THE REHABILITATION OF AJBA CONCRETE DAM

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ABSTRACT

The Ajba concrete buttress-gravity dam, which is part of the hydro-power plant Plave on the Soča River in Slovenia, was built in 1940. Its structural height is 39 m, and its dam crest length is 72m. Monitoring of the Ajba dam started in 1969 and includes deformation measurements, visual inspections of structural elements and several other types of measurements.

The refurbishment of concrete and stone elements of the Ajba dam is described in the paper. The long term monitoring of the dam showed that the concrete elements of the dam needed to be repaired in order to achieve sustainable and durable structure and to retain the safety of the dam. The results of investigations in concrete parts of the dam, performed in 2004, as well as some basic technical data of the dam itself are presented in the paper. The systematic repair took place in 2005 and 2006.

The different types of degradation of concrete that were identified on the structure after 65 years of exploitation and the extent of the damages are described in the paper. Some of the methods for concrete repair, that showed good results, are presented in the paper as well as materials that were used for repair and protection of reinforced concrete and natural stone facing.

Post rehabilitation monitoring of the condition of concrete and stone parts, e.g. occurrence of cracks until 2011, showed that the rehabilitation was successful and the working life of concrete elements was extended.

1. Introduction

Large dams are due to their height, safety requirements and loads one of the most demanding engineering structure. The construction of new large dams as well as rehabilitation or reconstruction are demanding task for civil engineers. These structures are exposed to abrasion, freezing and thawing cycles, dynamic actions, corrosion processes etc., earth dams also to internal erosion processes. Damages are likely to occur on exposed spots of massive as well as reinforced concrete.

Due to the large risk of human losses in the case of a dam breach, large dam structures have to be monitored in their entire life-span. To fulfil safety requirements and to ensure functionality of a dam regular maintenance and remediation measures are necessary. The Ajba dam has been regularly monitored since 1969 and its equipment was regularly maintained.

The Ajba dam, which was constructed in 1940, due to its architectural and engineering solutions belongs to the Slovenian technical heritage. The paper describes the remedial works on the concrete elements of the Ajba dam that were performed in the years 2005 and 2006.

2. Dam structure

The Ajba dam can be classified as a combination of a barrage and gravity dam. The retaining structure consists of four massive piers with three large gates in between that can be opened or closed. The four pillars are connected at the elevation 111.5m a.s.l. with bridging elements in pairs, one at the upstream and one at the downstream side of the piers. The small bridges are arch shaped and made of reinforced concrete. The foundation level is 92.1m a.s.l. and the roofing structure with the mechanism for opening and closing the gates is at the 120.0m a.s.l. The roofing structure or 'upper deck' is constructed on top of the four pillars and it is made of aching girders, fixed with cross girders and reinforced concrete plate. The usual water-head is at 106 m a.s.l.

Figure 1 Ajba dam (2012)

Initially two spillways were constructed on the left side of the dam with the fixed spilling level at 106.0m. The pillars separating the two spillways were connected with the similar bridging structures as the dam piers. One of the spillways was reconstructed in 1974 to build a small power station that includes intake works, generator room and outlet. The piers, gates, remaining spillway and the small power station are shown from the downstream side in Figure 1. On the right embankment the intake structure, leading to the main power station located downstream, is visible.

Initially one intake structure leading to approximately 5.5 km long intake tunnel was built on the right bank. The second intake structure together with a new tunnel and power station was constructed just upstream of the first intake structure in 2002. Piers of the Ajba dam are made of massive concrete, while bridging structures between the piers and plates at the upper deck are made of reinforced concrete. Piers, spillway, bridges and some other exposed surfaces are protected with stone facing.

The average flow of Soča River is around 100m^3/s, but the differences between low and high waters are very high (Figure 2). On the 5th November 2012 at the gauging station near Ajba the flow reached 2400m^3/s.

