Conservation of Laigh Milton Viaduct, Ayrshire

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This paper is about an ICE-initiated project to conserve Laigh Milton viaduct in Scotland, the world's oldest surviving public railway viaduct. Between 1992–96, the project's directors raised £1·065 million, bought the viaduct and completed the necessary work within budget on a design-and-build basis. This paper covers all aspects of the project, from initial fund raising and planning to site investigation by radar scanning and structural refurbishment. It will serve as a useful case study for anyone involved in the increasing number of projects now planned and underway to conserve the world's civil engineering heritage.

History

The four-span Laigh Milton Viaduct, originally called Milton Bridge, over the Irvine west of Kilmarnock (Fig.1) was the major structure on the first public railway in Scotland, the Kilmarnock & Troon. The line was engineered by the eminent engineer William Jessop (1745–1814) and operated by horse traction from 1811–46. In 1824 Scotland's leading railway authority Robert Stevenson wrote

> 'the only public railway of extent in Scotland is that between the manufacturing town of Kilmarnock and the harbour of Troon; which agreeably to act of parliament, is open to all on payment of a certain toll'.[1]

The railway, or tram road, was surveyed in 1807 (Fig.2)[2] and constructed from 1808–12. It was nearly 16 km in length, double-track, and of 1·22 m (4 ft) gauge. It allowed a horse to draw an 8–10

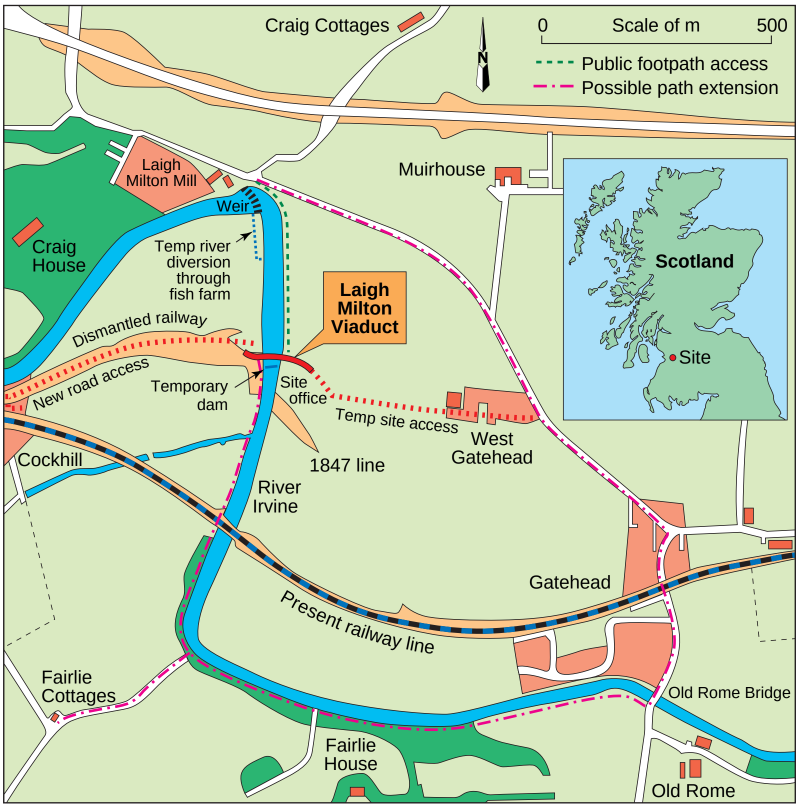

Fig. 1. Location and access

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Fig. 2. Part of plan of Kilmarnock & Troon Railway, 1807 (viaduct top left)

