OUR ENGINEERING HERITAGE

THREE NOTABLE EXAMPLES IN THE EDINBURGH AREA

DEAN BRIDGE
LEITH DOCKS
FORTH RAIL BRIDGE

NOTE ON FORTH RAIL BRIDGE ILLUSTRATIONS

The front cover design is from an original sketch by Frank White, to whom the Edinburgh and East of Scotland Association of the Institution of Civil Engineers express their thanks for permission to reproduce it.

The photographs illustrating the construction of the bridge are taken from the first edition of (Phillips, Philip) *"The Forth Bridge in its various stages of construction, and compared with the most notable bridges of the world,"* Edinburgh: (c. 1890).

The engraving on the back cover is taken from the supplement of *"The Engineer"* for 9 November 1888.

Copies of this publication can be obtained, price £1.50 post free, from: Maurice Williams, NSHEB, 16 Rothesay Terrace, Edinburgh EH3 7SL.

THE INSTITUTION OF CIVIL ENGINEERS

Edinburgh and East of Scotland Association

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THREE NOTABLE EXAMPLES IN THE EDINBURGH AREA

DEAN BRIDGE
LEITH DOCKS
FORTH RAIL BRIDGE

(with 22 illustrations)

by

Roland Paxton, John Kerr and Douglas McBeth

Second Edition

EDINBURGH

1981

FOREWORD

In 1971 the Institution of Civil Engineers formed its Panel for Historical Engineering Works to record, advise on and promote knowledge of our engineering heritage. In Scotland measures to further these aims have included this booklet and, more recently, another similar publication, *'A Heritage of Bridges between Edinburgh, Kelso and Berwick'*, both of which included previously unpublished material and attracted favourable press comment and an excellent public response.

Although the historical engineering works dealt with in this booklet are small in number, they are of great significance. The Port of Leith is probably the best example in Scotland exhibiting on site the progressive development of dock works over two centuries. These works form the basic infrastructure of the modern port. Dean Bridge, one of the most remarkable multi-arch masonry bridges ever built, will reach its 150th anniversary of completion in 1982. The year 1982 is also the centenary of the commencement of that mighty masterpiece in steel—The Forth Rail Bridge. It is a great tribute to their designers and builders that both bridges continue to make a major contribution to the movement of people in modern society.

This booklet has not previously been on general sale in the bookshops but has nevertheless quickly sold out and the opportunity afforded by a second edition has been taken to make minor improvements and to provide additional material relating to Dean Bridge, including a sketch illustrating the unprecedented nature of its construction, and also a dramatic view of work in progress at the Forth Bridge in 1888. The publication coincides with and hopefully will enhance two significant events in the Scottish engineering calendar for 1981, both to take place in Edinburgh, the 25th Congress of the Permanent International Association of Navigation Congresses and the visit of the Panel for Historical Engineering Works of the Institution of Civil Engineers.

In conclusion, I should like to thank my co-authors for their valuable contributions and also David Haldane and the other members of the Committee of the Edinburgh and East of Scotland Association of the Institution for their generous support without which this venture would not have been possible.

Roland Paxton

Member of the Panel for Historical Engineering Works

24 March 1981

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Fig. 1—Part of a plan of Edinburgh 1823.[1]

DEAN BRIDGE, EDINBURGH

by

Roland A. Paxton, M.Sc., C.Eng., M.I.C.E., M.I.Mun.E.