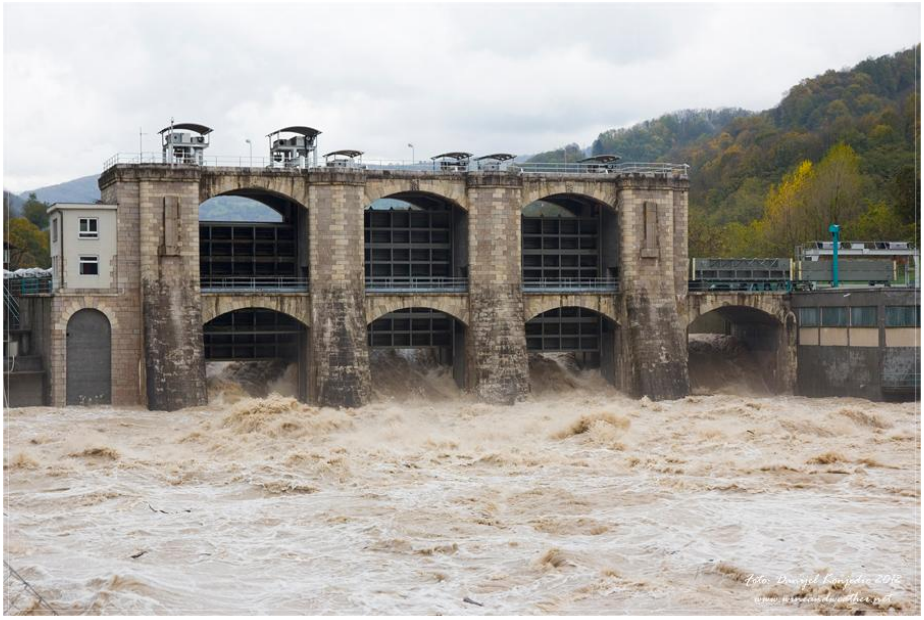

Figure 2 Ajba dam on 5th November 2012 (http://www.wineandweather.net/2012)

3. Material investigations

Sixty-five years of exploitation caused extensive damage on concrete e.g. cracks, corrosion of reinforcement, damages of construction joints and stone blocks, deterioration due to freezing and thawing cycles etc. The dam owner Soške elektrarne Nova Gorica decided to make extensive remedial works of the structure elements of the dam. Firstly thorough investigations of materials were performed in 2004 and the technical condition of the dam was determined. The aim was to establish the type and the extent of damages as well as the cause of them. Based on the findings of investigations, project of remedial construction works was designed. In the years 2005 and 2006 the remedial woks were performed. The research into materials comprised the following activities:

- Visual inspection of concrete and stone surface to establish scaling, roughness, extent of cracks, damages due to corrosion, mechanical damages, leakage, flowstone deposits, plant grow etc.
- Pull-off tests on concrete surface and on layers of concrete underneath.
- Drilling to obtain intact concrete core samples to establish the depth of cracks and perform laboratory test. Tests like compressive strength to verify the class of concrete and other test to establish surface water absorption of concrete were made in laboratory.
- Mapping of cracks and measurements of the depth of carbonisation on the structural elements of the dam.
- Establishing the thickness of reinforcing bar protective layer on structural elements.
- Divers also performed visual inspection of the underwater part of the dam.

