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Application of a fully bonding synthetic membrane by the refurbishment of the Lago Bianco Dams

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ABSTRACT: The need for sealing dam faces is gaining more and more in importance, not only due to the fact that old masonry and concrete dams have to be refurbished because of safety deficiencies, but also due to the wish of designers to allow a lower concrete quality in connection with an upstream surface sealing. A new and innovative sealing method was created and applied to the upstream face of an old masonry dam in Switzerland which suffered extremely under Alkali Aggregate Reaction (AAR). The new sealing method PP DAM® consists of a fully bonding synthetic membrane. The synthetic membrane was especially developed for the sealing of water structures. Due to the use in the Swiss Alps, the membrane was designed to withstand extreme climatic conditions (radiation, low temperatures and ice pressure).

1 INTRODUCTION

The lake of Lago Bianco, with a maximum storage level of 2234.65 m asl on the Bernina pass (Switzerland) is impounded by two old masonry dams. The Scala dam (Figure 1) in the south of the lake with a height of 26 m and a crest length of 190 m is an arch-gravity dam, the north dam (Arlas dam) with a maximum height of 15 m is a gravity dam. Both dams were constructed as rubble masonry dams between 1910 and 1912. In 1941 the dams were heightened by 3.6 m with concrete (Figure 3). The downstream faces of the dams were covered with dressed quarry stones. The supply level was raised by 1.5 m to the current level. Stability assessment of the Scala dam showed that with the new supply level the dam was not stable.

Therefore a cyclopean masonry was added to the downstream face of the Scala dam in 1942. Both dams were maintained carefully during the long time of operation. The upstream faces of both dams were sealed by dam inspection personnel periodically with shotcrete to prevent seepage through the dam body and cracks in the masonry, believed to be caused by frost.

Figure 1. Scala dam under construction 1910-1912.

2 BEHAVIOUR OF THE DAM

The behavior of the dams was controlled by visual inspection only, up to the year 1980. Since the early 1980's the crown movements were controlled by geodetic measurements

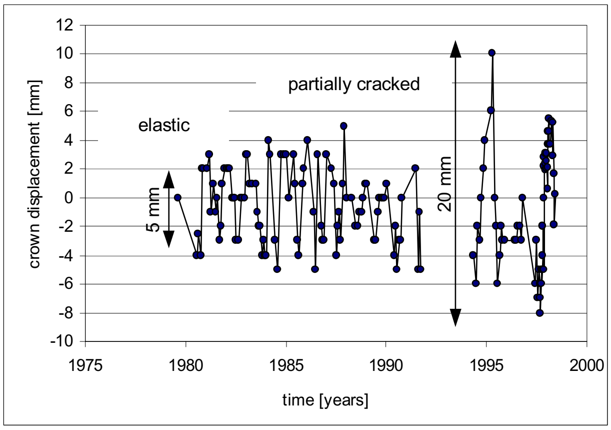

Figure 2. Measured crest displacements by means of alignment measurements.

Figure 2 shows typical results. The deformations caused by the water load are much smaller than those caused by temperature. As the temperature rises, especially in the southward exposed (upstream) side of the dam, the dam concrete expands. This causes the arch to tilt towards the upstream side. This mechanism explains the observed annual oscillation of measured deformations up to the mid '80s. After that time the dam showed indications that horizontal cracks started to develop. FE analyses with a partially cracked model gave results of 20 mm (Figure 2) for the crest deformation. It was obvious that something had happened to the dam.

Alkali Aggregate Reaction (AAR) in the concrete, poured in 1941, was postulated to be the reason for the observed phenomenon (Baumann et al. 1998). Laboratory tests indicated that the concrete had the potential of AAR. When analyzing in detail the Extensometer measurements over a period of 3 years, it was noted that the Extensometers in the upper section of the dam did not show a reversible behavior as one would anticipate. Every year the readings increased in magnitude, indicating more expansion of the measuring base length. This expansion occurred always between mid October and the beginning of December when the water level was high. It was concluded, that the crest concrete of 1941 was expanding due to AAR.

