Detailed investigation of an old masonry dam

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SYNOPSIS. The gravity dam, described in this paper, is now over 100 years old. After such a long period of operation, a rehabilitation of the upstream face of the dam is necessary. During the last rehabilitation between 1965 and 1967 a protective shotcrete layer was applied on the upstream face. In the present rehabilitation the shotcrete layer will be maintained and a drained geomembrane will be installed. The geomembrane will be fastened by a system, which consists of inner and outer stainless steel profiles. These profiles are anchored onto the shotcrete layer.

Because the strata for fixing the anchors (the shotcrete layer) is now over 30 years old – and requires maintenance – major testing(e.g. georadar) of the shotcrete layer was carried out to give a guarantee of a sufficient bearing capacity of the anchor. The testing of the shotcrete is important to establish a basis for the design of the anchorage system.

This paper will describe the construction of the geomembrane lining with special consideration of the fastening of the steel profiles and the testing of the shotcrete layer.

INTRODUCTION

The dam was built by Prof. Intze between 1898 and 1900, and was one of the first Dams in Germany. The dam is used for the drinking water supply. The original dam had a height of 34 m and was designed as a gravity dam and is curved in plan (r = 176 m). In 1934 the dam was heightened to 38 m. The base width is 23.6 m and its width decreases to 4.5 m at the dam crest. The crest has a length of 215 m.

The dam consists of masonry with a volume of 47,000 m^3. The masonry consists of quartzite greywacke and a lime mortar with river sand and fly ash. Revetted masonry formed the upstream and downstream faces. The reservoir has a storage capacity of 2,855,000 m^3.

Long-term benefits and performance of dams. Thomas Telford, London, 2004.

PREVIOUS REHABILITATIONS

There were two main rehabilitation activities in the past. The first was between 1950 and 1952, the second between 1965 and 1967.

Rehabilitation from 1950 to 1952

Investigations of the dam foundation showed that there was a high permeability on joints on the silty clayey slate, which were mainly rectangular to the dam axis. This explains a high water pressure in the dam foundation. Piezometer readings showed values up to 75 % of the hydrostatic pressure of the reservoir level. So after 50 years of operation the dam was rehabilitated by cement grouting, to seal the dam body and the dam foundation. The objectives were:

- Sealing the masonry and dam foundation
- Reduction of seepage water
- Avoiding the ongoing deterioration of the bond between the masonry and the lime mortar

Rehabilitation in 1965 to 1967

In the previous rehabilitation the sealing of the masonry was not satisfactorily achieved.

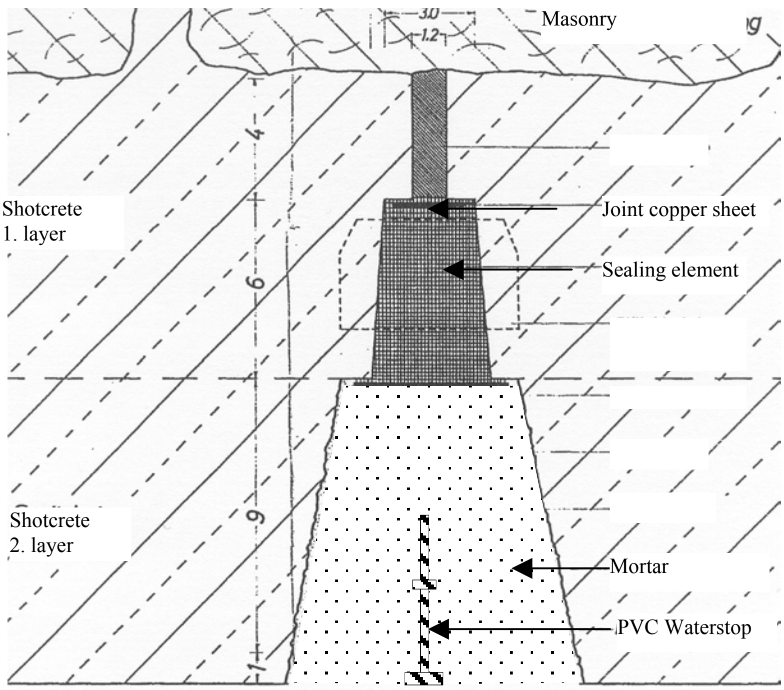

Figure 1. Cross section through joints of shotcrete layer

The main aspect of this rehabilitation was to seal the upstream face of the dam. The rehabilitation consisted of a reinforced shotcrete lining in panels of 5.0 x 5.0 m. Figure 1 and 2 show the shotcrete lining and the joints as a plan and as a photograph.

Each panel was anchored into the dam by 16 anchors with a diameter of 20 mm and a length of 2.50 m. The shotcrete was applied directly onto the masonry in two layers, each 10 cm deep. The joints between these shotcrete panels were formed with a sealing element and mortar, see figure 1.