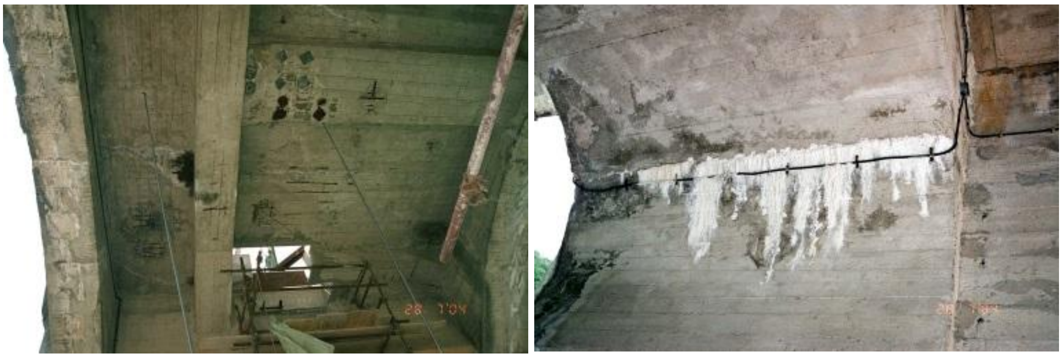

Figure 3 Typical deterioration damages (corrosion, cracks filled with flowstone) in 2004

The examination showed corrosion of the reinforcing bars on all reinforced concrete elements. It was most severe on the bridging elements on the level 120.0 m (see Figure 3) and on the level 111.5 m. A smaller amount of cracks was recorded on the bridging structure above the spillway and on the housing of the new power station. The main cause for the extensive corrosion were very thin reinforcing bar protective layers and deep carbonisation of concrete, that on several locations exceeded the thickness of protective concrete layer. The corrosion was most severe on the bottom surface of the 'upper deck', where leakage through the deck was observed. Precipitation water penetrated thru concrete and wetted the bottom surface of the reinforced concrete slab.

It was decided to reduce the permeability of the 'upper deck' by adding a waterproofing layer on the concrete slab at level 120.0 m and on the bridge structure above the spillway together with the rehabilitation of corrosion damages.

On concrete elements of the dam most of the damage was caused by the degradation effect of frost cycles. These damages were most severe at locations where constant leakage and wetting of concrete, due to precipitation water or Soča River waters, was established.

Open construction joints and numerous cracks were clearly visible on all sections of the dam. Most of them were initially caused at the time of construction due to applied technology of construction. At these cracks leakage and flowstone were observed (see Figure 3). The width of cracks was up to 3 mm. It was necessary to seal the open joints and cracks to re-establish integrity of each construction element and prevent further degradation of concrete.

Stone facing was mostly in a very good condition (Figure 4). Some destruction was recognised within joints, where flowstone was found due to leakage thru concrete elements and further thru joints. Stone facing was harmed on one pier in a larger scale due to explosion of a bomb during the World War II. Explosion caused cracks and lamination of some stone blocks as well as crumbling of stone blocks.

On concrete surfaces of the dam extensive damage was caused by freezing and thawing cycles e.g. crocodile cracks, fragmenting and delamination of surface layers of concrete.

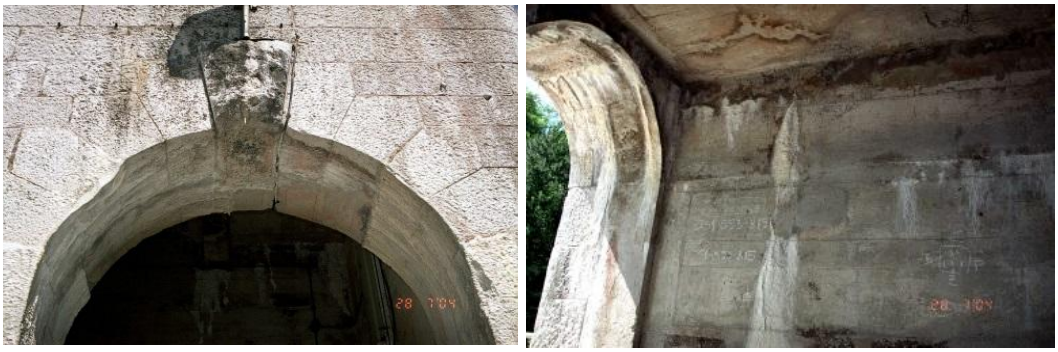

Figure 4 Stone facing with joints filled with flowstone in 2004

Locally on the vertical surfaces of piers, which were exposed to high waters, damage due to abrasion was established. These types of damages were limited in length and depth.

