

The Falkirk Wheel - design of the aqueduct and wheel support structure

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Photo: Jim Mackintosh Photography

Figure 1: The Falkirk Wheel: aqueduct, wheel building and supports.

Introduction

The Falkirk Wheel, a unique rotating boatlift mechanism, was officially opened on 24 May 2002. Located midway between Glasgow and Edinburgh, it is on the Forth and Clyde Canal, completed in 1790, and takes 25 minutes to travel by road to each city. The Wheel forms the centrepiece of an ambitious and successful project to restore the canal network of central Scotland (see Figure 1). The form of the aqueduct, wheel building and supports is integrated with that of the wheel. It has gained much critical acclaim, including the Institution of Civil Engineers Brunel Medal and the Structural Steel Design Award.

While the wheel mechanism has been fabricated from steel, the remaining support structure and aqueduct was constructed from in-situ concrete for reasons of durability, low maintenance requirements, cost and aesthetics.

Design constraints

The design and construction of the Falkirk aqueduct and wheel support structure posed some interesting engineering challenges. Arup, the designer, successfully resolved these without compromising the original architectural concept within the budgetary constraints of a design and build

contract (see Figure 2). This was achieved in close co-operation with RMJM Architects and the contractor, Morrison Bachy Soletanche Joint Venture. It was necessary to resolve interface issues, such as loadings, structural movement tolerances and the construction tolerances between the wheel and supporting structure. This involved development of the scheme in conjunction with Butterley Engineering Ltd, the wheel fabricator, and the designers, Tony Gee and Partners and Bennett Associates.

The site is located on a 25m backfilled opencast coalmine with iron oxide contamination in the groundwater. The geometry of the wheel structure means that the formation level is up to seven metres below the water table.

The aqueduct

This structure consists of a 110m-long reinforced concrete trough supported from the sides by the curved concrete aqueduct pier arms with a semicircular void below the deck. The aqueduct pier and deck geometry is defined by a series of concentric circles determined by the wheel geometry. The deck is cast integrally with the central piers. These flex to permit deck movement under temperature loads (see Figure 3). Movement joints are provided at both deck ends.

The external curved form of the aqueduct trough was achieved by inclining the inside faces of the trough. This allows a simple and effective reinforcement configuration to be applied and reduces the deck weight. To enhance the concept of a 'floating' deck, a recess has been provided at the connection between the deck and pier so the form of



Figure 4: Grillage and finite element models.

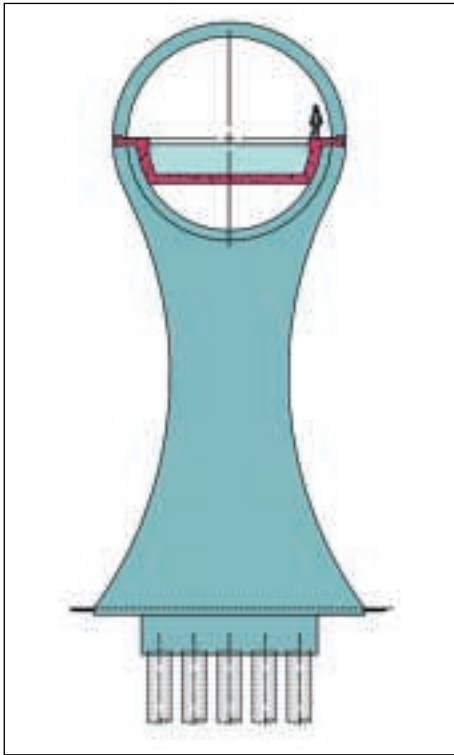


Figure 3: Geometry of the aqueduct deck and pier.

the hoops above water is mirrored in the piers below.

The analysis of the structure was carried out using a grillage model (see Figure 4). This simulated the:

- three-dimensional form of the trough
- vertical and transverse applied loads
- soil/structure interaction of the piled foundations.

This demonstrated that the piers provide additional horizontal and rotational restraint to the trough, resulting in a complex interaction of forces at the connection.

An efficient reinforcement connection at this junction was achieved by applying the reactions derived from the grillage model to three complementary strut and tie models (see Figure 5). The forces resolved on each of these models were combined to establish the stresses in the concrete and reinforcement. Further finite element analysis was undertaken to validate the strut and tie approach (see Figure 6).