3 REMEDIAL MEASURES

The following remedial measures were taken to upgrade the structure for the next period of operation (Figure 3):

- Replacing the old crest which suffered from frost and AAR by a new one
- Anchoring the cyclopean concrete to the main dam concrete
- Reinforcing the toe of the cyclopean concrete
- Constructing a new inspection gallery upstream of the dam
- Sealing the upstream face of the dam and the crest.

Further expansion of the horizontal cracks in the dam due to AAR had to be stopped. Several sealing methods for the upstream face of the dam were investigated for a potential use at the dam. The extreme alpine climatic condition such as intense radiation, large temperature variations and thick ice on the lake, together with the short construction time (the owner did not allow a special emptying of the lake) were the main parameters to take into account. Out of a detailed evaluation the designer and the owner decided to choose a new method for the sealing of the concrete. The new system had been tested for several years on concrete structures of the owner. These tests gave the confidence to choose a new system on an entire dam face.

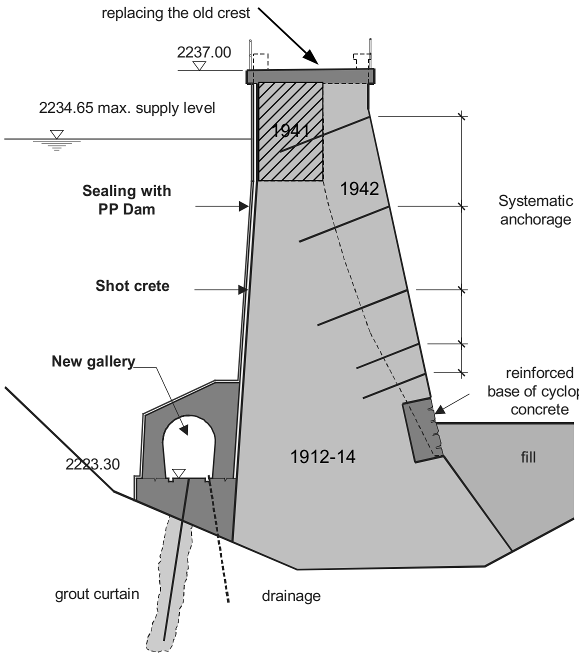

Figure 3. Remedial Measures.

4 THE PP DAM® SYSTEM

The sealing system consists of a multiple layered fully bonding Polyurethane-synthetic material that is applied in a viscous condition on various grounds. In the case of the dam it was applied directly onto masonry stones, old and new concrete as well as directly onto the rock surface.

For the application on a dam face the following material characteristics were of importance:

- Very high crack bridging capability (larger than 5 mm)
- High long life elasticity at very low temperatures (down to -20 °C)
- High bonding capacity on the concrete and shotcrete surfaces
- High vapor permeability
- Reduced adhesion on ice
- Resistance against frost, de-icing salt, organic material and microorganisms
- High abrasion and shock resistance

The sealing system shown in Figure 4 had been tested in the laboratory and in-situ. Since the mid '80s various recipes of PU-synthetics were applied on water-submerged parts of powerhouses, other civil structures and parts of dams. At the Albigna Dam open rock joints just upstream of the dam toe were sealed, dam crests were partially sealed and on the dams of lake Bernina various test fields were installed on the upstream face of the dams since the early '90s.

These field tests were necessary to test the membrane on the extreme climatic condition. Damaging by ice, deterioration due to organic material, long term bonding characteristics and the aging due to the thermal variation and UV light impact were of prime interest to the designer and the owner of the dam.

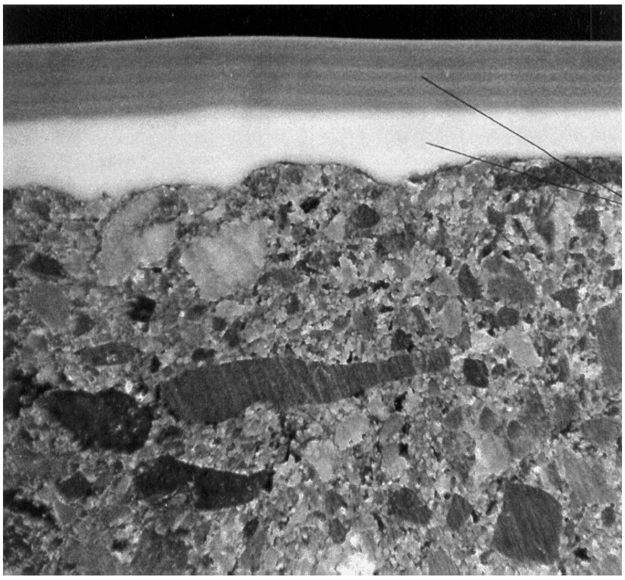

Figure 4. The sealing system applied on concrete (primer, support layer, sealing membrane, ultraviolet protection layer)

