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Repair at Winscar bituminous concrete facing rockfill dam

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ABSTRACT: Winscar is a reservoir for potable water supply. Since 1970, when the rockfill dam was built, there were leakage problems. In summer 2001, the bituminous concrete facing was rehabilitated with a PVC geocomposite, mechanically anchored and drained. The paper describes the problems, the criteria that lead to the selection of the waterproofing solution, and the installed system with the performance data available to date.

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1 INTRODUCTION

Winscar reservoir, constructed between 1972 and 1975 for public water supply and owned by Yorkshire Water Services, is formed by a rockfill dam with a maximum height of 53 m and a crest length of 520 m. The capacity of the reservoir is 8 million cubic metres. The embankment, made of compacted sandstone, has an upstream slope of 1V on 1.7 H. The dam has a 25,000 m^2 upstream impervious membrane made by two layers of dense asphaltic concrete. A cement grout curtain extends beneath the upstream toe to depths of up to 70 m. Seepage through and under the dam is collected in a series of underdrains.

2 PROBLEMS AND INVESTIGATIONS

2.1 *Past performance*

At first filling, rising seepage was observed, increasing significantly when the water reached permeable strata on the left abutment. The water was kept at a low level to allow remedial grouting to be performed. As the situation did not improve, suggesting the presence of defects in the asphalt facing, in 1989 the reservoir was dewatered, a hole was found in the membrane and repaired. This remedial measure drastically reduced the leakage and the reservoir was impounded again.

All over the 1990s, leakage remained more or less stable, depending on the water level. In the late 1990s, the pattern showed a tendency to increase. Starting in June 2000, seepage flow had a sharp increase.

2.2 *January 2001*

In January 2001 a large spring issued from the toe of the dam with an estimated flow of about 15 litres/second. As a precaution, the reservoir was drawn down and the response of seepage flows was closely monitored. Examination of the drains indicated that the new leak was originated between the culvert and the left abutment. Flow reduced at approximately half-depth of the reservoir, suggesting a major defect at this level.

About 60 defects were found in the upper part of the asphaltic membrane, consisting in blisters, small cracks and more persistent cracks in correspondence of the construction joints between panels. This type of defect initially seemed to be the most likely explanation for the new leak. However, as there was no conclusive evidence as to the location of the leak. Hence the decision to totally dewater the reservoir was taken.

Emptying of the reservoir took over six months, as a range of measures were needed to avoid environmental damage, which included blending of different quality waters; filtration through straw bales, geotextiles and hessian; settling basins; and, timing of discharges.

3 SELECTION OF THE WATERPROOFING SYSTEM

3.1 *Repair strategy*

Taking out of use Winscar reservoir requires to supply its local treatment works with water from another reservoir, and to use the Yorkshire Grid at increased operating cost. Additionally, as the reservoir is large in respect to its catchment area, filling it totally usually requires two years. Taking the reservoir out of service for long and repeated periods to perform local repairs should similar leaks have arisen in the future would have resulted in high cost and impact on operation of the reservoir.

Local patching was discarded and major refurbishment of the entire waterproofing element was decided, including the reinforcement of the grout curtain to reduce leakage also from foundation. All works were to be completed before the winter rains of 2001/2002.

3.2 *Criteria for design*

Objective of the repair works was to secure a reliable water resource for the next 40 years. The selected waterproofing system had to be efficient, and have a durability proven by precedents in similar applications.

Logistics, environmental, and planning were also of particular importance. The construction schedule was very challenging, because of the fast-track nature of the project.

The performance criteria for the design of the liner was that it should be capable of reducing leakage through the face of the dam below 1 litre/second against full reservoir head.

3.3 *The alternatives considered*

The technical feasibility of various engineering solutions was investigated. The logistics, environmental and planning aspects were considered and the costs were estimated. Two options gained high evaluations: installation of a synthetic geomembrane liner over the existing face of the dam; and, removal of part of the existing facing and its replacement with a dense asphaltic concrete membrane over a bituminous bound drainage layer. High concern was the mobilisation of the necessary specialist (geomembrane) and the specialty equipment (asphaltic concrete), as was the timing of the works, which might have extended into a second year if inclement weather conditions prevented completion.