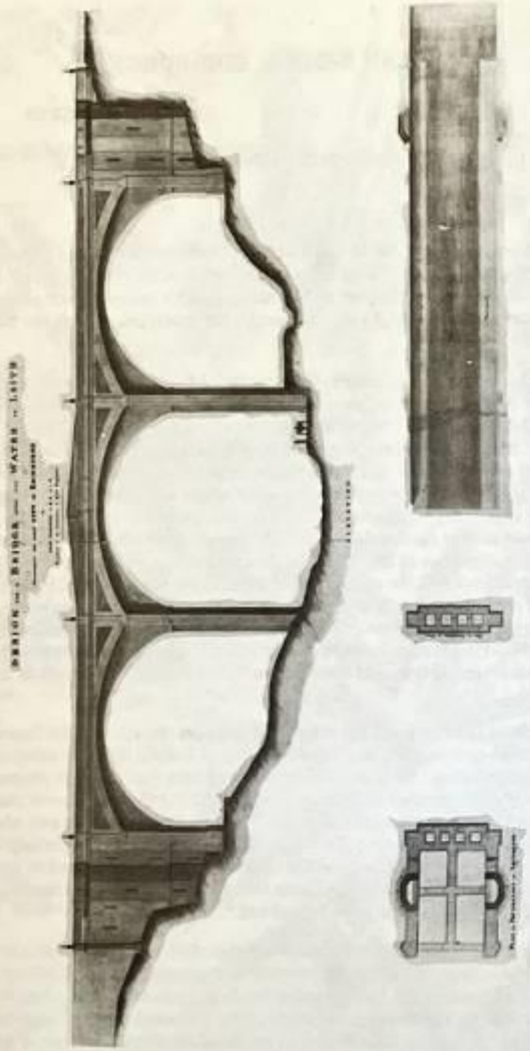
1. ORIGIN

The origin of the bridge can be considered to have stemmed from a proposal for a residential development of large villas on the estate of Sir John Nisbet (d. 1827) at Dean in, or just before, the year 1823. As part of this scheme it was proposed to build a bridge across the Water of Leith to connect the development with the New Town (Fig. 1).

The scheme began to crystallise in the summer of 1825 when a formal approach for assistance in building the bridge was made by Sir John Nisbet's agents to the Cramond District Road Trust. The Nisbet submission, which was considered by the Trust on 3 August, stated *"It has been suggested by gentlemen of the first talents that if a bridge were built over the Water of Leith, and the public road carried from the Drumsheugh Tollbar by that bridge through the Dean grounds, it would be one of the most splendid, imposing and useful improvements . . . It would render the approach from the north much easier than at present . . . in point of magnificence the bridge shall not be inferior in design or execution to any bridge in the kingdom . . . should the Trust give us their aid . . . in removing all the obstacles that stand in the way, we pledge ourselves to have the plans prepared instantly and commence building the bridge forthwith . . . we will find security for the erection of the bridge, which is to be 10 feet wider in the roadway than the Waterloo Bridge, London and to be erected in the most secure and handsome manner under the direction of eminent professional men . . . will cost at least £20,000 . . ."*[2]

The Cramond District Road Trust agreed to support the scheme and James Jardine, an Edinburgh civil engineer and close associate of Telford was instructed to survey and report on the matter. Early in 1826 he reported back that *". . . the proposed road through the Dean grounds is all an easy ascent and is 140 yards shorter than the present dangerous abominable hilly road."*[3] (via Bell's Mills bridge and what is now Belford Road and Queensferry Terrace). At their meeting on 9 February the Road Trustees agreed to make and metal the road to a width of 60 ft. and to pay £3000 towards the cost of the bridge[3], a figure that was subsequently increased. The Trustees insisted that the bridge was to be free of toll.[4]

The main *raison d'être* for Dean Bridge was therefore a private building speculation. On the west side of Edinburgh the recently completed buildings in Moray Place, Ainslie Place and adjacent streets had extended the New Town to the deep ravine of the Water of Leith. But, as The Scotsman reported, *"the westward march of improvement is not to stop here. A spirited individual has purchased the extensive range of ground known by the name of the Dean . . . nearly 140 acres . . . The buildings to be erected here may be considered as forming a third New Town . . . the streets will run south and north or east and west, as in the Old New Town. Near the middle of the ground will be occupied by two squares and a Circus . . . the finest feature of the plan is the Terrace . . . along*



'— Dean Bridge. Telford's proposed 3-arch design of 8 May 1829.[9] The gothic style embellishments, were, perhaps fortunately, omitted as an economy in the 4-arch, as built, design.

the high bank of the river following its windings from St. Ann Street to Bell's Mills. The houses to be built here will generally front the south . . . the situation will be one of the finest in Europe . . . such a splendid suburb will require a new communication with the town . . . a handsome bridge is to be thrown over the ravine . . . will cost £30,000 . . . parapets 80 feet above the river . . . its length . . . not less than 300 feet . . . these details . . . we believe . . . to be substantially correct . . .'[5]

The spirited purchaser was undoubtedly John Learmonth, a coach-maker of 3 Prince's Street[6] and later Lord Provost (1831-3). He had feued the land from Sir John Nisbet and as part of the agreement had bound himself to erect *"a handsome and sufficient bridge over the Water of Leith which was to be designed, executed and completely finished to the satisfaction of Mr. Gillespie Graham, Architect."*[7] Gillespie Graham had also made out a development plan for the Dean lands[3] which may have been that described above in the Scotsman.
For further details of the origins of the project and the circumstances under which Telford came to be associated with it the reader is referred to the most useful paper by Skinner.[7] Briefly, between 1825 and Telford's acceptance of the remit to design and build the bridge in April 1829, there were many discussions between the various parties. Jardine made out a plan for the bridge which was acceptable to the Trust but not to Gillespie Graham, who decided to make out his own design. In 1828 matters came to a head and the Road Trustees decided not to accept any scheme unless it had Telford's approval. Telford was brought in as a referee and, not being satisfied with Gillespie Graham's design, was requested to make out one of his own.