Parallel to the field test, laboratory test were carried out to test the mechanical characteristics of the synthetics alone and also in the applied form on shotcrete and concrete. For these tests differently aged material was used, from freshly produced to 10 year aged on the dam face.

The sealing of the upstream face of the Scala dam was carried out in the following steps:

- To even the very rough surface of the old masonry dam face, with lots of voids and holes, a reinforced shotcrete layer was applied. For normal cast concrete structure this step is not necessary.
- On the upper part of the dam (concrete of 1941) the small voids in the concrete surface were sealed with a filler material.
- To guarantee the adhesion of the synthetics on the concrete, an adhesion layer was applied.
- On the adhesion layer the flexible stretch layer was applied. The synthetic was rolled in a viscous condition. Several layers were applied to a thickness of 2 mm. The thickness of the material is chosen depending on the crack bridging capacity of the membrane. The larger the crack bridging, the thicker the flexible stretch layer has to be. The thickness is generally controlled by the consumption of synthetics and in particular with drill cores. The control is very simple because each layer applied has a different color.
- The sealing layer was applied on top of the stretch layer in the same fashion. The thickness chosen was also 2 mm.

- At last the sealing layer was protected by a UV-protection layer, which is necessary to guarantee that no change in color occurs during the years. During the application of this layer quartz sand can be added to protect the membrane against mechanical impact. It is often applied on crests (drive ways). Against vandalism it is also very effective.

Figure 5 shows schematically the sealing of the dam faces in the test field and the sealing as applied to the entire upstream face of the Scala dam.

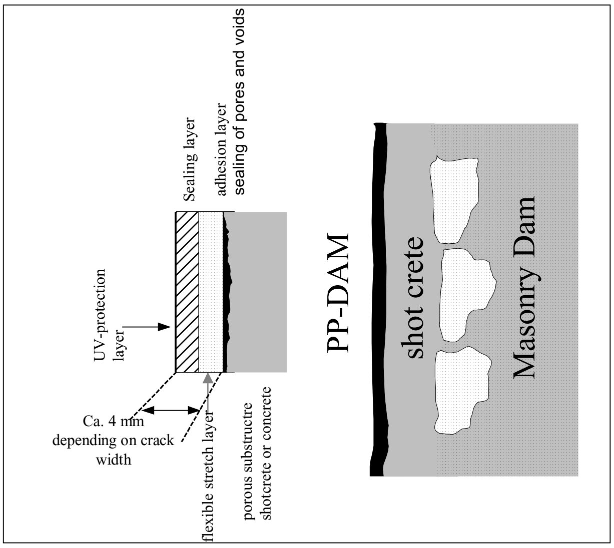

Figure 5. The entire sealing system.

5 TEST RESULTS

An important mechanical parameter when considering synthetic materials for use as a sealing material under outdoor conditions is its tensile strength under extremely low temperatures since synthetics tend to react very brittle under extreme cold. Results from laboratory tests shown in Figure 6 indicate a very favorable behavior of membrane materials. The stretch material can withstand strains of 10 to 15 for low and normal temperatures respectively for stresses of 50 to 30 N/mm2. The sealing layer, which is also responsible for the abrasion and shock resistance is stiffer and stronger than the stretch layer. Its tensile strength is 65 N/mm2 at a respective strain of 5. This material showed almost no increase in stiffness and strength with decreasing temperatures.

A second important mechanical parameter is the bonding characteristic of the sealing system on mineral sub-ground such as shotcrete and cast concrete. The bonding strength was tested on the patches of in-situ test fields on the upstream face of the dams at lake Bianco. The sealing patches were 2 to 3 year exposed to the alpine climate at an altitude of 2200 m asl.