A tender was called, and received tenders were evaluated for both alternatives.

3.4 *Selection of the membrane liner*

Information gathered by ICOLD, the International World Commission on Large Dams, indicated that synthetic geomembranes had been used since 1959 to repair more than 180 dams worldwide and had an excellent performance record. ICOLD data indicated that various geomembrane materials had been used. Main alternatives are PolyVinylChloride (PVC), bituminous membranes, and some small-scale application of high-density polyethylene (HDPE) membranes, PVC having by far the largest and oldest experience among them. The mechanical and physical characteristics of the materials are similar but PVC has the further advantage of successful precedents, of easier weldability, even at low temperatures, of possibility of associating it during fabrication to a geotextile, simplifying installation (Carter et al. 2002).

PVC had never previously been used in UK for a water supply reservoir, and approval of the Drinking Water Inspectorate (DWI) was requested. Potential loss of plasticisers (leaching of phtalates) was a concern in that it may act as an endocrinal disruptor for some species, and also make the PVC less flexible, more permeable and more prone to damage with time. Research into the phenomena during the 1980s (Aguiar & Blanco 1995) indicated that while losses could be substantial, there was a considerable variability between different PVC products. No evidence was found that PVC could be harmful to human beings.

Accelerated ageing tests indicated that the PVC based geomembrane proposed by the tenderer that was then selected could have an effective life exceeding 50 years when exposed. Field evidence on samples of the same geomembrane exhumed from dams where it had been already in service indicated that loss of performance was insignificant over time (Cazzuffi 1998).

Evaluation of the compliant tenders showed that the geomembrane alternative was less influenced by the timing and weather factors than the asphaltic concrete and on this occasion there was also a clear cost advantage. The geomembrane alternative and the patented installation system as proposed by Carpi Tech S.A. from Switzerland/Italy, were selected.

The selected membrane is SIBELON CNT 3750, a geocomposite manufactured in Italy and formed by two layers of geosynthetic materials mechanically heat-coupled together: a PVC geomembrane 2.5 mm thick, and a geotextile, made out of pure polyester fibre, having a mass per unit area of 500 g/m².

To minimize environmental impact in an area that has an intense recreational use, the geomembrane was coloured dark green on the exposed face. The geomembrane has been coextruded, forming a layer of 0.8 mm thick PVC dark green colour associated to a 1.7 mm thick PVC grey standard colour. Table 1 lists the main characteristics of the product.

Table 1. The characteristics of SIBELON CNT 3750.

Property	Test method	Value
Thickness (only geomembrane)	ASTM D 1593 - UNI 8202/ 6	2.5 mm ± 5%
Specific gravity (only geomembrane)	ASTM D 792 - UNI 7092	1.30 g/cm^3 ± 2%
Geotextile mass per m^2	UNI 5114	500 g/m^2 ± 5%
Tensile strength	UNI 8202/8 - DIN 16726 par.5.6.1. Table 1 - A - VII	≥ 30 KN/m
Elongation at break	UNI 8202/8 - DIN 16726 par.5.6.1. Table 1 - A - VII	≥ 250 %
Tear resistance	DIN 53363	≥ 100 N/mm
Puncture resistance	DIN 16726 par. 5.12	≥1800 mm
Hydrostatic pressure resistance	DIN 16726 par. 5.11	≥ 10 bar
Brittleness at low temperature	UNI 8202/15 mandrel of 2 mm	no failure at - 30°C
Thermal ageing in water*	DIN 16726 par. 5.18	≤ 2,0%
UV radiation Resistance**	DIN 16726 par. 5.17	No cracks

* Maximum weight variation after 28 d at 70°C and drying.
**4500 NJ/m² exposure.

3.5 *Design of the system*

The waterproofing membrane is installed on the upstream face, in exposed position (Fig. 1), and is anchored mechanically at the periphery and along vertical tensioning lines on the upstream face.