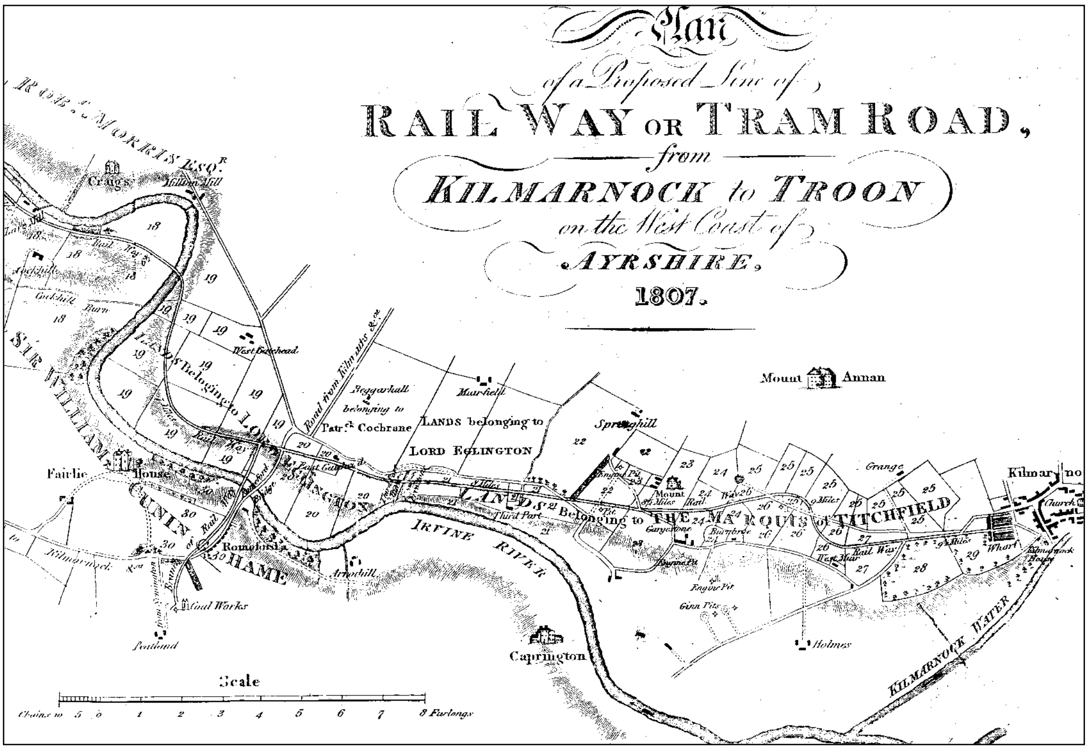


Fig.3(below). Passenger carriage by 'Fair Trader' (courtesy East Ayrshire Libraries)

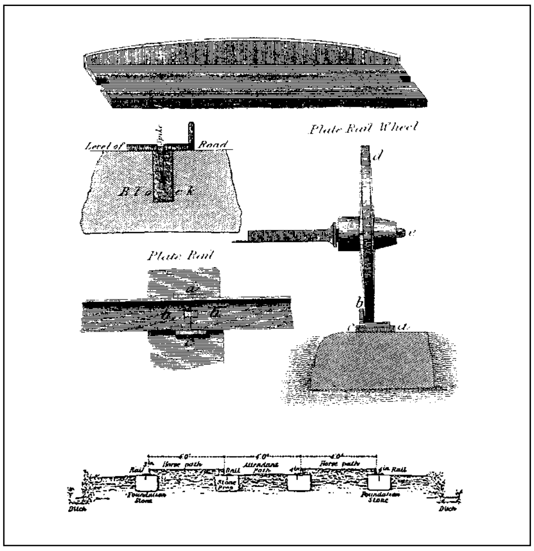


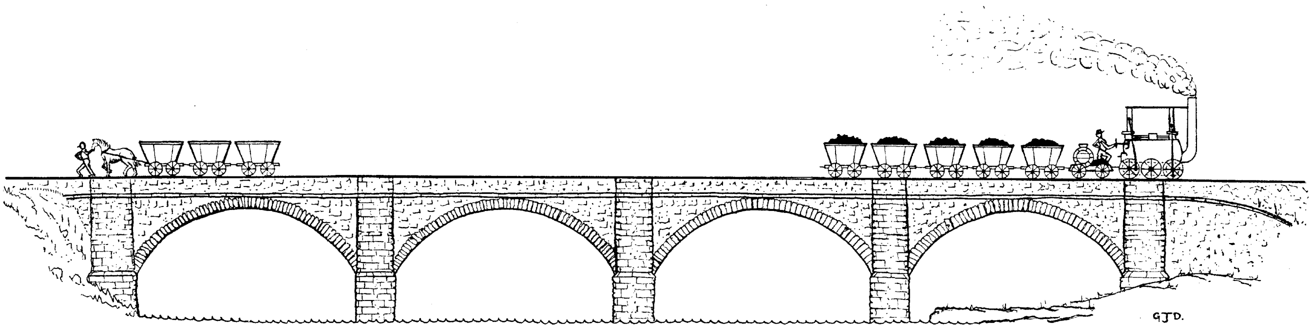
Fig. 4 (above right). Iron plate-rail details

times greater load than it could by road and enabled this type of railway to make a significant contribution to the national economy for several decades. The railway, in conjunction with the deep-water harbour at Troon, also planned by Jessop and constructed concurrently, made an immense contribution to the development and prosperity of the area and led to the creation of the town of Troon. These improvements were effected almost entirely at the expense of the 4th Duke of Portland, mainly to facilitate the carriage and export of coal from his collieries near Kilmarnock. The projects eventually cost about £150 000, [3,4] now equivalent to about £40 million using a multiplier of 280 based on broadly comparable viaduct tender prices of 1809 and 1994. The railway engineering work cost about £42 000,[5] including about £3600 for the viaduct.[6]

The Kilmarnock & Troon line had the unexpected distinction of becoming Scotland's first public passenger-carrying railway. Passengers were travelling over the viaduct by August 1811. From 1812 they were conveyed in privately-owned wagons, known as 'caledonias', drawn by one horse, supposedly 'at no faster than a walk'[6] (Fig. 3).[7] By 1826 the railway and its bridge over the Irvine were serving the then fashionable sea resort of Troon.[8] Passenger usage in 1837–38 can be estimated from tonnage dues at about 200 000 passenger miles a year, or two to three return

Fig. 5. Worn rail section at mid-length (far left) and replica plateway detail (left) (now in the ICE museum at Heriot-Watt University)

Fig. 6 (below). Conjectural view of Milton Bridge in 1816, looking south



trips daily between Kilmarnock and Troon, doubling in summer. In freight terms, coal dues alone for the same period were nearly 90 times greater at £7196.[9] Commercially, the railway was so successful that, on Robert Stephenson's advice, it was leased rather than purchased by the Glasgow & Ayrshire line in 1846, and its company continued to exist until 1899.