Figure 7 shows the results of the direct tensile tests of the membrane on the test fields. A total of 15 tests were carried out. In 7 of these tests the bonding was so strong, that the rupture occurred in the shotcrete. The bonding strength was higher than 1 N/mm2 (1 MPa) with an average of 1.7. In the other tests the failure occurred at the interface between sealing membrane and shotcrete. The failure never occurred within the various layers of the synthetic membrane. The rupture in the interface occurred in general at stress levels of 1 to 1.5 MPa.

The most important mechanical parameter is the capacity of the fully bonded synthetic material to bridge single opening cracks in the substructure. Crack bridging tests were carried out in an official laboratory (LPM AG, Beinwil am See, Switzerland) on 45 mm wide specimens (Figure 8). The sealing system was applied to the concrete specimen and a small initial saw cut was made half way into the concrete from the bottom. From this cut a crack could develop during the test.

Testing was done under room temperature and in the cool box at -23° C. The increase of force on the specimen led to the fracturing of the concrete in the area of the saw cut. From that point on the entire tensile force is taken by the membrane. With further increasing force the joint (crack) opens and at higher stress levels the sealing system starts to peel off the leading edge of the joint as shown in detail in Figure 9. The joints were opened to a maximum of 100 mm without a failure and with a marginal peeling off of the membrane. In general the joint was opened up to 50 mm.

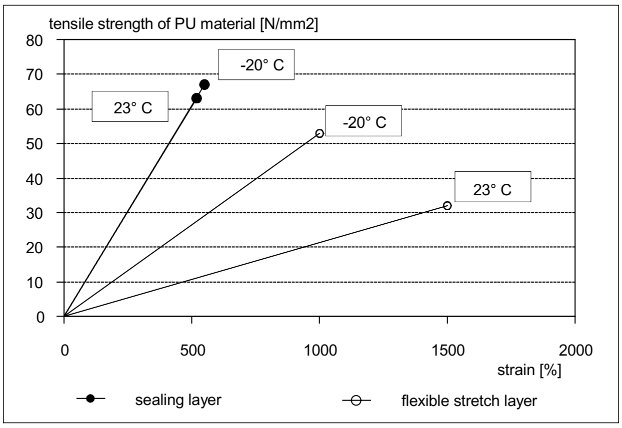

Figure 6. Tensile strength of the PU materials for room temperature (23°C) and –20°C.

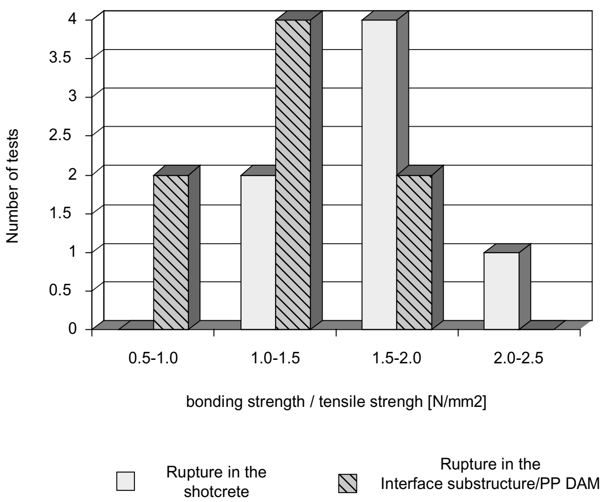

Figure 7. Bonding strength of the sealing material on in-situ aged specimens.

Three tests were done to a crack opening of 100 mm at room temperature without a failure of the synthetic and a maximum peeling off of 15 mm. Four dynamic cycling tests were carried out and 13 static tests under room condition and in the cool box at -20°C. Figure 10 shows the results of the tests (opening to 50 mm). The peeling off was in all the tests smaller than 15 mm, even under extremely cold conditions. A slight increase of peeling off behavior can be measured between test under room condition and under cold condition. The remaining crack after the tests was smaller than 0.4 mm in all the tests showing the excellent elasticity of the material.