2. DESIGN AND CONSTRUCTION 1829-32

For an authoritative description of the bridge and its construction it is impossible to better Telford's account. He wrote,

"I declined entering upon the business unless the several parties interested signed a missive letter, stating that my plan should be adopted, and the bridge built under my direction. These preliminaries being settled, I furnished a plan, elevation and section, with detailed specifications; and a contract was entered into with Mr. John Gibb of Aberdeen . . .

The arches are 90 feet in span, and the edifice 106 feet in height from the bed of the river to the surface of the roadway; the breadth of the carriageway 23 feet, with a footpath on each side of 8 feet; so that the whole breadth between the parapets is 39 feet; the total length is 447 feet.

My design originally consisted of three arches (Fig. 2), but on commencing the excavation for the foundations on the south side, the rocks were found to be so much dislocated that no security could be obtained . . . prudence, therefore, induced me to change the design into four arches . . . whereby the south abutment is placed upon solid rock . . . The piers are 31 feet in length . . . built internally with hollow compartments; the side walls are three feet in thickness; the cross-walls two feet. Projecting from the piers and abutments are pilasters of solid masonry. The main arches have their springing at 70 feet from the foundations, and rise 30 feet; and at 20 feet higher, other arches, of 96 feet span and 10 feet rise are constructed, and the face of these, projecting before the main arches and spandrils, produces a distinct external soffit of five feet in breadth; and this, with the . . .piers, are the distinguishing features of this bridge. Inside the external spandrils are longitudinal walls, and the interstices are

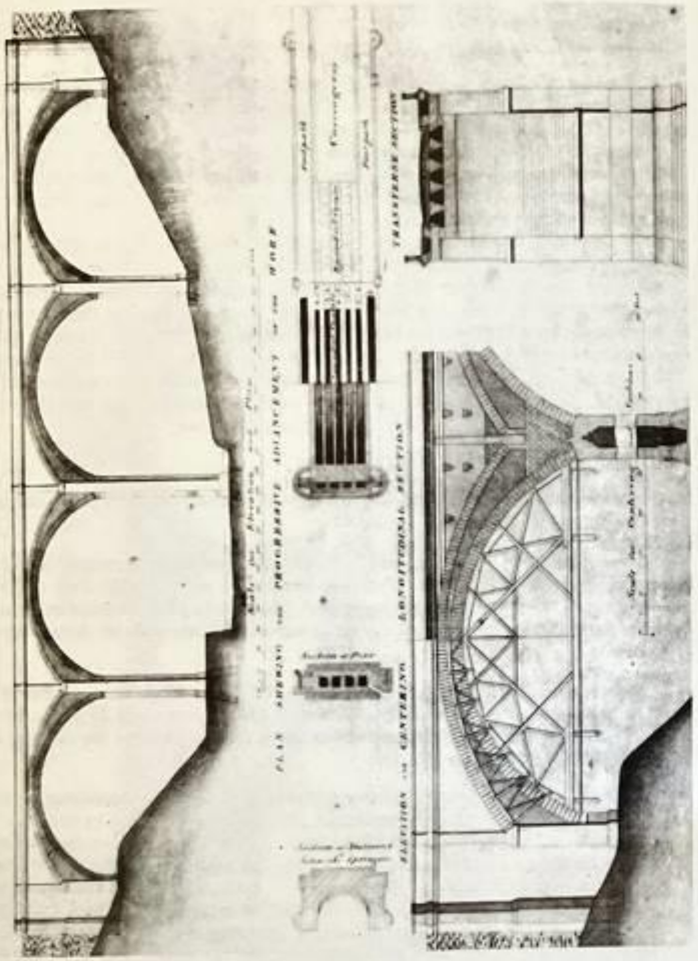


Fig. 3–Dean Bridge as built. Drawing by the Resident Engineer, Charles Atherton in April 1833.[9] *Note the hollow piers and spandrels.*

covered with flat stones, to support the roadway. The whole of the masonry of this bridge consists of square sandstone, of excellent quality . . . "[8] (Fig. 3).

