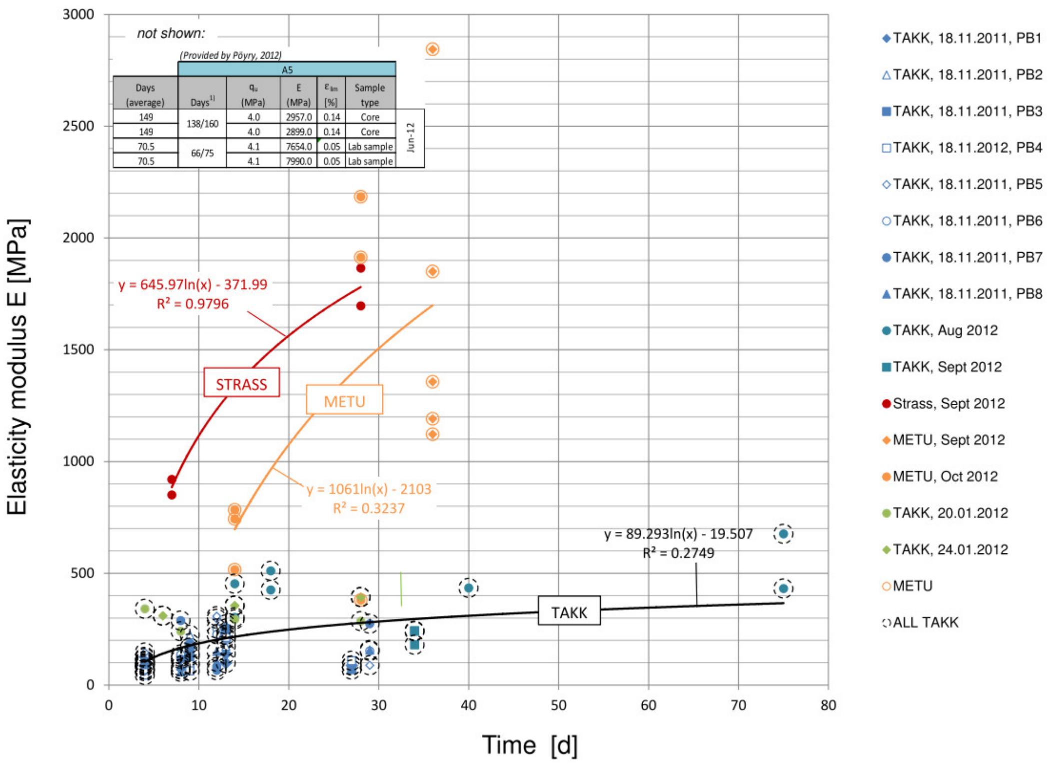

Figure 4. Elasticity modulus of plastic concrete samples after placement days

2.2. Grout Curtain

The grout curtain is another part of the sealing system of Arkun Dam. Volcanic rock masses dominated the Arkun Dam foundation. Especially the left bank abutment was affected by tectonic processes so that a strongly jointed rock mass is left. The dominating joint set is directed vertically which was unfavorable in terms of the designed vertical grouting drillings. Hence, inclined drillings were added in order to cross the vertical joints. In order to evaluate the natural rock mass permeability eight more deep exploration holes have been carried out.

The number and distance of grouting drillings was adjusted. Figure 5 shows general layout of the final grout curtain design.