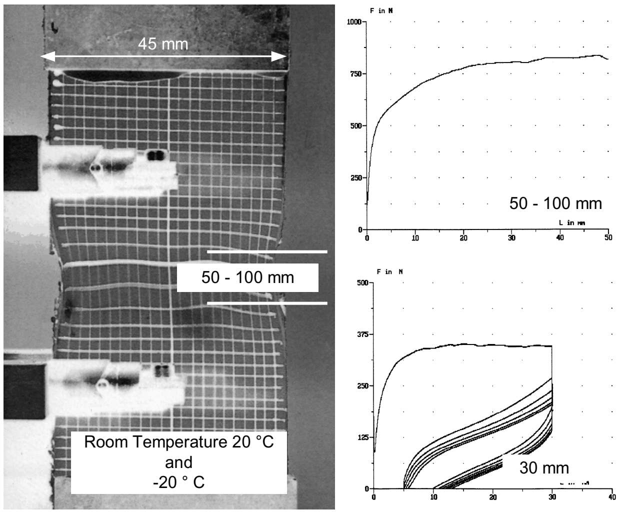

Figure 8. Static and cyclic crack bridging test of sealing membrane on concrete base

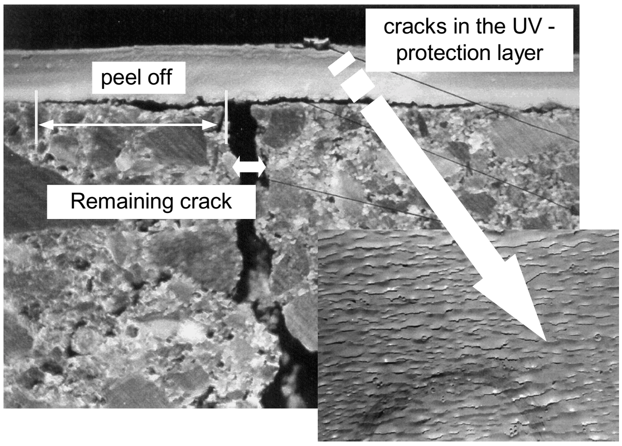

Figure 9. Detail of the crack area after the bridging tests.

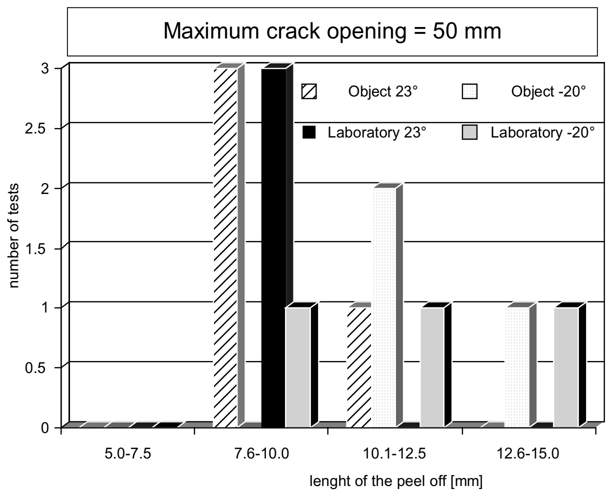

Figure 10. Length of the peel of zone after the crack-bridging test.

6 CONCLUSIONS

The testing of in-situ aged sealing membrane over the last 10 years has shown that the system is matured to be applied on entire dam faces for the sealing as a protection against AAR and pressure build up in distinct joints of the dam. The fully bonding PU-based synthetics, which is applied in a viscous condition, can bridge very large cracks. Its behavior under extreme climatic condition is excellent and shows very little increase in brittleness due to aging and UV exposure

In the spring of 2000 the entire face of the Scala dam on lake Bernina in the Southeastern Alps was protected with the synthetic membrane system. The state of the sealing after the first two filling periods and the metre thick ice and snow loading during the last two winter seasons is faultless.

The rehabilitated face of the dam needs no air entrainment system to prevent from freezing at the dam face. Long term in-situ field test showed that the sealing is not damaged by ice. Due to the different colors of the individual layers of the synthetic membrane deficiencies can be detected very easily and the depth and extent of the damage can be predicted accurately. Due to the fully bonding of the synthetics possible damages have only local effect and a build up of water pressure behind the synthetics over a large area is not possible.

In the case of the Scala dam the application of the new sealing method was a cost efficient way of protecting the dam against AAR. Only long term in-situ tests at the dam site gave the owner and designing engineers the certainty that this new system can be used for important and long life structures in the field of waterpower construction.

REFERENCES

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