Union Canal Aqueduct, Edinburgh

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INTRODUCTION

Edinburgh City Bypass

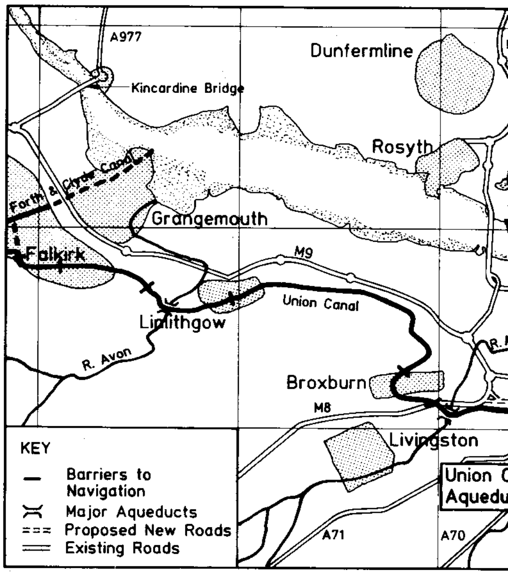
THE Union Canal aqueduct is currently under construction as part of the Sighthill Section of the Edinburgh City Bypass which is due for completion in 1987. (Figure 1).

The bypass is a Lothian Regional Council project which, when finished, will provide a route between A8 to the west and A1 to the east.

The Engineer for the Sighthill Section is Lothian RC Department of Highways (LRC), and the aqueduct was designed by Scott Wilson Kirkpatrick and Partners (Scotland) (SWK), on behalf of the British Waterways Board (BWB), for inclusion in the contract. Lothian RC will be responsible for maintenance of the aqueduct on completion of the contract.

In their original proposals for the Sighthill Section, LRC intended to carry the bypass over the canal using a bridge with very small headroom over the canal. A small marina for pleasure craft was to be provided to the west. SWK were appointed by the BWB in 1979 to advise on alternative bypass schemes in this area, which would maintain full continuity of the canal as a navigable waterway, in line with BWB's current philosophy.

BWB and others subsequently raised objections to various aspects of the Sighthill planning proposals and, following public consultation and an examination of various alternative alignments, LRC concluded that the provision of an aqueduct, and a revised vertical alignment of the bypass, were justifiable, principally on grounds of cost. (Figure 2).



■ **Figure 1. Location plan.**

Canal History

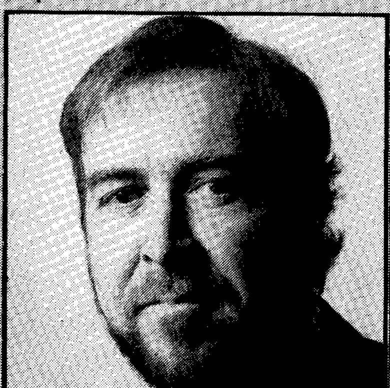
A canal linking Edinburgh and Glasgow, essentially for the transport of coal and other goods, was first proposed in 1793 when John Ainslie and Robert Whitworth Jr were commissioned to survey possible routes. In 1797, John Rennie examined the proposals adding two more of his own.

The Napoleonic Wars brought planning and speculation to a temporary end but the idea was revived in 1813 when Hugh Baird, engineer for the Forth and Clyde Canal completed in 1791, proposed a branch line from the canal at Falkirk to Fountainbridge, Edinburgh. (Figure 1).

Thomas Telford, gave his approval to

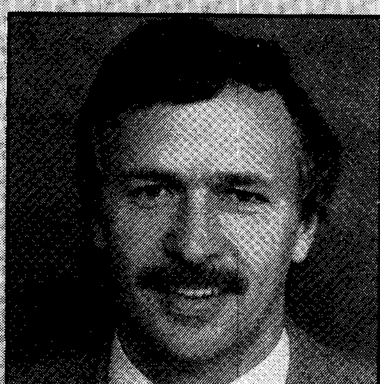
THE AUTHORS

JAMES McCafferty graduated from Strathclyde University in 1967 and is now an Associate, Scott Wilson Kirkpatrick and Partners, responsible for, among other things, the bridges and structures groups of the Scottish Partnership.



■ James McCafferty

His early experience was on the design and construction of various roads and motorway projects in Scotland, where he specialised in bridges. In 1976, he joined the Hong Kong Partnership, where he was responsible for major road and bridge works.