A convenient facility for railway users was that the flat plate-rails, in conjunction with frequent 'turn-outs' on to adjoining highways, enabled the double-handling of freight and passengers to be obviated. According to John Wilson, the railway company's surveyor, this arrangement attracted a great deal of use by wagons and carts meeting the company's requirements.[10] A drawback was that rail surfaces tended to collect dirt and stones and traction was impeded. To facilitate operation, the track between rails was filled with small, hard, angular broken-stone to near the top of the upstands (Fig. 4).[11] A good design feature, which had involved major cut and fill, was the formation of the railway as a continuously inclined plane with a uniform slope of about 1 in 660 from Kilmarnock down to Troon.[1] This arrangement enabled a good horse to draw at least three loaded wagons each of 0·66 t and containing 1·67 t of coal[10] easily to Troon and to return with empty wagons against the gradient.

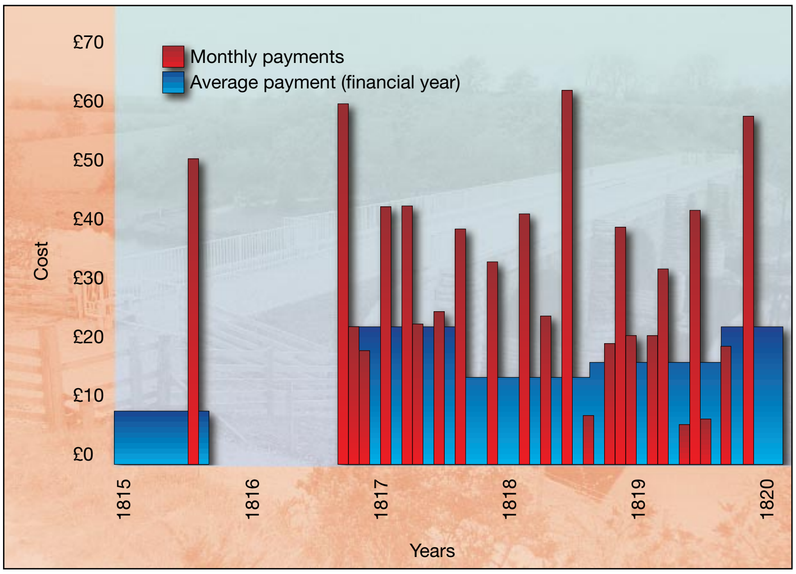


Fig. 7. Payments to Kilmarnock Foundry for replacement rails and castings 1815–1819

Several original cast iron rails were found on site during the conservation work, one of which was used to make a pattern for the replica track rails which have been provided as part of the viaduct's refurbishment (Fig. 5). Each rail was 0·91 m (3ft) long with a longitudinally curved upstand on the inside increasing from about 50 mm at each end to 76 mm in the middle. Its form and method of sup-

Fig. 8. West end, north face with bulging, stone loss and vegetation

Fig. 9. (below). West pier, south face with cracking and stone loss

port and connection are indicated in Figs 4 and 5.[1,10] A rectangular-headed wrought iron spike secured adjoining rails in place. Most of the original rails were made by Glenbuck Iron Company which by 1813 had received £13 345 for about 72 000 rails,[6] representing nearly one-third of the railway's engineering cost. By 1818 a stronger rail invented by Wilson was in use, with two longitudinal 'feathers' underneath (Fig. 5). Several years later he facilitated replacement rail-laying by introducing an iron saddle under each rail end (Fig. 4).[1] The viaduct, although closed to most operators in July 1846, was still carrying some colliery traffic in November 1846 just before its abandonment. The upgraded, locomotive-traction edge-railway, with larger radii curves, became operational over a timber structure immediately south of the viaduct in spring 1847.

About five years after the railway had opened, and nine years before the opening of the Stockton & Darlington railway, the Duke of Portland introduced steam locomotion on the line to haul coal from his collieries (Fig. 6).[12,13] A trial was conducted using, it is believed, a Stephenson Killingworth type locomotive with six, flat-soled wheels. The engine was appropriately named *The Duke* and, according to an eye-witness,[14] its trial was conducted by Robert Stephenson, George Stephenson's brother. It is understood that the engine 'from its defective construction and ill adaption to the rails drew only 10 tons at the rate of five miles an hour'.[3] Buchanan stated that the locomotive 'succeeded well', but was 'given up on account of its destructive effect on the cast iron rails although its weight was only five tons'.[15] Modern-day calculations indicate that a wheel load of 1·7 t would have been sufficient to break a rail in shear near the edge of a block, a finding consistent with broken rails found. This load would have been easily achieved at times with hammer-blow effect and rocking caused by the locomotive's primitive vertical to horizontal load transmission. A study of the railway company's monthly payments to the Kilmarnock Foundry for replacement rails and castings revealed a significant increase in expenditure from September 1816, indicating that the locomotive was probably in use by then (Fig. 7), though its duration on the line is not known.