Wheel building and support

This structure consists of the aqueduct support pier, the south wheel support and plant room facilities. It is composed of a cellular concrete structure that supports external cladding to form an hourglass



Figure 2: Erection of the wheel after completion of the concrete structure.

shape. A link trough is provided between the aqueduct and wheel to allow the aqueduct deck to expand and contract without compromising the tight positional tolerances required at the interface between the structure and the wheel (see Figure 6).

Close liaison with the wheel designers was required to identify the magnitude of the loads and interaction of loadings simultaneously applied on various sections. Four main scenarios were identified to

establish the critical load combinations:

- storm wind (wheel fixed in position)
- operational wheel loads
- restrained gondola (e.g. when the gondola was attached to the building, allowing boats to cross on the aqueduct).
- jacking of the wheel for maintenance.

Factored load combinations were identified. These included the 900-tonne

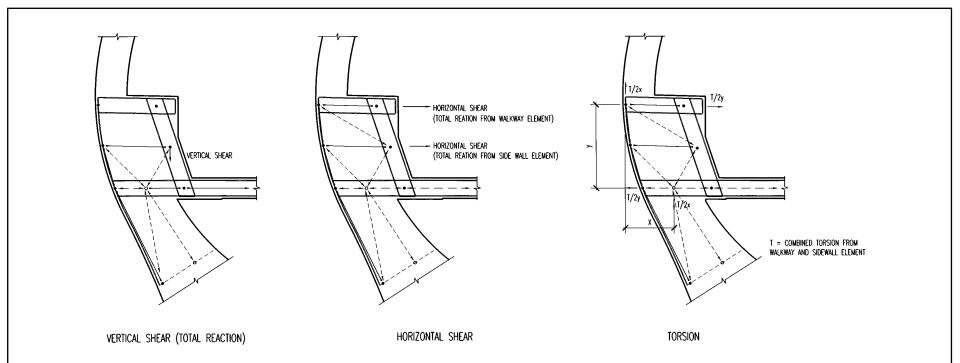


Figure 5: Strut and tie models for the pier/deck interface.

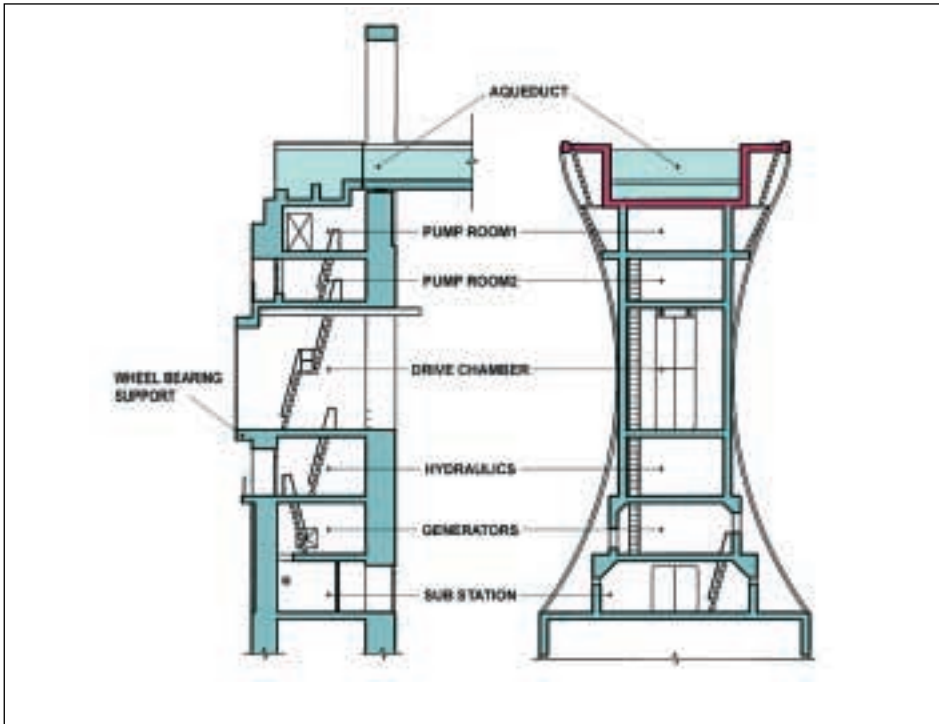


Figure 6: Wheel building and support structure.

self-weight of the filled wheel at each support, the mechanical effect, which accounts for ±160 tonnes at each of the bearings supporting the wheel drive, and a horizontal boat collision load of 40 tonnes applied at aqueduct level.

