Left: Efflorescence and subsequent spalling on the Stwlan Dam
Below: General view of the dam
Photos courtesy of the author

A New Face on an Old Problem

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Stwlan Dam is the 34-metre-high bu tress dam standing amongst the pea of Snowdonia near Blaenau Ffestini the slate-quarrying heart of Nort Wales and, once upon a time, the world. Stwlan [nounced "stoolán"] impounds 2.2 million cubic met of water, all for hydro-electric generation of a spec kind: pumped-storage. Water from Stwlan falls 300 ... through shafts and tunnels to four 90-megawatt hydro-turbines in Ffestiniog power station, generating up to 360 megawatts within minutes of switch-on. This energy is crucial in helping the UK electricity grid system meet its rapid fluctuations in demand hour by hour, even minute by minute. The reservoir is refilled by pumping water back up the tunnels and shafts on cheaper electricity at times of lower demand, generally overnight.

When opened by Her Majesty the Queen in 1963, Ffestiniog Power Station was the first of its kind in the world. Assisted (but never superceded) by its larger sister station at Dinorwig, also in Snowdonia, it continues to operate efficiently and reliably

The care and maintenance of the dam presents some challenges during this continuous use, especially when work is required on the lake-side face. This article highlights one particular problem with maintaining the dam and describes the solution reached.

The Problem

Like many mass concrete structures of its age, Stwlan's downstream face became streaked with efflorescence soon after completion. What became called the "stale-bread" effect was due to a combination of too much cement content and overly slow rates of construction. This combination created high differential temperatures during early curing, which resulted in slightly un-bonded lift lines. Water seepage through the dam walls reacted with free lime and slowly sealed almost all the leakage.

Stwlan also had an unusual double-wedge contraction joint between its buttresses. These joints were generally never quite sealed, and seepage continued, freezing and thawing winter after winter, until eventually, fragments of concrete began to spall and fall off. The ground between the buttresses had then to be fenced off to protect the public and grazing animals from falling concrete.

Water loss was insignificant to reservoir safety and to the operation of the power station, but minimizing further structural deterioration was necessary, so the search began to find a material to seal the seepage and eliminate the frost damage. Then, effective concrete repairs could begin.

Sealing the more accessible downstream face of the dam was rejected; water would continue to enter the structure, and repairs were likely to fail under the high and cyclical water pressure coming from the reservoir. So the less accessible upstream face would be sealed.

The first major investment in coatings began in the early 1990's with a polyurethane-based elastomeric material that required exacting environmental conditions for its successful application. A portable "environmental chamber" was suspended against the dam face within which the application was made. Unfortunately, the difficulty in creating the environmental conditions and the inconvenience of relocating this chamber for each area severely reduced productivity After a whole summer of applications, the entire application budget was consumed, but only about 10% of the face at the top of the dam had been coated. The obvious difficulty of using a product of this type led to the search for more prac tical materials that were far more tolerant of varying weather conditions.

A material was therefore needed that could be applied to the upstream face and survive under the following conditions:

Access platform suspended from special mobile rig on the dam crest for second round of coating trials

- no temperature control on an exposed mountain well over 500 m above sea level;
- no humidity control with an average rainfall of over 2.4 m a year; and
- wet concrete exposed for as little as two hours before being re-flooded.

The Trials

Product trials were initiated in 2000. Manufacturers were invited to prepare a patch of the dam face to their requirements and to apply their most suitable coating. Eight manufacturers took up the challenge, proposing a wide range of products, including elastomeric polymers, polymeric membranes, and cementitious-based products.

All were left on for a winter or two of daily exposure and submergence, and then reassessed. By 2002, three materials looked promising: a) a cement-based product, b) an epoxy resin reinforced with glassflake, and c) an epoxy-based polymer. The dam owners, First Hydro, decided to further assess these three products.