On dam piers large areas of porous and segregated concrete were established next to steel gates on the downstream side.

4. Rehabilitation works

Based on the findings of the visual inspection and laboratory tests the scope and cause of damages was established. A detailed plan of rehabilitation works was prepared, technological procedures and characteristics of materials to be implemented were defined. The scope of quality control of workmanship and employed materials was also defined. The important steps in the rehabilitation process were as follows:

1) Preparation and cleaning of concrete surfaces with water blasting. On stone surfaces abrasive additive was added to the water.
2) Injection of cracks and open construction joints.
3) Sand blasting and anticorrosive protection of exposed reinforcement.
4) Reparation of all cracks and other damages. In the case of localized cracks polymer cement mortars were applied manually or with the use of suitable equipment. On large cracked sections the mortar was applied using the shotcrete technology.
5) New protective layer of concrete was applied over the exposed reinforcement bars.
6) Concrete surfaces were smoothed with fine-polymerized cement mortar. Protective coating of polymerized cement was applied.
7) Waterproofing layer was carefully placed.
8) The stone facing was repaired.

The look of the dam after rehabilitation works had to resemble the look of the dam at the time of construction as much as possible, since the dam is regarded as Slovenian technical heritage. That is why materials, texture, technical procedures and colour were carefully chosen.

For injection of wide and long cracks and joints up to approximately 0.3 mm wide cement material and polyurethanes that swell in the contact with water were used. Most of the cracks, where leakage had been evident, were sealed with the polyurethane rasins. Construction joints as well as active cracks of small width were filled with the injection of elastic epoxy raisin on water base to achieve good adhesion on moisted concrete surfaces.

Dry cracks, cracks without flowstone deposit and not active construction joints were first grooved and cleaned. Subsequently grooves were sealed with polymer cement mortar.

On the frost affected concrete surfaces of the Ajba dam, firstly all deteriorated layers of concrete were removed with waterblasting equipment and light shock hammers. Then in the case of large areas dry-mix shotcrete method was used. The dry components comprised mortar and polymer fibers for micro-reinforcement. Mineral additives ensured a low percentage of waste and good cohesiveness of mortar. Sprayed mortars were finally trowelled and in most cases the application of additional final layer was not necessary. For small-scale degraded concrete areas reparations were carried out by hand or by using smaller machines for wet placing of polymerized cement mortar (PMM).

Figure 5 Intake structure HP Plave 1 before rehabilitation in 2004 and five years after it

On the bridging structures and other reinforced concrete elements, where corrosion of reinforcing bars has been detected, the usual rehabilitation procedure was used. Firstly concrete around corroded rebar was removed, exposed rebar was cleaned and new concrete layer for corrosion protection was applied.

On the bottom side of the bridge girders an additional layer of micro reinforced and polymerized cement mortar was applied to achieve realkalisation of existing concrete and to improve its protective ability against corrosion of reinforcement.

For the reconstruction of the existing waterproofing (bituminous stripes) on the roof of control room and the small power station additional polymer modified bituminous stripes were applied over the existing waterproofing layer. On the 'upper deck' areas at the level 120.0 m and on bridge over the spillway at level 115 m the waterproofing was enhanced by elastic polymer modified fine mortar, which was approx. 2 mm thick and reinforced with polymer reinforcing mesh.