The wheel building was constructed before erection of the wheel and fixing of associated plant. Critical interface areas were boxed out to allow casting in of fixings at a later date once plant had arrived on site.

Foundations

As the aqueduct and wheel support is located on an area of backfilled opencast mine, large-diameter bored concrete piles were used to avoid obstructions in the variable backfill material. These extended up to 25m through the backfill, being socketed in the underlying sandstone bedrock to minimise settlement of the aqueduct and wheel supports.

Concrete

A high-quality, durable, water-retaining concrete was specified to:

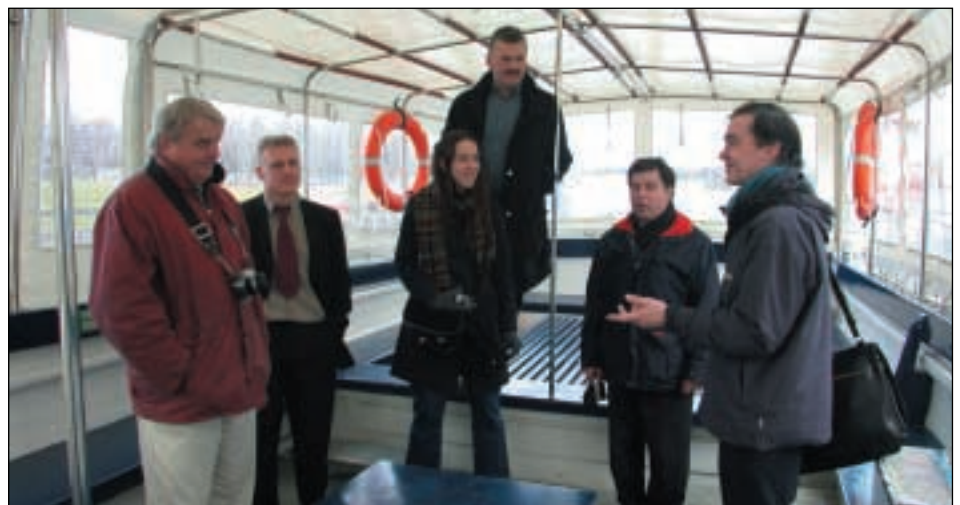
- retain canal water in the aqueduct
- keep out groundwater for elements below the water table
- provide a durable surface, particularly for zones subjected to freeze-thaw cycles.
- resist the sulfates in the groundwater.

Summary of concrete requirements.

(See table below)

The designated mixes, preferred by contractor, were specified in accordance with the Manual of concrete documents for highway works: Volume 1⁽¹⁾ incorporating the following additional requirements:

	Class	Required workability	Air entrainment	Sulfate class
Piles	RC40	150+mm	Yes	Class 2
Aqueduct, wheel building and supports	RC40	75mm	No	Class 2



Members of the Irish Concrete Society visiting the Falkirk Wheel - November 2002.

- the recommendations given in BS 8007: 1987 Code of practice for design of concrete structures for retaining aqueous liquids⁽²⁾, including a tighter specification of the mix proportions and cement content.
- the recommendations provided in CIRIA Report C559 Freeze-thaw resisting concrete - its achievement in the UK⁽³⁾ including use of air entrainment and reduced aggregate water absorption.
- a mix incorporating pfa was specified to optimise sulfate resistance without compromising other concrete properties, such as strength development.
- for water-retaining surfaces and splash zones on the aqueduct, an additional level of protection/waterproofing was provided using a cementitious waterproofing slurry with hygroscopic properties.

References:

- 1 THE STATIONARY OFFICE. Manual of concrete documents for highway works: Volume 1 - Specification for highway works,
- 2 BRITISH STANDARDS INSTITUTION. BS 8007: 1987 Code of practice for design of concrete structures for retaining aqueous liquids, London, 32pp.
- 3 HARRISON, T., DEWAR, J and BROWN, B. CIRIA Report C559 Freeze-thaw resisting concrete - its achievement in the UK, London, 2001, 80pp.