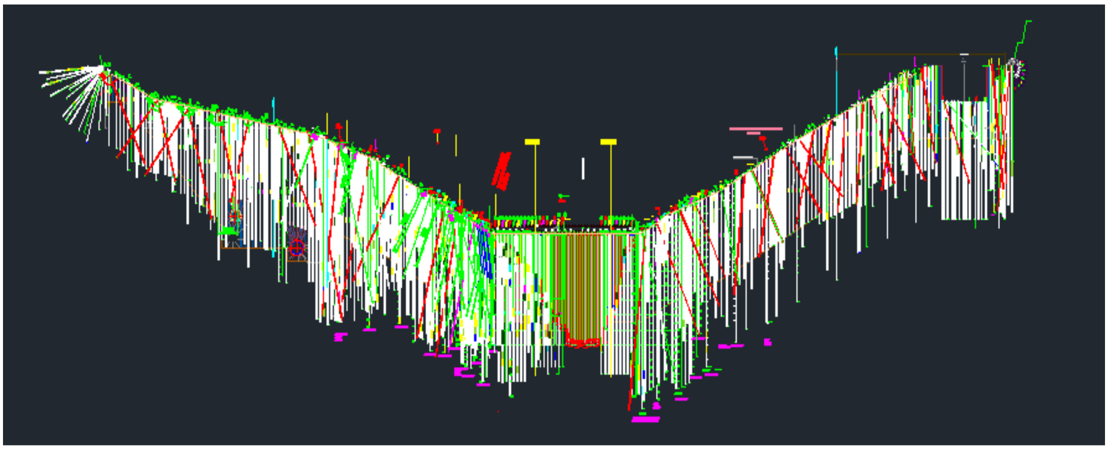

Figure 5. General view of grout curtain (from upstream to downstream)

2.2.1. Performance of the Left Bank Grout Curtain

The left bank is more geologically more difficult in terms of grouting compared to the right bank. This fact is also stated in the development of the control Lugeon tests and values carried out regularly after a grouting sequence was completed. Figure 5 shows clearly the success of the grout works at the left bank.

Although the Lugeon-value was already quite low before the drilling works started the design responsible engineers decided to perform grouting to reduce the permeability. The success is documented by a reduction of the Lugeon value from approx. 5 to less than one after grouting drillings were completed (Figure 6).

Since the Lugeon value is a quite soft indicator for the groutability of rocks the takes were also documented as shown in Figure 7. From the beginning grouting holes (P = Primary) to the cross check holes (CC = cross check) the takes were reduced from 173 kg/m to less than 10 l/m which is reflecting the filling of the drill hole itself, respectively.

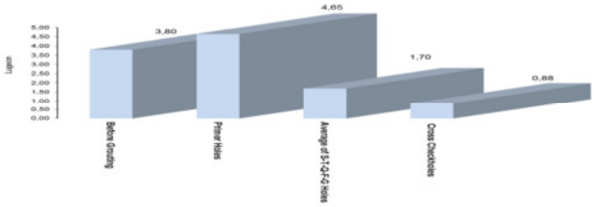

Figure 6. Evaluation of Lugeon values at the left bank

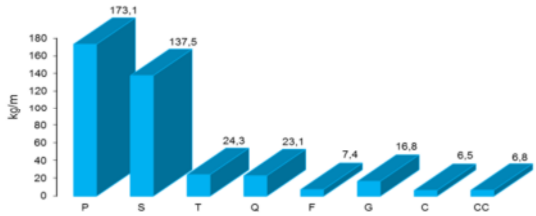

Figure 7. Grout takes at left bank from primary (P) to cross check holes (CC)

In the other hand grout take evaluation also should be evaluated. Figure 6 also shows the success of the grouting works according to the grouting phase situation.

2.2.2. Performance of Right Bank Grout Curtain

Figure 8 documents the success of the grouting works at the right bank. While natural rock mass permeability value reaches to 8 Lugeon the cross check hole shows an average Lugeon value smaller than 0.4 Lugeon on average. Figure 9 also shows the takes at the left bank according to the grouting drilling sequence which confirms the success of the works.