Fig. 4–Dean Bridge. Workman standing inside the hollow spandrel on the extrados of a 96 ft span ascititious arch. Note the stone cross-tie and the good quality of the internal masonry work. The cavities are interconnected transversely by means of access holes.

The resident engineer Charles Atherton in an early account of the bridge[8] emphasised the advantages of its hollow construction for inspection (Fig. 4) and economy in labour and materials. Telford continues,

"It remains to be explained by what method the ascititious or external arches were executed, so as to allow of their subsiding freely upon the centering, without obstruction from the lower spandril-walls . . . The course pursued, was, by striking the centres of the lower arches as soon as the arch-stones were laid, and immediately proceeding in like manner with the turning of the upper arches, and also striking their centres previously to the completion of the lower spandrils. This was a delicate operation and is understood to have been unprecedented; for the four upper arches of 96 feet span each were supported solely upon their pilasters of five feet projection from the main piers, and five feet wide, being only one-nineteenth part of the arch span. To accomplish this, it was evidently necessary that all the four arches should be struck as gradually and equally as possible never allowing the slack-blocks to be driven out more at one time than sufficient to let down the centre a quarter of an inch. It was found that these external arches subsided equally and gradually, during a month, by which time they had acquired permanent stability, and their total subsidence amounted to four inches and a half at the crown, while the lower or main arches subsided about three inches at the crown . . .

After having allowed the external arches to attain permanent stability, a portion of their spandril-wall was built, and the centering removed, and the masonry of the lower spandrils was then made good up to their soffits . . .

Telford emphasised the necessity for cranes, or other mechanical contrivances in heavy masonry work *". . . for it will frequently be found, upon setting a stone in its place, that its bed is too full or too lean, or that from some other cause, the stone must be lifted, examined and re-set. If this can be readily done, the fault will be rectified; but if this operation creates much trouble, the masons will slight it . . . The entire success which attended the execution of the Dean Bridge, and the expedition with which the work was carried on, are in a great measure attributable to the judicious manner in which the machinery and scaffolding were constructed* (Figs. 5 & 6). *The bridge was commenced in October 1829 and completed (with the exception of the parapets) in December 1831, without any accident whatever–the cost being £18,556, exclusive of making roads of approach."*[8]

Fig. 5–Masonry lifting shears or nippers.[10]

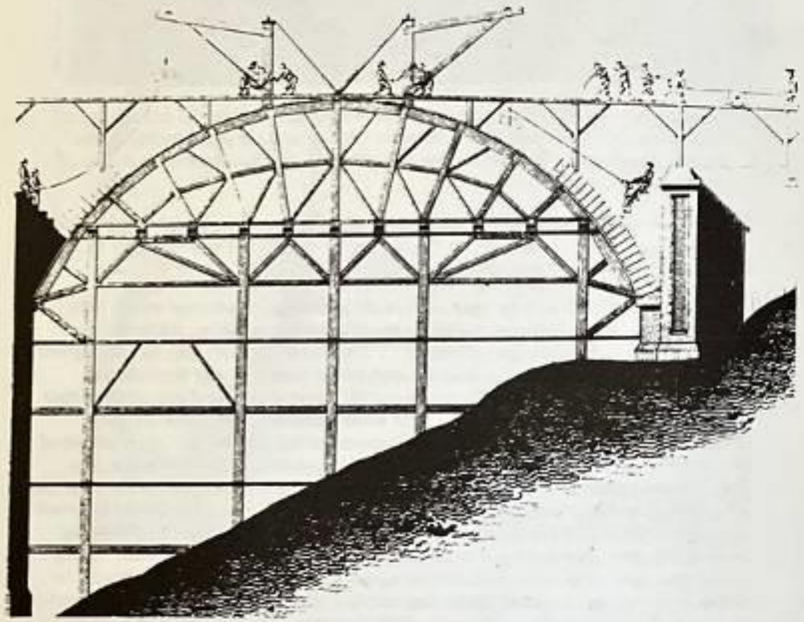


Fig. 6–Dean Bridge–Forming arches. Note machinery, scaffolding and modus operandi.[11]