One product seemed to be too good to be true. The weather was rough and the water level was high when it was applied, with application by roller continuing below the cold waves. “No problem,” said the applicator. “No way!” retorted Bryn Williams, First Hydro’s assistant civil engineer. When he returned the next day with company civil engineer Owen P. Williams, Bryn expected to see the whole panel washed off, certainly where applied under water. But the trial was intact, and showed no sign of tidemark at all—three years later, it still doesn't.

First Hydro's term maintenance contractor, formerly Palmers but now Pyeroy of Rosyth and Newcastle, then applied the three best coatings from an access platform suspended from a special mobile rig on the dam crest road.

Each product was applied in a 4-metre-wide strip the full height of a double buttress joint, each under the direction and supervision of the coating manufacturer. Preparation was by high-pressure washing of the concrete only, with no repairs to the slight concrete defects. Application rate, bridging of joints and defects, and waste varied considerably.

These three trials were left for more than eight months and re-assessed in the spring of 2004. After exposure and re-flooding more than 250 times, it was clear that, for adhesion, uniformity, residual thickness, crack and defect bridging, and edge integrity, only one product was virtually blemish-free: a 100% solids epoxy incorporating Kevlar® (aramid fibers). Moreover, wind, rain, temperature changes, and humidity problems during application and early curing did not adversely affect the epoxy.

In conjunction with no waste and no visual contamination of the lake water on first submergence, First Hydro considered the epoxy to clearly be the best performer. Despite its higher unit cost, it was also evaluated to be the best overall value. Accordingly, the product was specified for all the remaining joints on the dam.

Continued

Properties of the Successful Coating Material

A 2-pack liquid epoxy/polyamine with inert plasticiser and fibre incorporation

Volume solids	100%
VOC	zero
Flash point	> 100 C (200 F)
Typical dry film thickness	250–500 micron
Theoretical coverage	$2m^2$ / litre (at 500 micron dft)
Application method Pot life (15 C) Drying times (15 C)	brush or roller 45 minutes touch: 6 hours hard: 20 hours
Min/max recoating time (15 C)	20 hours / 8 days

The Solution

Balancing the opportunities created by longer daylight hours with the lower operating lake levels and the restrictions due to other station maintenance, First Hydro planned to carry out the coating work on the face of the dam over two summers, 2004 and 2005.

Accordingly, in the summer of 2004, 7 of Stwlan's total of 19 buttress joints were prepared and coated, a total of 900 m^2.

All surfaces were prepared by 10,000 psi water washing alone to expose clean concrete surfaces and to remove loose laitance, small patches of surviving bitumen paint (the original coating applied in 1961), silt, and biofilm growth.

The strips were increased in width from four metres to eight metres, including the trial strips in place. Coated and uncoated areas would then be in equal hit-and-miss strips so that, if future monitoring dictated, the rest of the dam could be sealed in single-pass infill strips also eight metres wide.

Early coating effectiveness was confirmed by routine dam inspections through the winter and in spring of 2005. No seepage reaching the downstream face through the treated joint zones was identified.

In summer of 2005, the trials were re-started, and the remaining ten buttress contraction joint zones were coated, a further 1,150 square metres, again by Pyeroy, making an overall total of 2,050 sq m.

The work was concentrated in bursts of continuous shift work over long weekends whilst the power station was on "outage"; this meant the reservoir was kept empty, and the full face of Stwlan dam was therefore available and accessible.

Alex Brown, Area Director for Pyeroy, commented: "Our first reaction when speaking to First Hydro Company regarding the proposals for the initial trials was one of scepticism. However, it became clear at an early stage that the coating chosen was (from an application point of view) the way forward. Having now recoated over 2000 sq m of surface area on the upstream dam face, we would conclude that the [coating selected] was the correct solution."

First Hydro's company civil engineer, Owen P. Williams, concluded, "For us it's a problem solved whilst keeping Ffestiniog's vital generating capacity almost continuously available. To date, performance is excellent and we now plan to carry out the necessary repairs to the concrete on the joints at the downstream face."

The 100% solids, fibre-reinforced epoxy is manufactured under license by Crosbie Casco, Manchester, UK, for TFT UK, Ltd (the UK affiliate of Thin Film Technology of Houston, TX, U.S.).