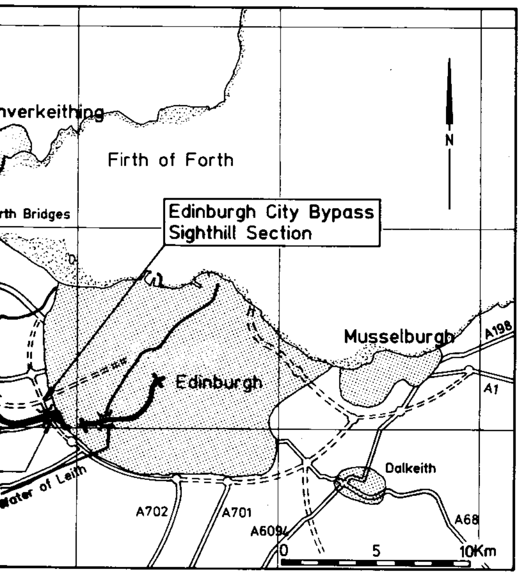
■ Frank Osborne

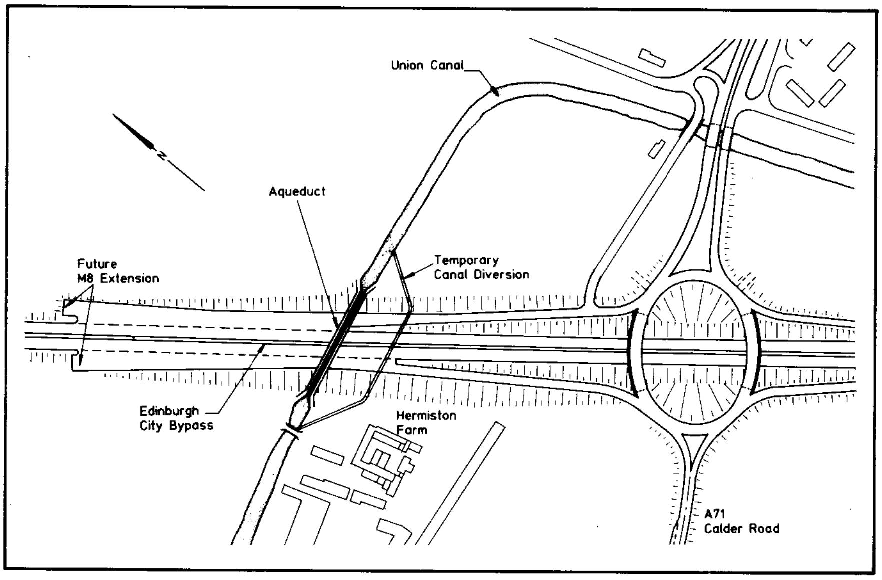
He rejoined the Scottish Partnership in 1981, from where he has been involved in the design and checking of many bridges in UK, Nigeria and Hong Kong.

FRANK Osborne graduated from Paisley College of Technology in 1975 and his early experience was with consulting engineers in the design, supervision and construction of marine works, bridges and other structures. In 1980 he spent some time in Nigeria, involved in the supervision of construction for a new port at Sapele.

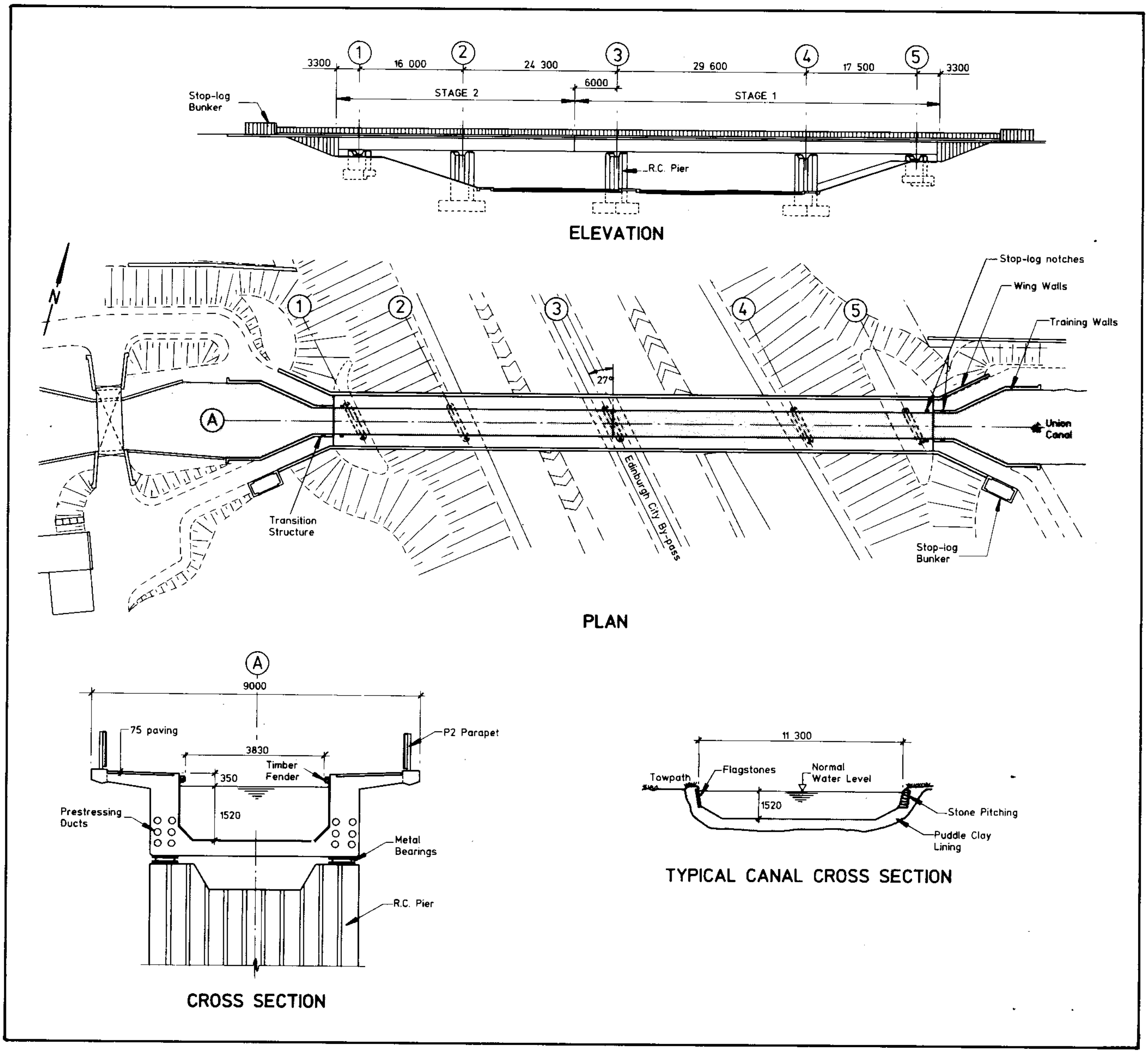
He joined Scott Wilson Kirkpatrick and Partners in 1982, and was involved in the design of bridges and structures for projects in the UK and overseas.