The viaduct carried the railway about 8 m above the river on 12·3 m (40 ft) span freestone arches. Each arch is of segmental elevation with a rise of one-third span and a 0·61 m deep voussoir. The resident engineer was Thomas Hollis, who was probably allowed considerable autonomy by Jessop in the design as built. The contractor was a Mr Simpson, almost certainly the stonemason John Simpson (d. 1816), who was extensively employed by Telford and who is known to have been working at Ardrossan and the Caledonian Canal at about that time. Simpson had just completed Ballater Bridge, timber from the centring of which was

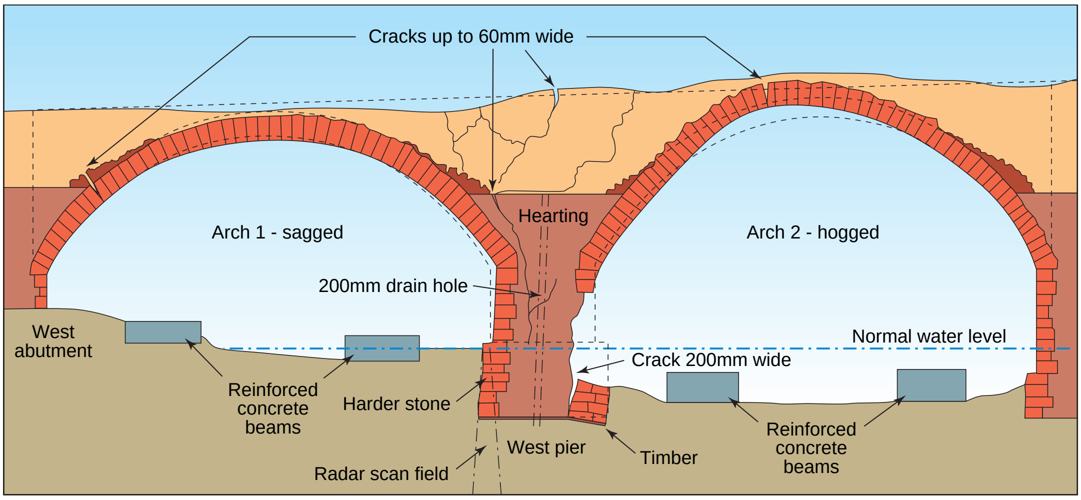


Fig. 10. Section of west pier and adjoining arches with spandrel fill removed—looking north

Fig. 11. West pier, east side—erosion into lime-mortar-bedded hearting (courtesy Mr F. M. Jones)

probably used for the same purpose at Milton Bridge.[16] Hollis was refused permission to dismantle part of the mill-dam (Fig. 2) in order to lower the water level sufficiently to enable the bridge piers to be founded. In July 1809 he was authorized to proceed by means of a cofferdam, involving 'very little more expense', with the advantage 'that the stones for the bridge can be floated down on a punt'[6] from near the mill. In March 1810, it was decided to use stone from Third Part, a mile west of the site (Fig. 2). By September 1810 Simpson had received £1934 for work done and ten months later the viaduct was operational.

This utilitarian, medium-scale viaduct was designed in accordance with traditional rather than 1810 state-of-the-art practice. It did not incorporate the hollow cross-tied spandrel improvement then being adopted with increasing frequency by leading engineers. If this had been adopted here instead of clay fill, it would have obviated the spandrel bulging and some of the stone loss that occurred. Much of the viaduct's stone quality and some workmanship at the west end were only just adequate for the purpose (Figs 8 and 9) but the flat-stone, lime-mortar-bedded, pier hearting carried up to 1·5 m above arch springing was an effective feature which had probably saved the piers from collapse (Figs 10 and 11). In cross-section, the spandrels presented an unusual application of the classic gravity retaining wall (Fig. 12). Although a valuable example of early railway construction, the viaduct's outstanding historical significance rests mainly on its important associations and in being the earliest known survivor of a type of multi-span railway structure subsequently adopted universally.

Fig. 12. South spandrel wall and undressed extrados of arches

The conservation project

The conservation project was particularly challenging because of the viaduct's

- lack of any recent use
- indeterminate ownership
- inaccessibility to the public road network
- unknown ground conditions and foundation state
- precarious and generally ruinous state
- requirement for substantial funding.