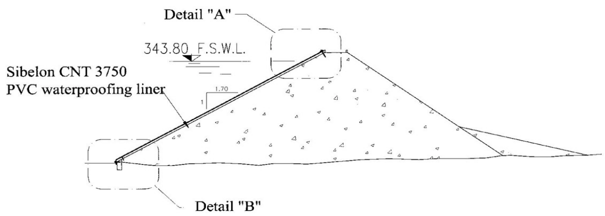

Figure 1. Cross-section of Winscar dam. The waterproofing liner is installed in exposed position on the upstream face.

The upper perimeter seal is made in the concrete at the base of the parapet wall and is watertight against rain, snowmelt and waves (Fig. 2).

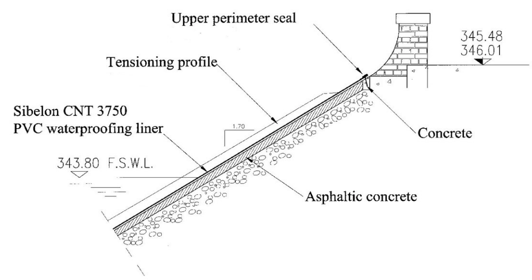

Figure 2. Detail A. The upper seal and stratigraphy of the waterproofing system.

At toe, a double perimeter seal anchors the PVC liner. The primary seal is of the insertion type and is positioned at the bottom of the asphaltic membrane. The secondary seal is of the mechanical type, achieving watertightness by compression, and is positioned on the vertical side of the concrete toe beam. The secondary seal reduces the head on the primary seal. The two seals form separate drainage compartments to allow ascertaining the source of any future leakage.

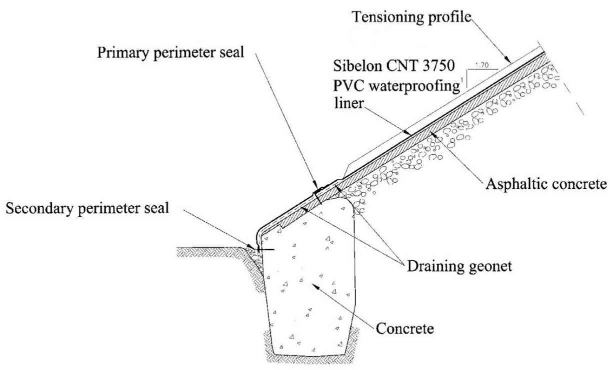

Figure 3. Detail B. The two watertight seals at toe.

The waterproofing liner is anchored along the upstream face by parallel vertical lines made by an assembly of two stainless steel profiles. The profiles anchor the liner to the face of the dam, tension it to assure planarity and absence of folds, and construct vertical free-flow pipes for drainage. The anchorage of the vertical profiles has been designed in function of the strength of the subgrade and of service conditions, including wind up to 160 km/h. All anchorage profiles have been waterproofed with PVC cover strips of the same geomembrane material of the main liner.

The face drainage system is formed by the geotextile underneath the geomembrane, by the tensioning profiles, by a peripheral geonet that serves as a collection conduit, and by transverse discharge pipes into the culvert. The drainage system is independent from the existing underdrainage system beneath the embankment. Any leakage through the membrane will be intercepted by one of the two compartments that form the drainage system. Measurement of discharge into the culver will monitor the performance of the waterproofing system.

Design addressed also the possibility that the grout curtain had been subject to leaching: the original cement grout was thin, and the low pH of the reservoir water seeping through fractures in the foundation could be expected to react with alkaline grout forming the curtain. The grout curtain was therefore reinforced, to provide a complete water barrier from crest to deep foundations. Particular attention was given at the foundation to the left of the culvert, since the new leakage was concentrated in that compartment of the foundation. The standard grout was a 1:1 mix of water and microfine cement. Two phases of grouting were undertaken with an interim review to allow methods to be evaluated and modified.

3.6 *Membrane protection*

The physical properties of the adopted PVC liner were considered by YWS (Carter et al. 2002) compatible with impact by floating debris, sailing craft, ice etc. Vandalism could affect the membrane but its detection and repair is so simple and quick that the extra cost for a mechanical protection was considered unjustifiable. Nevertheless, protection strategies that could be installed at a later stage if necessary, such as a light cover system, fencing, and surveillance, were identified.