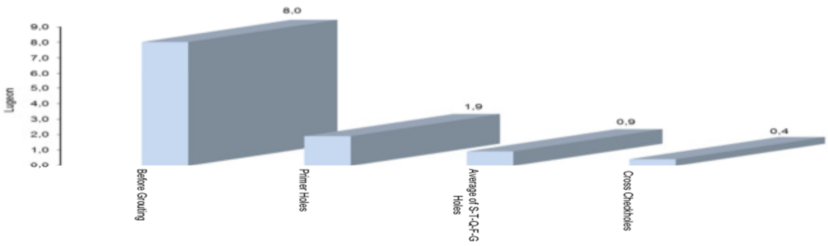

Figure 8. Evaluation of Lugeon at the right bank

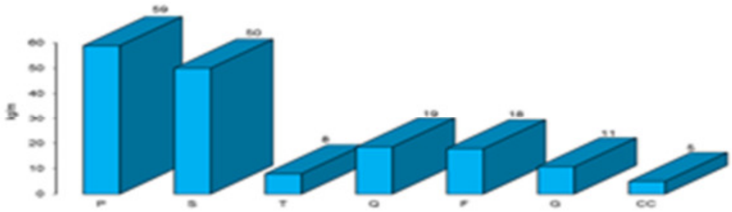

Figure 9. Grout takes at right banks from primary (P) to cross check holes (CC)

2.3. Face slab and Perimeter Joint Sealing Design

The initial face slab joints and the perimetric joint sealing design of Arkun Dam was re-designed as already mentioned. The detail design was optimized also in terms of adding more safety in form of an upper water barrier to the sealing system.

In order to connect the upper water stops to the concrete face bolts and steel frames were used with compressible rubber layers to guarantee the impermeability. The PVC plastic cover was applied on this upper copper water stop to form another water barrier.

The Fly-ash should seal the seepage path if flow occurs. As seen below Figure 8 detail design has been showed. Sections of the different main joint sealings are given in Figures 10, 11 and 12.