He is currently a Project Engineer with Bullen and Partners in their Glasgow office.

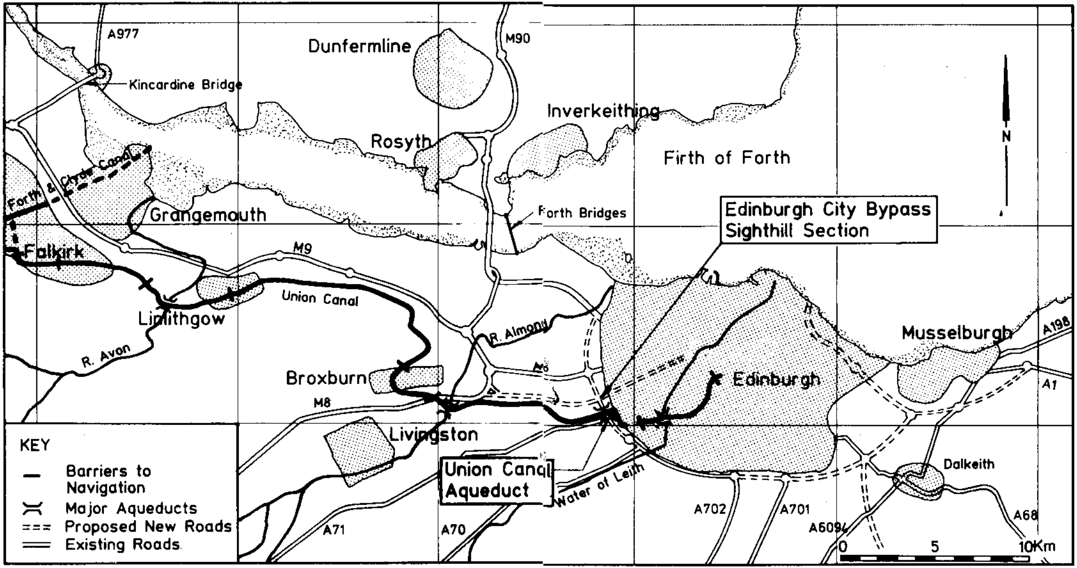




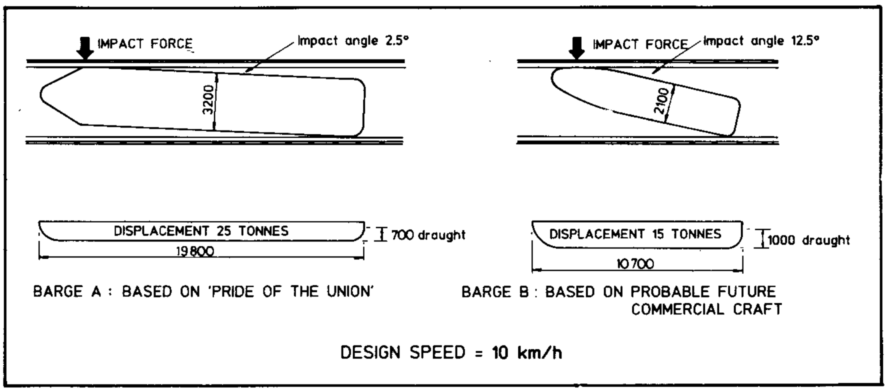
■ **Figure 2. Edinburgh City bypass at Hermiston Aqueduct.**