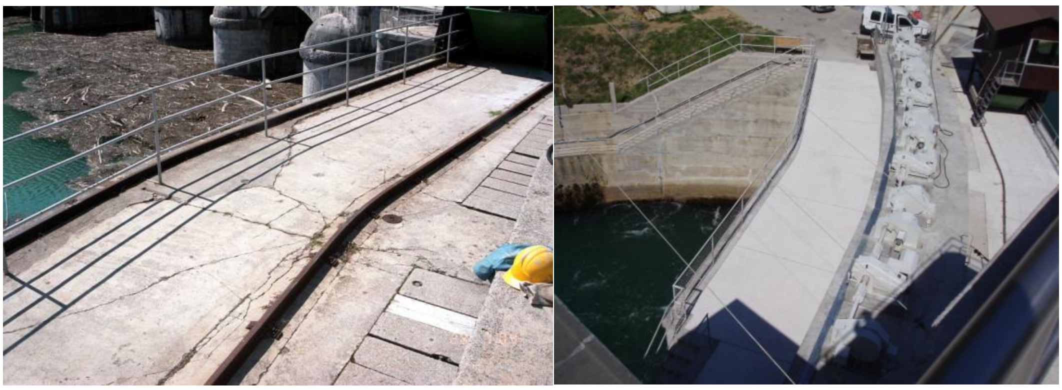

Figure 6 pavement of the intake structure before rehabilitation in 2004 and after it

Rehabilitation of existing pavements including new waterproofing protection was performed with polymerized cement concrete reinforced with steel fibers (Figure 6).

Figure 7 Sandblasting of stone facing on the right pier at the deck level (121m) in 2006

Rehabilitation of stone linings consisted of reparation of damaged joints and reparation of severely damaged stone blocks with bonding of new stone pieces in epoxy mortar onto existing stone blocks. All stone surfaces were cleaned with sandblasting (Figure 7). Joints between sand blocks were repaired with polymer modified mortar.

5. Monitoring after rehabilitation

Regular monitoring of the Ajba dam consists of numerous activities which include also yearly surveying and measurements of cracks, periodic visual inspection of concrete and stone linings, underwater inspection of stilling basin etc.

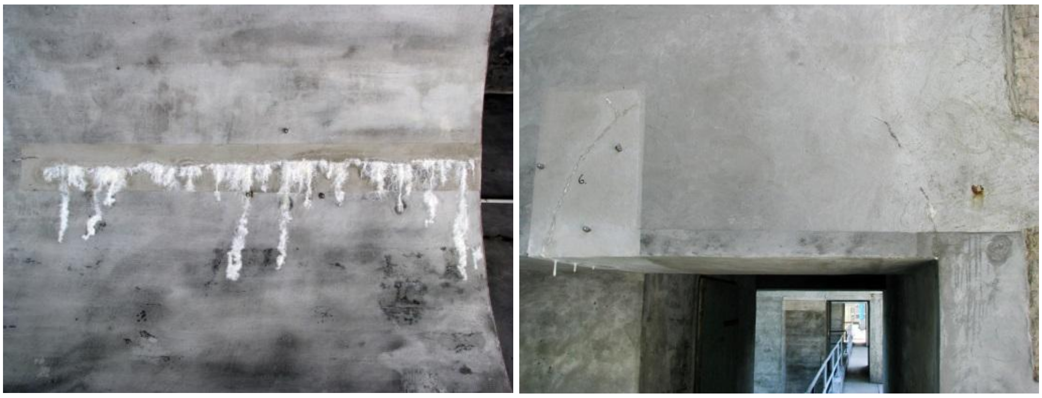

Figure 8 Reappearance of small number of cracks (in 2011)

Five years after rehabilitation works were finished most of the former cracks and joints are still closed and not visible. At some locations, especially where leakage was not entirely prevented, the cracks and flowstone deposits reappeared (Figure 8).

6. Conclusions

Rehabilitation of concrete elements of Ajba dam was a challenging task from the technological point of view. In addition to the rehabilitation of different types of degradation processes, the appearance of the dam had to stay unchanged.

Based on the results of quality control of the implemented materials during rehabilitation works and the results of five year post rehabilitation monitoring, it can be concluded that the rehabilitation was successful and the working life of concrete elements was extended. However at some elements further interventions within the regular maintenance plan will be necessary.

7. References

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[2] RAVNIKAR TURK M., 2011. Monitoring of the dam Ajba – final report for year 2011, pages 30, April 2012, ZAG Ljubljana, Slovenia