3. COSTS

Lettice Rae, biographer of the Gibb family, gives the cost of the bridge as £34,000[12] but it is quite clear from the correspondence at the Institution of Civil Engineers that Telford's figure is of the right order. Gibb's contract price was just over £15,000[13] and the work was originally to have been finished by November 1831.[14] Most of the cost of the bridge was borne by Learmonth, but the Cramond District Road Trustees, thought they *"had acted liberally in contributing between £8-9000"*[15] towards its construction. Due to the alteration in design from three to four spans, early in 1830, and other factors, an extra cost of nearly £4000[16] was incurred which Learmonth at first refused to meet. It was only after receiving personal confirmation of an earlier assurance from his friend Telford that *"you have a good bridge and at a comparatively moderate sum"*[17] and the instruction of James Hope W.S. by Gibb to act on his behalf, that Learmonth finally agreed to meet Gibb's account in full in August 1832.[18]

4. COMPLETION 1832

It is often thought that the bridge was *"open for traffic at the end of 1831"*[19] but this was not so in any meaningful sense as the roadway was not formed. By 27 February 1832 nearly half of the kerbs, channels and footway pavement on the bridge had been laid and the parapets were ready for setting.[20] On 8 May 1832 Atherton certified *"the bridge is now completed in a substantial manner, no cracks, skirps* or defects arising from bad workmanship being perceptible throughout . . ."*[21] Metalling of the carriageway by the Trust was authorized by Learmonth on the following day.[22]

In constructing the carriageway the traditional Telford hand-pitched stone construction (Fig. 7) does not appear to have been adhered to as can be seen from a recent trial hole section (Fig. 8). Telford's proposed use of a 4" layer of concrete (Fig. 7) at this early date is of particular interest in the historical development of road construction on bridges. Its purpose seems to have been primarily to inhibit water penetration into the hollow spandrels.

* Crushing of the front edges of horizontal joints.

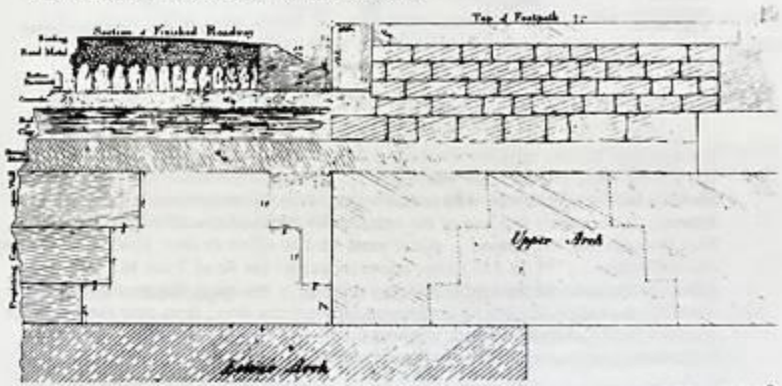


Fig. 7–Dean Bridge–Proposed roadway construction, 8 May, 1829.[9]

Lettice Rae tells us that John Gibb, although a man of irascible temper was beloved of his workers. When building the Dean Bridge he had an elevated perch made from which he could survey their progress and bellow criticisms through a sort of megaphone. On occasions he descended amongst the workmen *"to exchange blows, banter and snuff"* to the delight of all.[12] There is a good story, which perhaps should be taken with a pinch of salt, that the bridge was finished ahead of time and its Trustees wished to take it over immediately, but Gibb said, *"Na, na, the briggie's mine . . . until the time specified in the contract for its completion"* and he charged a penny for every foot passenger and wheel.[12]

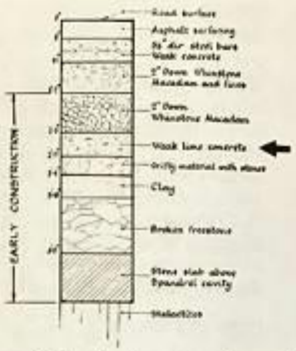


Fig 8–Dean Bridge–Section of carriageway[23]

5. **POINTS TO LOOK FOR ON SITE and POSTSCRIPT**

1. The direct line and high level of the bridge which is typically Telford.
2. The impression of lightness that the external arches and pilasters give to the bridge elevation. Try to envisage the delicate operation of arch formation from the narrow pilasters before the main arch spandrels were built (Fig. 8A).