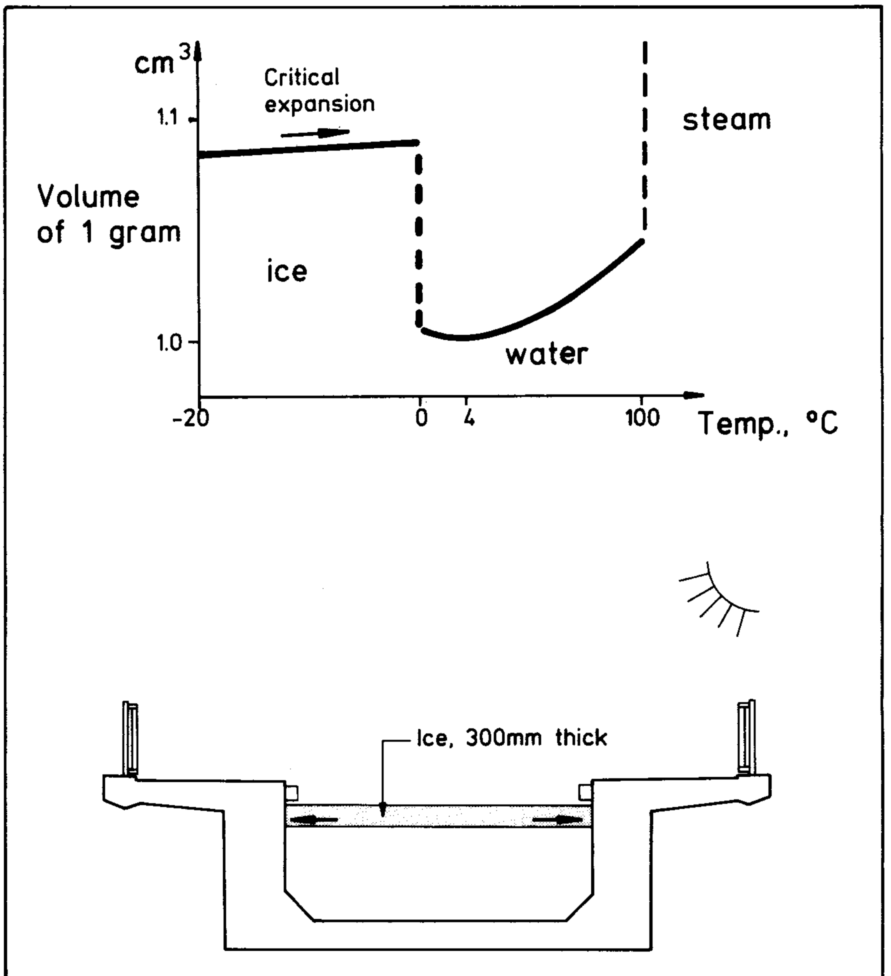
■ **Figure 3. Aqueduct - General arrangement.**



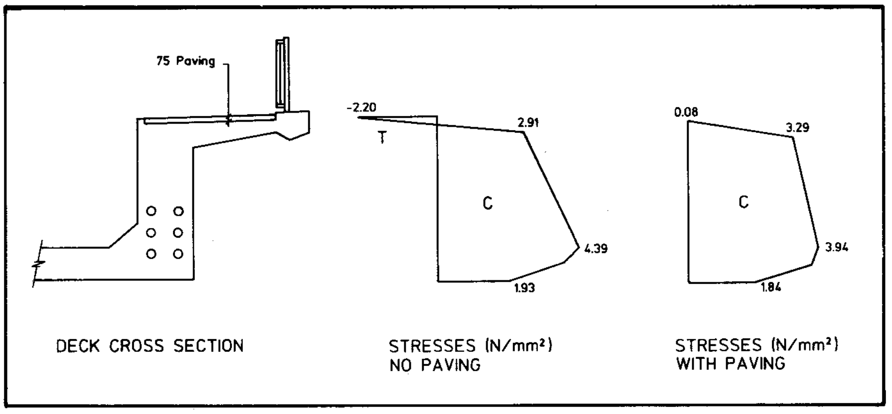
■ **Figure 1. Location plan.**



■ **Figure 5. Barge impact.**



■ **Figure 6. Ice thrust.**



■ **Figure 7. Differential temperature effects.**

superstructure is designed as a prestressed concrete section with no tension allowed under any load combination. The prestress design was carried out using SWK Program BDGDES.

