

# Katrine Aqueduct Refurbishment

## essential capital maintenance refurbishment of a strategic raw water supply

The use of Loch Katrine for Glasgow's water supply has its origins in Victorian times. In the early part of the 19th Century, a mere 30 public wells – and a handful of private ones – provided the city's only sources of water. In 1848, after a second outbreak of cholera had again decimated the city's population, moves began to bring the water supply under municipal control in an attempt to overcome the growing public health problem. Five years later, John Fredrick Bateman – a civil engineer of considerable contemporary repute – concluded his studies with a recommendation to bring the high quality water to the city by gravity from Loch Katrine, some 35 miles away. The resulting supply system took three and half years to complete and involved the construction of a dam on the loch, a 42km-long aqueduct and the Mugdock storage reservoir at Milngavie on the outskirts of Glasgow.



Pipe condition prior to refurbishment works - Courtesy of George Leslie Ltd

### Background

On 14 October 1859, Queen Victoria herself officially opened the scheme "amid the booming of cannon and the applause of thousands of spectators"! It was seen as the engineering marvel of its day and remains an outstanding example of sustainable civil engineering public works construction, which has stood the test of time.

The original aqueduct comprises 21km of unlined 2.4m diameter hard rock tunnels - mostly under spurs of Ben Lomond – and 14km of arched aqueduct built in cut-and-cover. For over 6km the

aqueduct crosses the deep valleys of the Duchray, Endrick and Blane in 1.2m diameter cast iron pipes. The aqueduct has some 25 (No.) substantial iron and masonry aqueducts up to 24m in height and 27m in span over the numerous valleys and watercourses, the largest of which is the 200m long aqueduct bridge in the Duchray Valley which comprises a rectangular cast iron trough 2.4m x 2m, some 16m above ground level.

Despite being designed and constructed to cope with foreseeable increase in demand at that time, construction of a second aqueduct

was commenced in 1885 to accommodate the rapid expansion of Glasgow during the latter part of the nineteenth century. A more direct (shorter) route was chosen requiring fewer large bridges and although involving a greater length in tunnel, friction losses were reduced by incorporating concrete lining. The original aqueduct has the capability of delivering 205MI/day, with the 'new' delivering a potential maximum of 365MI/day. Cross-connection breaches allow raw water to be diverted between old and new to enable short-term shut-downs for inspection and operational maintenance with the downstream raw water reservoirs maintaining sufficient supply.

### Surveys

Over a number of years, Scottish Water commissioned extensive condition surveys over the length of this strategic aqueduct asset. The original Bridges & Tunnels Inspections & Report was undertaken in 2007-08, a supplementary Bridge Inspection in 2009 and a further report on the condition on the valves and valve house structures also prepared in 2009, from all of which a detailed inventory of repair work was established under several principal headings:

- Control valves and valve houses
- Inlet basin dam strengthening
- Masonry, cast iron and steelwork repairs to bridge structures
- Protection works to exposed pipework
- Concrete repairs to tunnel sections

With failure of the aqueduct presenting a risk to the security of supply of water to Glasgow, critical repairs and essential maintenance works were prioritised from the various reports and following a competitive tender, a £4.7m NEC3 Option A contract for repair works was awarded to George Leslie Ltd in July 2012. The tendered work covered three main areas:

**Valve & Valve House Repairs:** In total, 33 (No.) large diameter valves and penstocks were inspected with the necessary repairs and refurbishment carried out wherever possible without recourse to mains shut-down. Where this was not practicable, the works were rescheduled to run concurrently with other work being carried out under planned isolations. The objective of this work was to improve operational control of the aqueduct to enable easier future maintenance and to reduce reaction times when responding to any emergencies.

In addition, repair works were undertaken within three valve houses, principally to the floors and roofing and also to make access improvements, all to reduce operational health & safety risks.

**Structural Repairs to Bridge Structures:** Urgent repair works were identified on 16 (No.) bridges on the old aqueduct and a further 3 (No.) on the 'new', many of which were substantial structures. The schedule of repair works typically comprised replacement of steelwork and the provision of enhanced steelwork supports, crack sealing, masonry repairs to abutments and supporting piers and comprehensive grit blasting and the application a new full-protection coating system.

This protection work was undertaken within full 'Enviwrap' encapsulation to contain the grit and create ambient conditions for the application of a proprietary epoxy glass flake coating to provide a '25-year Life to First Major Maintenance' protection. Forced ventilation was also necessary to overcome the high humidity within the encapsulation, particularly where raw water flows were being maintained across the structures through 2.4m x 2.0m open troughs, including the 300m long Corrie 'Old' bridge.

At three locations the supply crosses the bridges in large, 1.2m diameter pipework, where a new pipe protection system was applied which comprised petrolatum primer coat, petrolatum and bitumen tape wrappings and an acrylic copolymer final coat.



*Kinlochard No1 in the depths of winter - Courtesy of George Leslie Ltd*



*Man-access and tunnel ventilation shaft  
Courtesy of George Leslie Ltd*



*Golf Buggy access for tunnel works - Courtesy of George Leslie Ltd*



*Winter access challenges - Courtesy of George Leslie Ltd*

Additionally, Endrick (Old) Bridge required further specialist work. Spanning the Endrick Water the bridge comprises a two-span masonry arch bridge with masonry spandrels and headwalls. Inspection reports had indicated significant scouring below the masonry pier located centrally within the river channel. Protection works involved excavation and the construction of a new concrete collar around the pier, with additional protection from further scour provided by gabion mattresses.