Following authoritative predictions that the viaduct was in imminent danger of collapse, the Scottish Office was requested by the ICE panel for historic engineering works (PHEW) to take it into care for the nation. Although this request was refused, the Scottish Historic Buildings and Monuments Division (now Historic Scotland) indicated its willingness to consider grant-aiding the viaduct's repair through an appropriately constituted trust. Accordingly, in February 1992, the Laigh Milton Viaduct Conservation Project was formed and soon afterwards constituted as a limited liability company with tax advantageous charitable status by reason of its community benefit. A company was considered to be more advantageous than a trust in limiting the liability of its members and to allow greater flexibility in financial decision-making. The project's directorate consisted of four civil engineers, including two leading contractors and an eminent journalist, an elected member representing each of the local authorities involved and a banker/lawyer with company and trust expertise.

The project's objectives were

- to conserve the viaduct without necessarily taking on ownership
- to seek local government commitment to the viaduct's future repair
- to promote knowledge of the viaduct and its future use
- to seek, receive and disburse the necessary funding.

It became necessary for the project to acquire ownership of the viaduct as a condition of the major funders but this was done, in February 1995, only when the following criteria had been met.

- Strathclyde Regional Council (SRC) had agreed to contribute the formulation, letting and overseeing of the main contract as employer and to take over the viaduct's ownership on completion. In the event, SRC's contribution through its directors of physical planning and roads proved crucial to the success of the venture.
- The probable costs were known and covered by adequate funding.
- Acceptable terms for access and future ownership of the viaduct had been agreed with all parties.

Ownership

From a study of old records a good case seemed to exist for at least part of the viaduct being owned by British Rail Property Board. This opinion was reinforced when it was discovered that the board had offered to sell one of the farmers land which included part of the viaduct in 1977. In reply, the farmer disputed the board's ownership of the land, but not of the viaduct, following which the board declined any further interest in ownership. This decision increased the difficulty of fund-raising as it precluded any financial contribution either from the board or the Railway Heritage Trust. After a diligent search by the project's solicitors, ownership of the viaduct was deemed eventually to rest with the adjoining farmers. Agreement was reached with the farmers to acquire the viaduct for £1·00 on condition that, if for any reason it was not taken over by SRC, ownership would revert to them. The farmers' legal costs were met by the project.

Input to specification

In April 1994 a decision was made to proceed with the main work by a design-and-build, lump-sum contract. The project notified SRC's roads division of the following points to be covered as far as practicable in the specification.

- All work to be of the requisite standard to enable SRC to take over the viaduct's ownership on completion.
- The original masonry of the viaduct to be preserved in its existing state as far as practicable and the whole structure brought to a secure, waterproof, good state of repair for safe use by pedestrians. The work to involve, securing foundations, stabilizing piers and arches, cleaning off vegetation, and replacing masonry where missing or defective with matching stone of similar colour and quality. The deck and side railings or parapet walls to be of a design approved by the project which is compatible with the viaduct's character. All work to comply with the requirements of Historic Scotland.
- The work to be tendered for on a two-phase basis to suit the availability of funding.
- Each stage of work to be completed within budget before starting the next.
- The methodology for the safe conduct of each stage of work, and the security of the structure at all times, to be clearly stated and demonstrated at the tender stage and to be subsequently implemented and monitored.
- A photographic record to be taken before and during work.
- The project to be safeguarded as far as practicable against possible claims from the farmers and river authority in respect of damage to their property and interests.

Contract procedure

It was recognized that the design-and-build, lump-sum contract procedure would involve the contractor in more expense and risk than the usual practice, but it was considered that the likelihood of any claims would be reduced. In the event, the lowest tender price received for phase 1 was about £200 000 more than the funding promised at that time. Fortunately, an urgently prepared case for additional funding was successful, and invitations to tender were extended to firms selected from SRC's list of approved contractors. Pre-tender presentations of proposals by prospective contractors were made at Ayr in July 1994. Within two months, tender bids were received ranging from £0·52–£0·87 million for phase l and from £0·98–£1·55 million for the whole refurbishment to be executed continuously.

Fig. 13. West pier — radar scanning with Oyo receiver

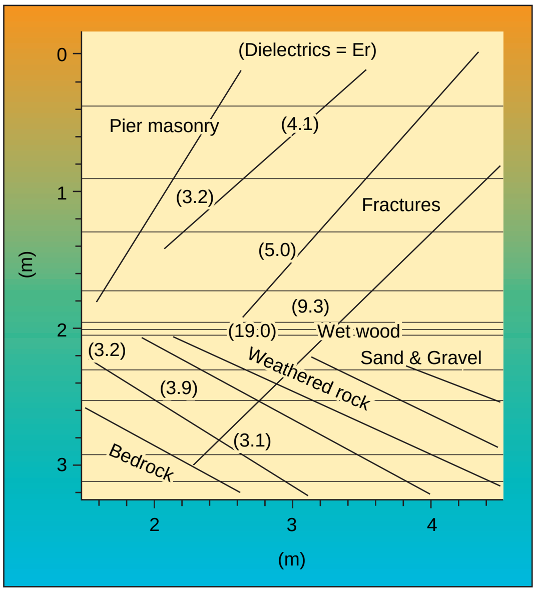


Fig. 14. West pier, west side—vertical radar plot to 3·2 m depth

Fig. 15. State of work on 3 August 1995 with water lowered at viaduct

To safeguard against a possible progressive collapse of the structure, each tender was based on all arches being supported independently of the existing structure before any refurbishment began. The lowest tender, for continuous execution of the whole contract, was accepted in February 1995.