In this instance, bending moments were collected from the grillage analysis, for critical points and generally at 2m centres. These were input as arrays of data with trial tendon forces and profiles, until an optimum arrangement of prestress was derived for transfer, short term and long term standing states, and the various live load combinations, including differential temperature stresses.

The effects of differential temperature were initially calculated using the gradients specified in SB6/74 for concrete superstructures. It was appreciated that these were not intended for use on water-filled aqueducts, but it was felt that they were indicative of the real situation and therefore adequate for design.

These effects resulted in large tensile stresses in the top 100mm of the webs and side cantilevers. Elimination of these stresses was achieved by the insertion of a 75mm lightweight concrete paving layer on the side cantilevers, thereby insulating the top surface of the deck. Modified temperature gradients, taking account of the paving layer, were adopted for design. (Figure 7).

Transversely, the superstructure was designed as a reinforced concrete section for appropriate combinations of water pressure, silt, barge impact, ice thrust and live loads, in accordance with BS 5337, to ensure water retention. It was found that the crack width criteria of BS5337, rather than the provision of strength, governed this design.

The specified prestressing system required the installation of six tendons (double end stressing) of 15/15.7mm diameter seven wire superstrand to BS5896, with a jacking force of 2981 kN (75 per cent UTS), before lock-off, for the webs of Stage 1, and six tendons of 19/12.9mm diameter superstrand with a jacking force of 2651 kN (75 per cent UTS), for the webs of Stage 2. Standard prestressing couplers were specified to achieve full continuity of prestress throughout. In the event, the contractor proposed, and was allowed to adopt, 22/12.9mm dia. superstrand with a jacking force of 2981 kN (72.9 per cent UTS), for Stage 1. Lower values of friction coefficient and wobble factor were also proposed and adopted.

Prestressing end blocks and bursting reinforcement above and below the bearings were designed in accordance with CIRIA Guide 1[6].

The combination of reinforcement for shear, torsion, transverse bending and bursting at the end blocks required careful detailing at the ends of the superstructure to avoid conflict with the movement joint seals, prestressing anchorages and stop log notches.

Grade 45/20 concrete and high yield steel reinforcement are specified for the superstructure.

Design - Substructure

The intermediate and end supports are reinforced concrete columns with pad footings, founded in very stiff boulder clay. grade 30/20 concrete and high yield steel reinforcement were specified, as was air entrainment for the concrete in the pier columns themselves, to enhance their durability.

The superstructure is pinned to the central pier which is consequently designed to carry the longitudinal wind load and 'out of balance' bearing friction and longitudinal barge impact. The other piers are designed to cater for bearing friction in the longitudinal direction.

Transverse wind load and barge impact are transmitted to the piers by the side restraint bearing described in 'Structural Form'.

The end supports are founded at a high level in the side slopes to the bypass, as are the wing walls and training walls. In consequence, it was necessary to ensure that the side slopes in the vicinity of the aqueduct had an adequate factor of safety against rotational or shear failure.

The wing walls and training walls are designed as normal cantilever walls founded in boulder clay. Grade 30/20 concrete and high yield steel reinforcement were specified.

SPECIAL FEATURES

Movement Joints and Seals

FUNDAMENTAL to the satisfactory performance of the aqueduct are the movement joint seals.

In addition to the accommodation of longitudinal movements due to creep, shrinkage and temperature variation, the joints were required to be completely watertight, easily maintained and replaced, and simple to inspect.

Traditional methods of effecting such seals rely on puddle clay or, more recently, sealing compounds or even PVC waterstops.

In this instance, the range of movement (up to 60mm at both ends of the aqueduct) precluded such simple solutions and proposals were sought from manufacturers of proprietary systems; the response was disappointing.

It was decided that a purpose-made joint seal would be required and that it should be failsafe and capable of accommodating the calculated movements without imparting large stresses into itself or the structure. Contact was eventually made with a rubber manufacturer, who co-operated in the evolution of the specified system. (Figure 8).

The joints comprise two individual seals which run around the three sides of the superstructure's 'U' shaped trough and span the end gaps between it and the abutment transition structures. (Figure 4).