Figure 2: photo of existing shotcrete lining

Despite these complex rehabilitations the sintering process deterioration was only slowed down slightly. As the joints were not really flexible joints the joints were disturbed due to thermal movement in the dam. Hence the water could leak through these joints into the dam.

CURRENT REHABILITATION

After over 30 years of operation since the last rehabilitation works in 1967, it was necessary to rehabilitate the upstream face of the dam. It was the wish of the owner to maintain the shotcrete layer. So the rehabilitation plan will be implemented by the following methods:

- Breaking out a gallery
- Installing drilled drainage holes
- Sealing the upstream face of the dam by application of a watertight geomembrane

A gallery in combination with drilled drainage holes is a very common method of reducing the subsoil water pressure and is thus not described in this paper.

Sealing concrete faces with a PVC geomembrane has been carried out now for over 40 years, especially on the upstream faces of dams, mainly either RCC dams or masonry gravity dams, e.g. the Brändbach Dam in Germany Veyhle/Jaup (2002) or Scuero/Vascetti (1996).

The geomembrane concept is in general quite simple: the synthetic impermeable liner extends over the whole area, which is to be sealed, not only joints or cracks. It is conceptually equivalent to a single waterstop, which covers the whole area. The geomembrane is attached to the structure as a separate element. The geomembrane is mechanically fastened by means of steel-profiles. The elasticity of the system allows it to bridge cracks that may develop due to external loads or changes in temperature.

The geomembrane consists of a flexible polyvinyl chloride (PVC) membrane, extruded in homogeneous mass from a flat die and heat bonded during manufacturing to a non-woven, needle punched geotextile (100% Polyester). The purpose of the geomembrane layer is to provide watertightness, while the purpose of the geotextile is to help to protect the geomembrane from puncturing and to give dimensional stability. The geomembrane is situated on the geogrid. This geogrid consists of a polymer–plastic, which serves as a drainage layer between the geomembrane and the dam. This construction enables a discharge by gravity of any drainage water that could infiltrate between the waterproofing liner and the dam body.

The Carpi PVC geocomposite is anchored by tensioning profiles on the shotcrete. The tensioning profiles belong to the patented Carpi-System, see figure 3. They are made of two parts, the inner and outer profile. The inner profile is anchored to the concrete structure by anchors. The outer profile is connected to the inner profile by means of a special adjustable threaded device. The connection of the two profiles creates a clamping effect to the geocomposite. Pre-tensioning gives the geocomposite best adhesion to the existing concrete surface.

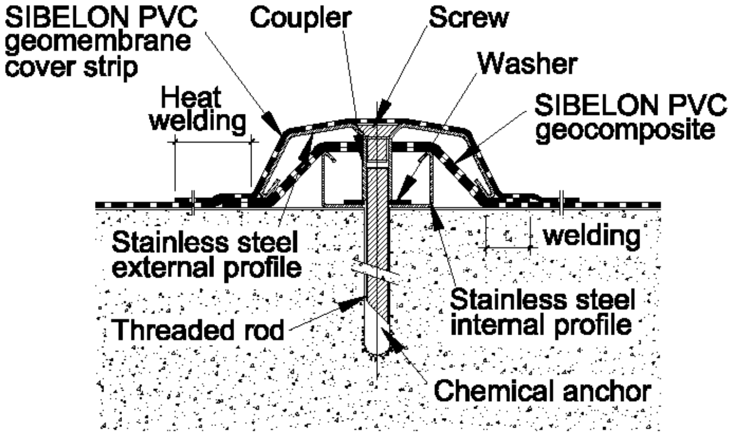

Figure 3: Cross section through pretensioning profiles.

INVESTIGATIONS OF THE DAM

As described in the previous section , the geomembrane is fastened onto the shotcrete lining by anchors. Hence the lining had to be tested in detail, as described in the following sections, to ensure a safe construction for the current rehabilitation.

Visual investigation

The whole surface of the upstream face of the dam was tapped with mechanical devices. A suspended platform was installed to allow access to the whole area of shotcrete. This first stage had the following objectives:

- Finding of areas where bond between the two shotcrete layers was poor
- Removal of loose shotcrete
- Marking on site of all repair areas

Findings

The visual inspection showed that the shotcrete itself was in good condition. Just one panel of the shotcrete layer was bad. In half of the panel there was no bond between the first and the second layer. Debris from the shotcrete was falling down during the tapping procedure. It was decided to remove the panel and to replace it completely.