Finance

In order to obviate having to return numerous small sums of money if the project did not proceed, funding was sought for substantial sums only. By February 1995 a package totalling £1·065 million had been assembled.

- National Heritage Memorial Fund—£400 000
- Historic Scotland—£277 300
- European Union (via SRC Planning)—£200 000
- SRC—£63 000 plus roads and planning services
- Kyle & Carrick District Council—£65 000

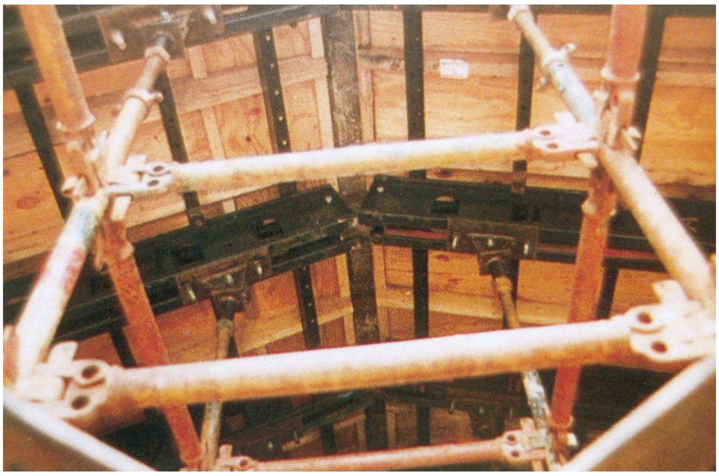


Fig. 16 (above left). Skate used for sliding temporary support frameworks into place

Fig. 17 (above right). Top of support framework from inside

Fig. 18 (below). West pier, west side—pointing and concrete surround to base

- Kilmarnock & Loudoun District Council—£45 000
- Enterprise Ayrshire—£15 000.

The project secretary prepared all the technical submissions, except that to the EU. The chairman, Lord Howie, and Historic Scotland, played a key role in obtaining the NHMF funding. The two largest sponsors required binding legal agreements to be entered into to safeguard their interests. Their contributions and that of the EU were payable only after execution of work. This situation was managed as follows. The local authority engineer's representative checked and certified the payment due on the contractor's monthly valuation. On receipt of a copy of the certified valuation the secretary then claimed and obtained payment from the sponsors and arranged for the transfer of funds as required. It was important for the management of the venture that the other funding was unconditional in this respect. The out-turn was that the main contract, with the minimal agreed extras which will be referred to later, was completed within budget for £1·024 million, accounting for 95% of the funding. Preliminary works accounted for a further 1·5% and legal costs and administration 3·5%.

Access

Rental agreements were entered into with both farmers for use of their roads and land for site compounds for the duration of the work. A preliminary contract for the 500 m long permanent access road to the site, from Cockhill farm (Fig. 1) along the dismantled railway line, was let in December 1993. In order to meet a dead-line for £140 000 of EU funding, this contract was prepared, priced, let by competitive tender and technically started, all within a fortnight. The work, which included strengthening an operational railway overbridge with a reinforced concrete saddle and parapet protection, was executed by August 1994. Temporary access to the site compound near the east end of the viaduct was gained from the road via West Gatehead farm. Agreements for

Fig. 19 (top). Non-structural concrete spandrel infill before waterproofing

Fig. 20 (above). East pier—piecing in new stone above reinforced concrete collar

Fig. 21 (right). Ductile cast iron plaque

public footpath access also were concluded with the farmers who, unfortunately from the standpoint of maximizing the viaduct's after use on completion, were not prepared to agree to cycle use across their land. Pedestrian access to the viaduct is by public footpath from the road to the north (Fig. 1). South Ayrshire Council is currently progressing the possibility of a footpath extension to the west and south of the viaduct and East Ayrshire Council, an improvement of the path access and signing.

Planning consent was not required. Listed building consent was obtained by June 1994, subject to approval of the handrails, which were considered essential for public safety, and deck details. Handrails had probably never existed previously and it was considered appropriate to make them of steel in an authentic period style. After examining photographs of the cast iron railings of Chirk Aqueduct and other early examples, agreement was reached with the planners to masonry copings and light-coloured railings comprising vertical 30 mm square bars at 120 mm centres with horizontal top and bottom rails. The planners also agreed to an historically appropriate segmental cap to the top rail to improve the appearance of the railings, to small broken stone similar to that used originally for the deck surface, and to explanatory plaques and a short length of replica plate-way.