With the Endrick Water a designated Special Area of Conservation by Scottish Natural Heritage for its population of Atlantic salmon and lamprey, extensive special protective measures were required to prevent silting of this important watercourse during the mid-river construction work.

At Endrick (New) Bridge misalignment of the 1.2m diameter pipework which had also suffered significant erosion, was corrected with a 27m long 1.1m diameter pipe-jack, with annulus grouting.

**Tunnel Lining Works:** Due to advances in tunnelling techniques and in particular drill & blast technology between the construction of the old and new aqueducts, 32km of the total 38km length of the 'old' is constructed in tunnel and is a mixture of concrete lined and unlined where suitable rock conditions prevailed.

Following a comprehensive survey, a number of locations had been identified where the concrete lining had either collapsed or was showing signs of distress and thus with an increased risk of a major rock fall. With its greater capacity, any longer term emergency closure on the 'new' would increase the risk of security of supply, and this 7.6km long section was identified as the highest priority for concrete repair work to the lining and invert.

Access over the repair length was only available from either end and at three intermediate 'confined space' chambers with cross-

over connections. This section of the works was undertaken under full temporary lighting and with forced ventilation. A surface Mines Rescue team was in permanent attendance and this, together with enhanced safety training for the servicing and attendance squad, ensured that trained personnel were readily available to deal with an emergency should it arise.

As part of these precautions, a 'mock rescue' was undertaken, with full emergency services in attendance, to evacuate a 'casualty' from the furthest mid-point of the tunnel. A permit-to-work entry protocol was also adopted whereby only personnel who had undergone bespoke health & safety training together with detailed briefings on emergency and evacuation procedures were permitted access into the working area.

#### Planning historic Scotland listed structures

Over the combined lengths of the 'old and 'new', there are over thirty historic Listed Structures, and planning permission for the essential repair works was conditional upon full consultation with Historical Scotland on both the nature of the work to be carried out, and the materials which could be used. Strict adherence to these constraints and restrictions was necessary to ensure that the character of the historic structure was preserved.

Reconstructed areas of masonry had to match the existing stonework in terms of appearance, texture, colour, size and coursing with hydraulic lime mortar jointing, with as much of the down-taken stone reworked and dressed for reuse as possible. Painting and protective coating systems were carefully chosen to blend with the surrounding structure.

#### Temporary raw water supplies

A particular feature of the supply is the significant number of properties which receive raw water supplies with connections from the aqueduct and these are a combination of legal agreements



Full Encapsulation at Kinlochard No 2 - Courtesy of George Leslie Ltd

made at the time of construction and other 'unknown' connections. Much of the essential repair work could only be undertaken under temporary shutdown and a supply to these customers had to be maintained. This was successfully undertaken through a combination of temporary piped supplies and bowser deliveries to local header tanks.

#### Accesses

Challenging access to the variety of work areas was presented in a number of ways. Many of the bridge structures were located deep into heavily forested areas of the Loch Lomond & Trossachs National Park with limited access along many miles of forestry track roads.

Temporary and upgraded accesses were necessary to accommodate deliveries by articulated lorries of the significant amount of scaffolding which was required on some of the substantial yet remote structures. Safe access had to be maintained throughout the depths of winter working during prolonged periods of low temperature and lying snow. Careful reinstatement upon completion restored the scenic amenity of this area of outstanding natural beauty.

Access for the tunnel repairs lay at the other end of the spectrum and required the transportation of men, equipment and materials up to 1km within the confined space, where the innovative adaptation of a golf buggy provided the principal means of conveyance.

#### Programming & phasing

Maintaining an adequate raw water supply to meet the anticipated demand played an important part in the sequencing of the work. Under fully operational conditions, the combined old and new aqueducts provide more than adequate capacity and coupled with the cross-connection feeds and the raw water reservoir storage capacity, short-term shutdowns can be accommodated. For works of a more major nature there was however a potentially far greater

requirement for prolonged shutdowns which would necessitate the augmentation of supply from alternative raw water sources, at considerable additional cost.

Through careful sequencing of the bridge repair works (which were predominantly on the old aqueduct) and by undertaking as much work as possible under live (operational) flow conditions with detailed method statements to prevent any contamination, the shut-down requirements were minimised on this section of the works.

The tunnel repairs in the new aqueduct were managed to utilise cross-feed connections and through carefully monitoring of supply, demand and storage levels, the requirement for additional pumping was once again minimised.

#### Conclusion

The Design & Build contract commenced in July 2012 with updating condition surveys to verify the full work scope on the bridges and tunnel which was undertaken by consultants AECOM in conjunction with the contractor George Leslie Ltd.

Mobilisation with a full start on site was made in September, with final completion of the Works achieved in July 2013.

The logistics of the varied accesses which were required presented the greatest challenge to undertaking these essential works over the length of this structure of historical engineering significance, on this critical raw water supply asset, where close cooperation between contractor, operations personnel and other key stakeholders was paramount.

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