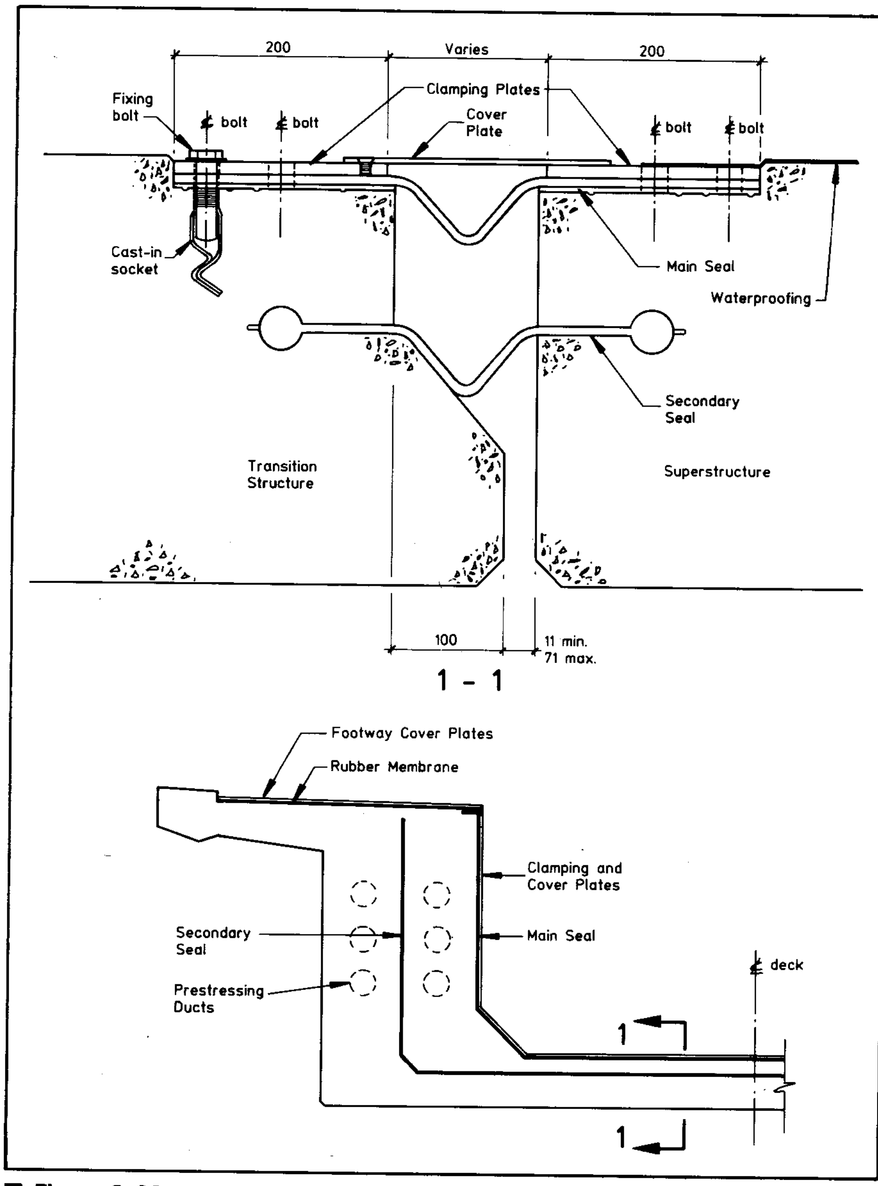


Figure 8. Movement joint and seal.

The main seal, located on the inside (water face) of the superstructure comprises a continuous, preformed, neoprene bellows, reinforced with a fabric ply, and soft rubber sealing strips. This seal is compressed against accurately formed concrete surfaces using stainless steel clamping plates, fixing bolts and cast-in sockets.

Cover plates are included, and the whole assembly is recessed into the concrete surfaces of the superstructure and transition structures to protect the seal from damage.

The secondary seal, a continuous, preformed, neoprene, bellows-type, eyeletted waterstop, is cast into both superstructure and transition structures. This seal is the back-up to the surface mounted seal, and comes into operation if the main seal is punctured or removed for maintenance or repair.

Puddle Clay

The traditional method of sealing the inverts of canals is to line them with puddle clay. The same traditional method was applied here, to effect the seals between the canal and the training walls and transition structures, and to make the connection with the existing canal where it had been severed during construction.

Waterproof Membrane

The superstructure is essentially watertight, being prestressed longitudinally and designed to BS5337 transversely. However, it was considered prudent to provide additional waterproofing.

The most important qualities identified for a suitable system were: ease of maintenance, resistance to impact and abrasion, resistance to ultra-violet light and the ability to accommodate thermal, shrinkage and flexural movements of the concrete.

The specified system required a coating of solvent-free epoxy resin applied in two layers over the entire inside surface of the superstructure. In addition, a layer of fibrated bitumen was specified for areas at the junction of the bottom slab and webs to provide additional protection where cracking of the more brittle epoxy lining might occur as a result of flexure.