Administration

The project, which handed over ownership of the viaduct to East and South Ayrshire Councils on 18 April 1997, was run by a management committee which met 30 times from 1992–97. In addition to its directors, the committee included representatives from the planning and roads departments of the local authorities and Historic Scotland. The secretary/director acted as manager, kept minutes of meetings and was designated company secretary for the requirements of Companies House. The project's banker/lawyer director advised on financial matters and instructed its lawyer in consultation with the secretary. The accounts were prepared and audited by a national firm of accountants. The company is to be wound up in 1998.

Insurance cover

From the award of the contract in February 1995 the project's directors were covered for its duration under the contractor's policy for all risks as principals, without additional premium. To minimize the directors' exposure to risk, the exchange of missives was timed to take place immediately before the contract was formally awarded. It was agreed that if the viaduct collapsed, liability would not extend to rebuilding it.

Refurbishment

The viaduct had become fragile largely because of the crumbling of much of its stone, which was

Fig. 22. North face with footpath ramps at each side, fencing and deck finishings

Fig. 23. South face in 1992

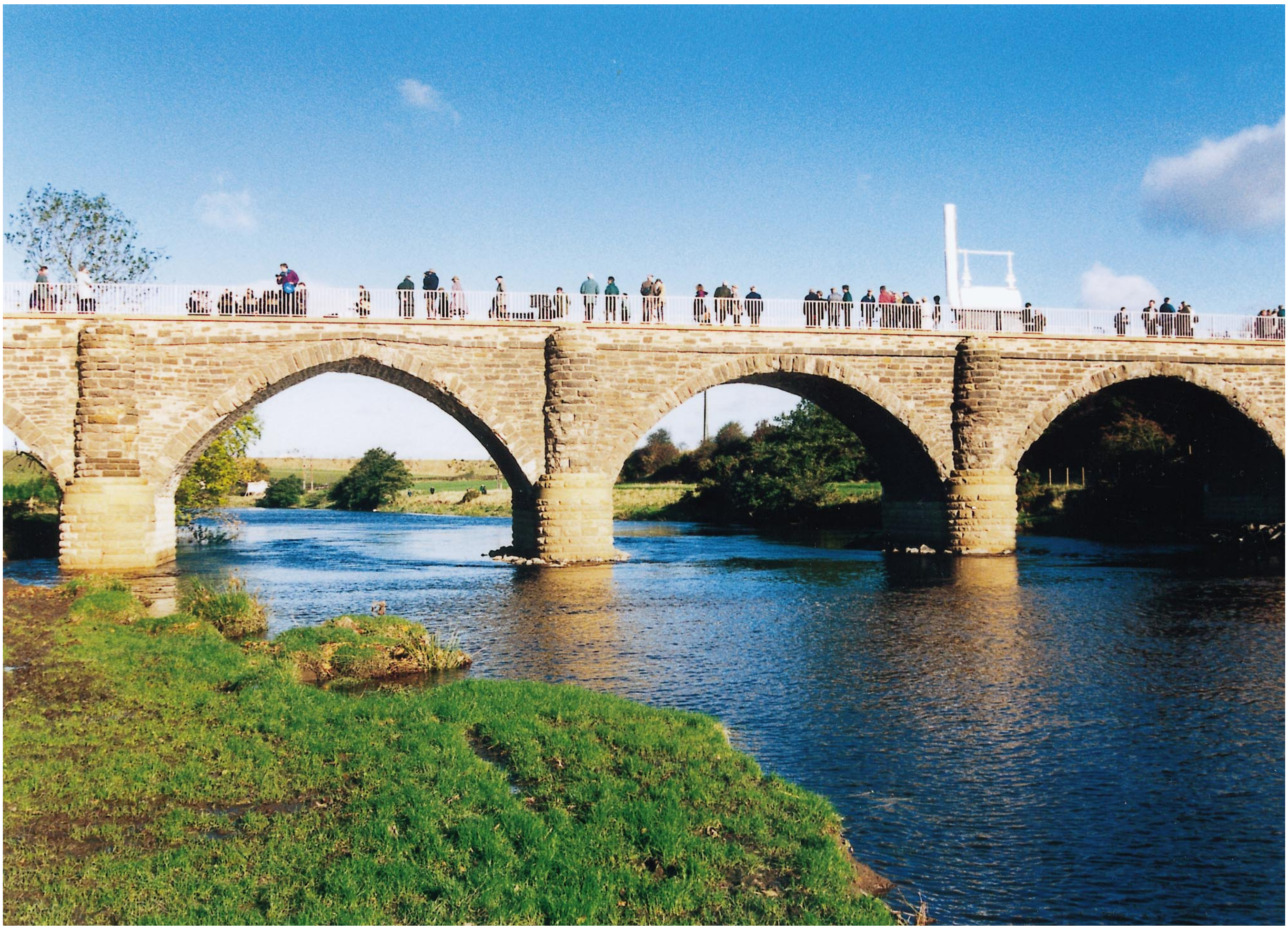


Fig. 24. South face at the re-opening (courtesy Dr M. Oglethorpe)

not of the best quality being of a minutely fissured weak texture. With lack of maintenance, vegetation and weather effects, this weakness had led to widespread stone loss and serious undercutting to all piers at or near water level. The west pier was seriously cracked, mainly around its traditional hearting, and had lost about a third of its 2·9 m thickness (Figs 10 and 11). Some movement had occurred long ago causing stretching and hogging of the arches adjoining the west pier. From an unbroken glass tell-tale installed in 1992 it was believed that no further movement had taken place in the three years prior to the start of work. The north spandrel wall had suffered extensive stone loss at the top and some peeling away of pier bull-noses (Fig. 8). Colliery records indicated that the structure had not been undermined by coal extraction.