In contrast to the shotcrete layer the panel joints were in a worse condition. This was because the joints were not flexible joints, see figure 1. Thermal movements of the dam caused high compressive stress in the joint material, which often resulted in cracks. More than two thirds of the joint material had to be replaced. The geomembrane needs a smooth subsurface with no protrusions, so these joints had to be reconstructed.

Shotcrete testing

For stability analysis of the anchoring system detailed knowledge of the shotcrete was necessary. Therefore five concrete cores with a diameter of 80 mm were drilled and analysed. The joint material was also examined.

Findings

- The concrete was classified as a concrete C20/25.
- All cores showed a steady microstructure. Also the transition zones between masonry and shotcrete and in between the shotcrete layers showed no voids.
- The geometry of the shotcrete layer could be confirmed: thickness 20 cm and two layers of reinforcement.
- In both the shotcrete and the joint material ettringite was found. Where ettringite fills the pores completely, an internal pressure arises and the microstructure is disturbed. As described above, the shotcrete is in good condition (no hollows, good microstructure), so the shotcrete will not be damaged by the ettringite. Figure 4 shows a microscopic view of the shotcrete. A pore with slight ettringite can be seen. Generally these very small pores are found in the shadow of the reinforcement. Further information on ettringite can be found in Jungermann (2000). In the joint material the pores were filled with the ettringite and the microstructure was destroyed. All the factors which lead to damage of the microstructure can also promote the formation off ettringite. The existence of ettringite crystals in concrete cracks is, as a rule, only a consequence and rarely the cause of the cracks, Stark/Bollmann (2000). This matches with the visual investigation, that the joint material was in a bad condition.

Survey

The entire dam was surveyed with a 3-D laserscanner. This scanner combines values from distances, angles and inclination to calculate 3D coordinates of each point of the dam. This method allowed a detailed design of the rehabilitation work considering the exact geometric condition of the dam.

Findings

This survey confirmed the general assumed dimension of the dam.

Figure 4: Microscopic view of shotcrete

Georadar

As mentioned above the geomembrane is fastened on to the shotcrete with anchors in vertical lines. To obtain detailed information of the shotcrete at each vertical line of a profile the shotcrete was surveyed by georadar, which had the following objectives:

- Recording of anchor plates of the shotcrete layer
- Recording of reinforcement (missing or overlapping reinforcement)
- Recording the structure of the concrete
- Recording the thickness of the shotcrete

In the Georadar technique electromagnetic impulses are radiated into the structure. Signals are reflected at interfaces between two materials (e.g. shotcrete - masonry) or at objects (e.g. reinforcement) and are registered at the surface. On the basis of the magnitude and the form of these reflections information on the structure can be obtained. The recording of the data is digital. First results can obtained during the measurement and a detailed evaluation including graphical presentation of the results will be made later. Figure 5 shows an example of the evaluation of the Georadar investigation

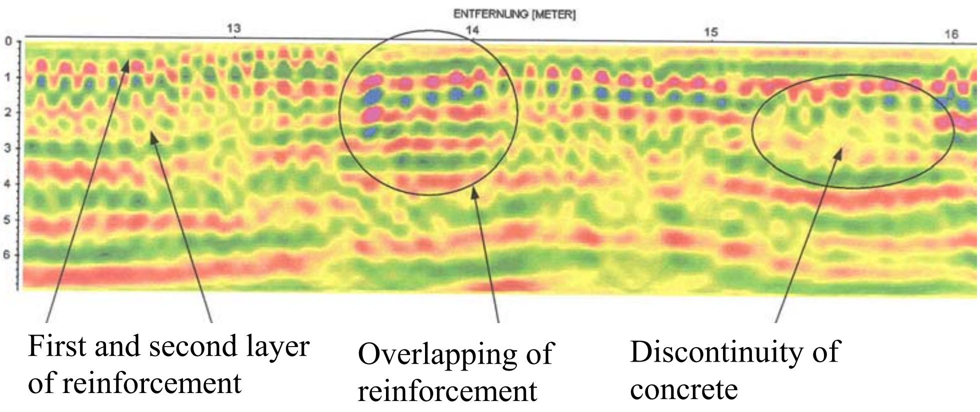

Figure 5: Example of evaluation of Georadar investigation

Findings

With the georadar survey the good condition of the shotcrete lining could be confirmed. There is a high consistency with the core drilling results, e.g. the thickness of 20 cm of the lining and the existing 2 layers of reinforcement. Discontinuities, e.g. the right side of figure 5, were in all cases minor.

CONCLUSION

As a result of all the investigations the main statements were:

- The shotcrete was classified as a reinforced concrete C20/25
- The lining has a thickness of 20 cm
- No big discontinuities were found
- The joints of the shotcrete lining had to be reconstructed

The results of all the investigations were satisfactory to decide that the geomembrane will be a safe and long-lasting construction. Parameters for anchor fixing were confirmed.

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