Water Test

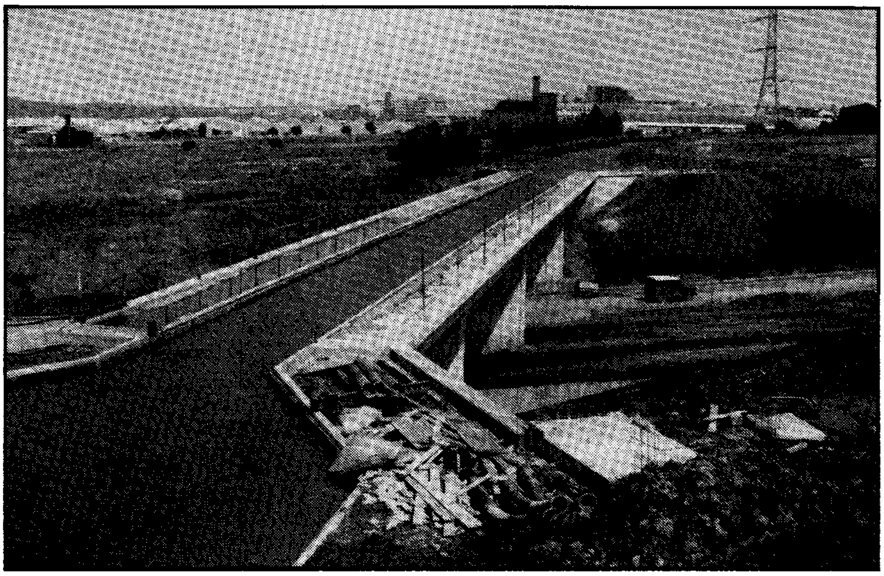
The contract required that the superstructure be water-tested prior to application of the waterproof membrane, to permit a visual inspection of the entire structure for leaks and other defects.

Timber Fendering

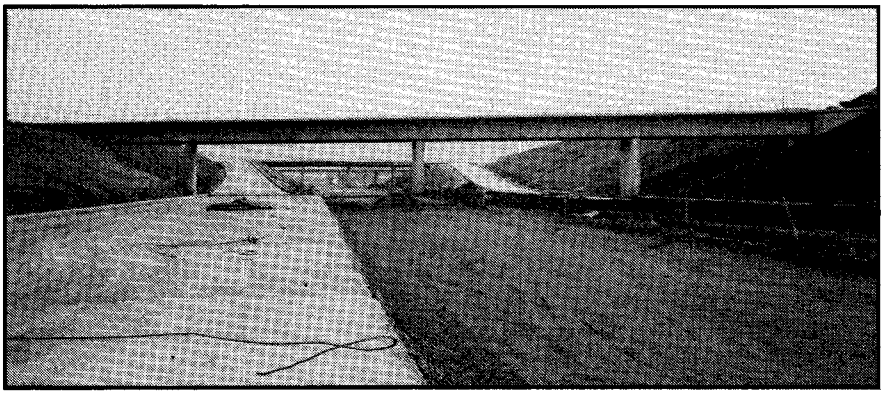
The internal faces of the superstructure and training walls are protected from barge impact and nosing forces by timber fenders located just above normal water level. The fenders are 200mm x 100mm in section, cut from mature, seasoned oak, attached to the superstructure by stainless steel bolts and cast-in sockets. Natural rubber pads are provided at each fender support (at 1.5m centres), to reduce the effects of barge impact.

Stop Logs

To enable the aqueduct to be isolated from the canal for maintenance purposes, stop log notches are incorporated into the training walls and superstructure. Steel stop logs, normally stored in RC bunkers near both ends of the superstructure, can thus be used to seal off either the whole of the aqueduct, or the movement joint sections which can then be drained for inspection or maintenance. (Figures 3 and 4).



■ **Figure 9. Aqueduct from towpath.**



■ **Figure 10. Aqueduct from bypass.**

TEMPORARY DIVERSION OF CANAL

THE aqueduct is positioned along the centre line of the canal and, consequently, provision had to be made for the maintenance of water flow through the site during construction to ensure adequate supply to the industrial consumers in Edinburgh. The flow of water is normally controlled by the Wester Hailes pumping station to the east, which was installed to preserve the water supply when the canal was piped in that area, to permit the construction of a housing estate.

The contractor was required to provide, either by diversion or by pumping, a canal bypass with a flow capacity of 237 litres per second during the period of canal closure. In addition, standby pumps of the same capacity were required.

There was a danger of the reservoir of canal water between Wester Hailes pumping station and the diversion being depleted in certain circumstances thus lowering the water level and possibly causing instability of the canal banks. In consequence, a further contractual requirement was that the difference in water level across the diversion was not to exceed 75mm.

The accepted canal diversion system was an open trapezoidal channel, 1.0m deep, lined with polyethylene fabric to ensure watertightness, and positioned to the south of the canal thus allowing construction of the northern section of the bypass cutting and the foundations of the aqueduct. (Figure 2).

Earth bunds were used to effect canal closure, and temporary inlet and outlet works were constructed, incorporating stop-log systems to allow controlled filling and emptying of the diversion channel, thus ensuring no local erosion damage to either the diversion channel or the canal.