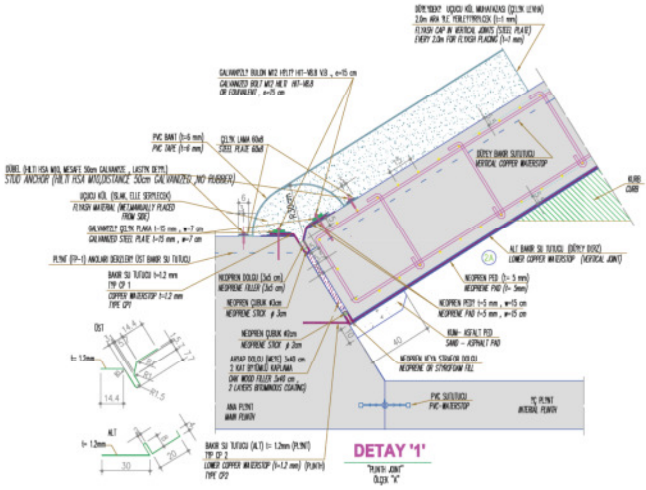

Figure 10. Connection details between face slab and toe plinth

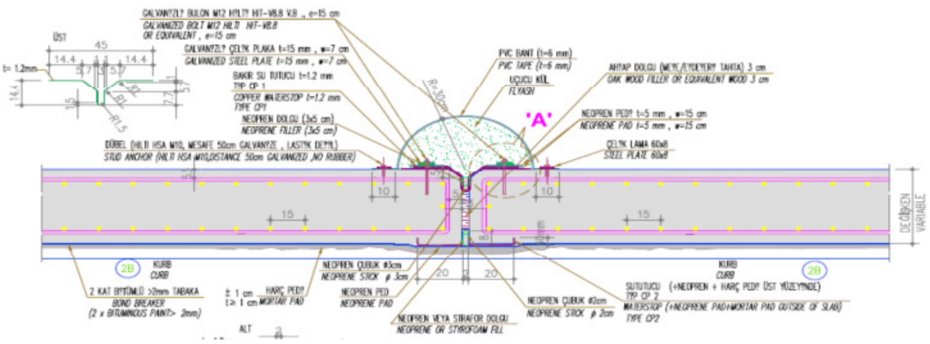

Figure 11. Extension joint detail design

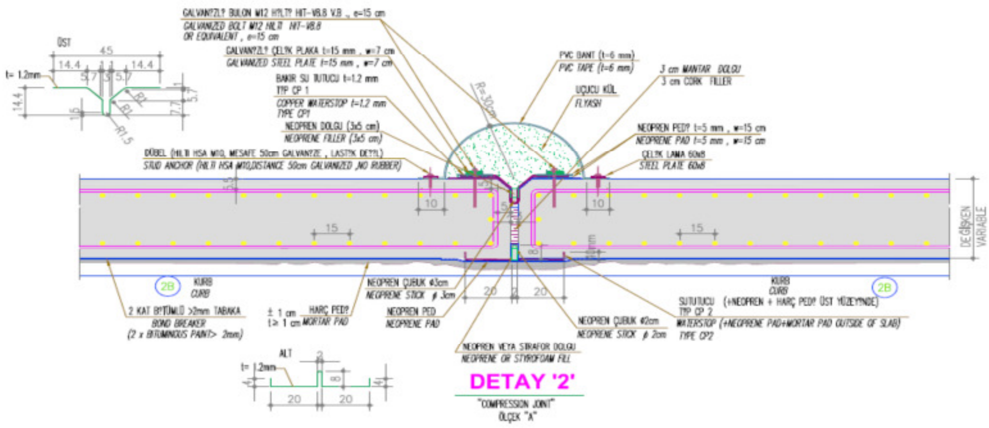

Figure 12. Extension joint detail design

- *Toe plinth line and face slab connection*

A sand-asphalt pad is placed in order to prevent cracking of the copper water stop; a neopren pad with 5 mm thickness and 15 cm width was used to protect the copper water stop from any damage in the interface. The lower copper water stop was placed as first barrier. The size and shape of the copper water stops was selected to standard Tech Specs and predicted joint opening. The neoprene fill and neoprene stick were used within the lower copper water stop to protect the copper from harmful deformations and a crack of the shank. The same function was overtaken by the oak wood filler. The upper copper water stop was installed corresponding to the same requirements as the lower copper waterstop.

- Vertical f*ace slab extension and compression joints connection*

The re-design concerning the vertical slab joints was similar to that one of the perimeter joint also in terms of the safety philosophy.

For the extension joints oak wood filler was used. For the compression joints cork filler was used to protect two face slabs from harmful deformations in form of spalling, cracking or similar effects.

3. CONCLUSIONS

The Arkun dam sealing structures works reliably as it is documented by the monitoring data during the first impoundment which started in December 2013. The seepage and water pressure instruments such as open standpipe piezometers and the vibrating wire piezometers indicate a high performance of the sealing system in general.

At the time of the preparation of this paper the dam behavior was observed for 3 months after impoundment started and the results confirm a high performance of the dam body not only in respect of seepage control but also deformations.

The performance of the sealing structures can be evaluated regarding different aspects as follows:

- The open standpipe piezometers do not show a significant rise nevertheless one of them indicated slight rise which was considered to be a result of the seasonal rainfalls.

- The drainage holes of the drainage gallery do not show any seepage at all for the time being.

- Generally the vibrating wire piezometers do also not indicate a rising water pressure in the dam body. All the installed 27 instruments confirm that the seepage conditions are controlled at every location where measured. However, very single instruments located close to the cutoff wall downstream of it showed slightly increasing water pressures which may an indication that some smaller leakages occur, e.g., as results of cracks. The responsible engineers defined a maximum rise of 10 % of the upstream head as critical value for the instruments directly downstream of the cutoff wall. The maximum values reached 7 % at single instruments. The seepage control design is explained in Haselsteiner et al. (2012).

- The vibrating wire piezometers that were located close to the face slab and joints haven't indicated any increased hydraulic pressure. This is the most important indicator for the evaluation of the face slab tightness.

- The final Lugeon values for both banks reached values which are in correspondence of also the strictest design criteria for dams.

4. REFERENCES

Haselsteiner, R.; Kaytan, E.; Pamuk, R; Ceri, V. (2012): Seepage control design of the Arkun dam in Turkey. Hydropower and Dams (H&D), 1/2012, pp. 90-96