Radar scanning

To provide as much ground information as possible for prospective contractors before tendering, a high-frequency radar scanning contract was let, which basically indicated firm ground conditions under the piers of the viaduct. Later, before the remedial measures to the west pier were finally determined, a vertical scan identified ten dielectric layers. Constants between 4·1–9·3 indicated stone, above what proved to be a 100 mm thick traditional pier platform of hard saturated wood at 2 m resting on acceptably firm material. Fractures indicated normal to the bedding and passing through both bedrock and structure may have resulted from seismic activity (Figs 13 and 14).

Design and construction

Work to the contractor's approved design started on site in June 1995. In August the water level had been lowered by nearly 1 m at the viaduct by creating a temporary rubble dam immediately upstream (Fig. 15), and temporarily diverting the river through the fish farm downstream and so bypassing the mill-dam (Fig. 1). This measure enabled plant and workmen to cross the river at the site independently of the viaduct and pairs of transverse reinforced concrete beams to be constructed on the river bed under each arch. Temporary steel support frameworks were then assembled between the dam and the viaduct and slid into place under each arch by means of skates running on the surface of the beams (Figs 15 and 16). Plywood against the intrados of each arch was held in place and supported from the framework by means of adjustable props (Fig. 17). As soon as all the arches were secured, an excavator commenced work on top of the viaduct, scaffolding was erected from the temporary frameworks and repair work began. Safety was a paramount consideration throughout the work.

By November 1995 the clay fill had been removed from the spandrels and the replacement of missing stones and pointing from scaffolding had begun (Fig. 18). It was considered impracticable, and unnecessary structurally, to try to replace most of the extensive loss from *in situ* stones, but all loose flakes were removed. The site agent had shown initiative by artificially ageing a trial area of new stone with peat and milk to resemble the old stonework, but it was insisted that the new stone should remain untreated in order that old and new work could be identified. The mortar mix for bedding was 1 hydrated lime: l cement: 6 sand and, for face pointing, 1 hydraulic lime: 3 sand. By July 1996, the spandrel walls were almost completed, surmounted with new copings and railings, and the cavity infilled with mass concrete to waterproofing level with a longitudinal fall to drains at each side of the viaduct (Fig. 19).

The undercut piers had been secured by means of reinforced concrete collar surrounds resting on foundation courses of harder stone which, following dewatering and debris removal, were found to be mainly intact (Fig. 15). The surround to the west pier (Fig. 18) was more extensive than to the other piers. The surrounds were faced with matching new stone (Fig. 20). Grouting up the fissures below the head of pier 1 consumed 320 l of cement mortar. Sufficient funding remained to provide 7·3 m of replica plate-way, ductile cast iron plaques with explanatory details of the viaduct and project, and fencing and public access ramps at each side (Figs 21 and 22). The good working relationship which existed between the contractor, engineer's representative and secretary helped to maximize preservation of the original structure and to achieve the best practicable quality of conservation. An indication of the extent to which this was successful can be gained from a comparison of Figs 22 and 8 and 23 and 24. Note the preservation of the 0·3 m distortion of arch 2 (Fig. 10) and that from the approach the light-coloured railings are unobtrusive visually against the sky. The viaduct was formally re-opened on 29 October 1996.

Conclusion

It is expected that the viaduct, formerly unappreciated and largely unknown, will soon make an important contribution to Scotland's industrial heritage circuit, currently estimated by the Scottish Tourist Board to attract 1·7 million visitors annually. Further afield, the project has already proved 'very instructive'[17] to the newly-formed Usui Railway Route Conservation Project dedicated to the conservation of one of Japan's most historic viaducts.

Acknowledgements

The author wishes to thank the Japan Society of Civil Engineers for permission to reproduce this updated version of the paper which he presented at Akita and Tokyo in June 1996.[18] For further information on historical matters, preliminary work and acknowledgements, the reader is referred to the JSCE publication,[18] copies of which are available at the ICE and National Library of Scotland.

Contractors and suppliers on the project were as follows. Barr Construction (preliminary works and main contractor); Solway Engineering (temporary arch support and handrailing); Sedgwick UK (insurance); Geospace Consultancy Services and Dr C. Stove (site investigation); Stirling Lloyd (deck waterproofing); Natural Stone Products, Hexham (new stone); A. McCluskie, Dalry (replica plate-rails); Ballantine Bo'ness Iron Co. (ductile cast-iron plaques).

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Discussion

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