CONSTRUCTION

CONSTRUCTION of the Sighthill Section of the bypass commenced in September 1984 and the canal diversion was brought into operation in May 1985, allowing construction of the bypass cutting and severance of the canal.

At the time of writing, (August 1986) the aqueduct is complete apart from parapets, some finishings and landscaping works.

Construction of the substructure went without incident but several problems arose during the construction of the superstructure.

During Stage 1 construction there was a failure of the concrete supply and the back up, with the result that the pour had to be aborted. After much consideration by all concerned, the contractor decided to demolish the partially completed stage. To aid construction it was agreed that Stage 2 be constructed in advance of Stage 1 leaving a gap between the two to allow Stage 1 stressing. The gap was then completed thus allowing coupling of tendons and stressing of Stage 2.

During the water test, damp patches appeared at several locations on the soffit and, at both ends, a few fine longitudinal cracks showed up on the soffit of the bottom slab allowing drips of water to pass. In addition, the main seals did not hold water at all, the gap between the two filling with canal water!

An investigation of the damp patches revealed their association with areas of poor compaction. These were sealed by scabbling the surface concrete and applying a cement base acrylic polymer patching compound followed by a heavy duty cement base waterproof coating. The same treatment was applied to the top of the bottom slab at both ends over the fine cracks.

Discussions with the supplier of the main expansion joint seal, revealed that initial leaks, particularly around bolt holes, were not uncommon. Following recommendations from the suppliers, cover plates were removed from the splay areas and the seal eased up to permit the injection of a polysulphide joint sealant. Polysulphide joint sealant was also applied along junctions between the main seal and the adjacent concrete and around every bolt head. The subsequent water test proved satisfactory with no evidence of leaks. Following the draining of the canal to allow the application of the waterproofing, the fibrated bitumen layer was applied over the movement joints, in addition to the specified locations, as a further safeguard.

No trace of original puddle clay was found in the lengths of canal exposed for construction, possibly due to the lodgement till, being considered by the original builders to have been sufficiently low in porosity. In consequence, the new puddle clay seals were extended as far as the temporary sealing bunds. Nevertheless signs of seepage from the canal are evident in the face of the cutting beneath the east abutment. These are being monitored pending a decision as to whether further remedial action is required.

CONCLUSIONS

ATTITUDES towards the preservation of canals as useful navigable waterways, even if only for recreation, have changed since the 1960s, when, it seems with almost reckless abandon, they were severed, piped, syphoned or filled in; often for the construction of roads and motorways.

LRC are to be congratulated for their enlightened attitude to the preservation of this stretch of the Union Canal.

The aqueduct is a relatively simple structure but it does involve an interesting combination of old and new technology, and required a slightly different line of thought than the typical motorway bridge.

It is hoped that the paper will be of interest generally but more particularly so to those called upon to design canal aqueducts, rather than pipes, elsewhere.

FACTS AND FIGURES

Client	Engineer (Scotland) British Waterways Board
Highways Authority and Engineer for the Works	The Director of Highways Lothian Regional Council
Consulting Engineer	Scott Wilson Kirkpatrick & Partners (Scotland)
Contractor	Balfour Beatty Construction (Scotland) Ltd
Prestressing sub-contractor	VSL Systems Ltd
Expansion joint seals	The Northern Rubber Co Ltd
Tender Sum(2)	£12.6m Sighthill Section Edinburgh City Bypass
Estimated cost of aqueduct	£500,000(1)
Contract period(2)	36 months
Date for completion(2)	October 1987
Plan area of structure between movement joints to outside of parapets)	850 m^2
Cost per m^2	£590(1) Complete structure including wing and training walls £360(1) Deck only

(1) SWK pre-tender estimate including an allowance for preliminaries and contingencies.
(2) For the complete contract - Sighthill Section, Edinburgh City bypass.

MAIN QUANTITIES

	Deck	Piers & End Supports	Walls
Volume of structural concrete (m^3)	595	392	261
Mass of steel reinforcement (tonnes)	97	54	50
Mass of prestressing tendons (tonnes)	19	–	–

ACKNOWLEDGEMENTS

THE authors wish to thank Mr R.B. Davenport BSc MICE, Engineer (Scotland) of British Waterways Board, Mr P.J. Mason MSc FICE FIHT MCIT DipTE, Director of Highways, Lothian RC, and the Partners of Scott Wilson Kirkpatrick and Partners (Scotland) for permission to publish this paper. The authors also acknowledge the assistance of their colleagues in SWK (Glasgow) and their opposite numbers in British Waterways Board and Lothian RC in its preparation.

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(5) **Design of Small Dams:** US Department of the Interior, Washington, US Government Printing Office, 1974.
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