3.7 *Leak detection system*

The waterproofing system was equipped with a leak detection system to allow spotting of any future leakage through the new liner. The system consists of a network of optical fibre cables fastened to the asphalt concrete beneath the liner. The system uses a laser source to measure the wavelength of light reflected back down the cable and sense temperature. The temperature at any point along the cable route varies depending on the season, reservoir temperature profile and other factors. However, passing a current through the external sheath of the cable can induce an artificial increase in temperature. In dry conditions the temperature rise would be constant. If there is a hole in the liner, the presence of water decreases the temperature and anomalies can be detected.

4 INSTALLATION OF THE SYSTEM

The geocomposite liner was manufactured in standard 2.10 m wide sheets. Three sheets were welded by automatic double track welding machines to prefabricate 6 m wide panels to maximise quality and minimise installation time on site.

Surface preparation consisted in clearance of debris, in removal of sharp edges, puncturing and smoothening of blisters, edge preparation of the asphaltic membrane above the toe beam, and repair of a limited section of the toe beam. The first profiles of the anchorage assembly were fastened on the asphalt membrane with anchor rods embedded in resin (Fig. 4).

Figure 4. The vertical anchorage profiles are fastened to the face of the dam at regular spacing.

The PVC panels were lowered by crane on the slope and unrolled into the correct position. Panels were temporarily anchored against uplift by wind prior to welding and installation of the second profiles. Field welds between adjoining panels were made with single-track manual welding guns. All field welds exposed to the action of water were tested for watertightness.

The second profiles were installed over the panels in correspondence of the first profiles already fastened to the dam face. The coupling of the first and second profiles achieved anchorage and tensioning of the PVC liner. The second profiles were then covered with a PVC geomembrane strip welded with single-track manual welding guns and controlled for watertightness. Figure 5 shows the tensioning effect produced by the patented vertical profiles that have already been installed and waterproofed on the left part of the photo, while the panels on the right have not yet been tensioned.

Figure 5. The panels on the left have already been tensioned by the patented tensioning assembly; the panels on the right are waiting for completion of the assembly.

The placement of the profiles and of the liner, and its fastening and welding, were performed by workers on travelling platforms suspended at crest, or by workers secured by standard roped access procedures. Installation of the geocomposite started at the beginning of August 2001, was interrupted two times, in October and November, to allow additional grouting operations, and terminated on December 21, 2001. The work was performed in a variety of weather conditions. Only very strong winds, heavy rain and very low temperatures prevented welding and placement. Total installation time for the 25,000 m^2 of liner was 14 weeks.

Figure 6. Detail of the secondary perimeter seal at right abutment.

5 PERFORMANCE AT REFILLING OF RESERVOIR

Refilling of the reservoir started December 22, 2001. The winter of 2001-2002 was rather rainy and about 500 mm of rain fell in the first three months after closure of the control valves. The reservoir rose quickly and the water level at that time was approximately ¾ of full depth, about 9 m below Full Supply Level.

The geocomposite has performed extremely well. Total flow from the first compartment, which covers the entire original asphalt membrane, is less than 0.02 l/s at ¾ full reservoir head. Flow from the secondary compartment, which covers the toe beam between the primary and the secondary seals (Fig. 6), is greater, as it can come from various sources, including toe beam waterstops, and imperfectly filled grout holes. This flow, which has non-linear relationships in respect to water level, was less than 0.6 l/s at half depth.

6 CONCLUSIONS

Installation of the drained geocomposite system has allowed performing total rehabilitation of the dam within the foreseen time window. The geocomposite liner has been found to be very effective in reducing seepage: early indications suggest that leakage through the face of the dam at Full Supply Level will not exceed 20 millilitres/second. The performance results are up to date amply below the values required by the owner by contract.

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Figure 7. Total leakage from the 25,000 m^2 upstream liner is less than 0.02 l/s at ¾ full reservoir head.

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