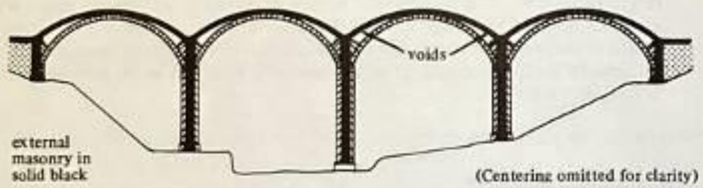


Fig 8A–Dean Bridge–Progress of masonry work on striking upper arch centering.

3. The high quality of the Craigleith stone masonry. The piers are particularly fine. Look for the close joints and nipper indentations on the ashlar blocks.

It seems that Telford remitted a substantial part of his own charges for the bridge and Learmonth wrote to him in October 1832 *". . . I deeply appreciate this mark of liberality and consideration. The concern has evinced no symptoms of being likely to improve, but certainly it is one of the most highly admired structures in the world, both in design and execution . . . and it* must *have an effect in time, you have given me that advantage . . ."*[13] In 1833 Learmonth requested the Road Trust to accept the future maintenance of the bridge but they refused; in the event this proved to be minimal. A road on the line of the present Queensferry Road from near the bridge to what is now Queensferry Terrace was completed c.1834, but it was not until about the mid-century that building commenced on the Dean lands.

Renovation work on the parapets was carried out in 1964/65 when badly spalled stonework was cut out and replaced with indents of Craigleith stone which had been salvaged from the demolition of Waterloo Bridge, London. The replacement stones were in the form of ashlar slabs 2 in. thick by 9-11 in. deep in random lengths from 8 in. to 4 ft. Over 300 indents were placed. This remarkable bridge which remains virtually as built is in good heart and now carries more than 7,000,000 vehicles per annum.

REFERENCES, NOTES, AND ACKNOWLEDGEMENTS

1. Plan of the City of Edinburgh . . . 1820. Altered to 1823 by John Wood.
2-4. Minute Book of the Trustees of the Cramond District of Roads within the County of Edinburgh. 3 August 1825. 9 February 1826. 16 March 1826. S.R.O. CO2/6/5.
5. The Scotsman, 12 October 1825, No. 601,654.
6. General Post Office Directory for Edinburgh. 1824-5. 122.
7. Skinner, B. *"The Origins of the Dean Bridge Project"*. Book of the Old Edinburgh Club. XXX. 1959. 166-8.
8. Telford, T. Life of . . . edited by J. Rickman. 1838. 196-201.
9. By courtesy of B. Annabel, Director of Architectural Services, Edinburgh D.C.
10-11. Telford, T. op-cit. Pl. 37 part and pl. 63 part.
12. Rae, Lettice Milne. Story of the Gibbs. 1961. 59-60.
13. MSS. Dean Bridge correspondence. I.C.E. Library. Various letters dated 22 July and 7 August 1829, 28 November 1831 and 19 October 1832.
14. ibid. Letter from Learmonth to Telford, 1 August 1829.
15 & 21. Minute Book. op-cit. March 1833 and 10 May 1832.
16. Letter from Learmonth to Gibb. 3 December 1831. Author's collection.
17. Copy letter from Telford to Learmonth, 30 November 1831. Author's collection.
18. Copy letter from Learmonth to Messrs. John Gibb & Son, 13 August 1832 with letter from John Gibb to James Hope, W.S. Author's collection.
19. Youngson, A.J. The making of classical Edinburgh 1750-1840. 271.
20. Letter from John Gibb & Son to Learmonth, 27 February 1832. Author's collection.
22. MS. Note from Learmonth to Lyon, Gibb's overseer at the bridge authorising James (of the Road Trust) to start metalling. 9 May 1832. Author's collection.
23. From a drawing made by the author in 1973.

Note: A plaque on the north parapet reads: The Dean Bridge. Completed 1832. Designed by Thomas Telford born Eskdalemuir 1757. This plaque was erected in 1957 by the Institution of Civil Engineers to commemorate the bicentenary of the birth of Thomas Telford, first president of the Institution.

The author acknowledges with thanks the helpful assistance of Dr W. H. Makey, City Archivist and members of staff of the Scottish Record Office, the Edinburgh Room of the Central Public Library and the Library of the Institution of Civil Engineers. Also, to the present custodian of the bridge, A. S. Crockett, Director of Highways, Lothian Region, his predecessor F. R. Dinnis, former City Engineer and A. Sinclair, Principal Engineer, for their interest and support.

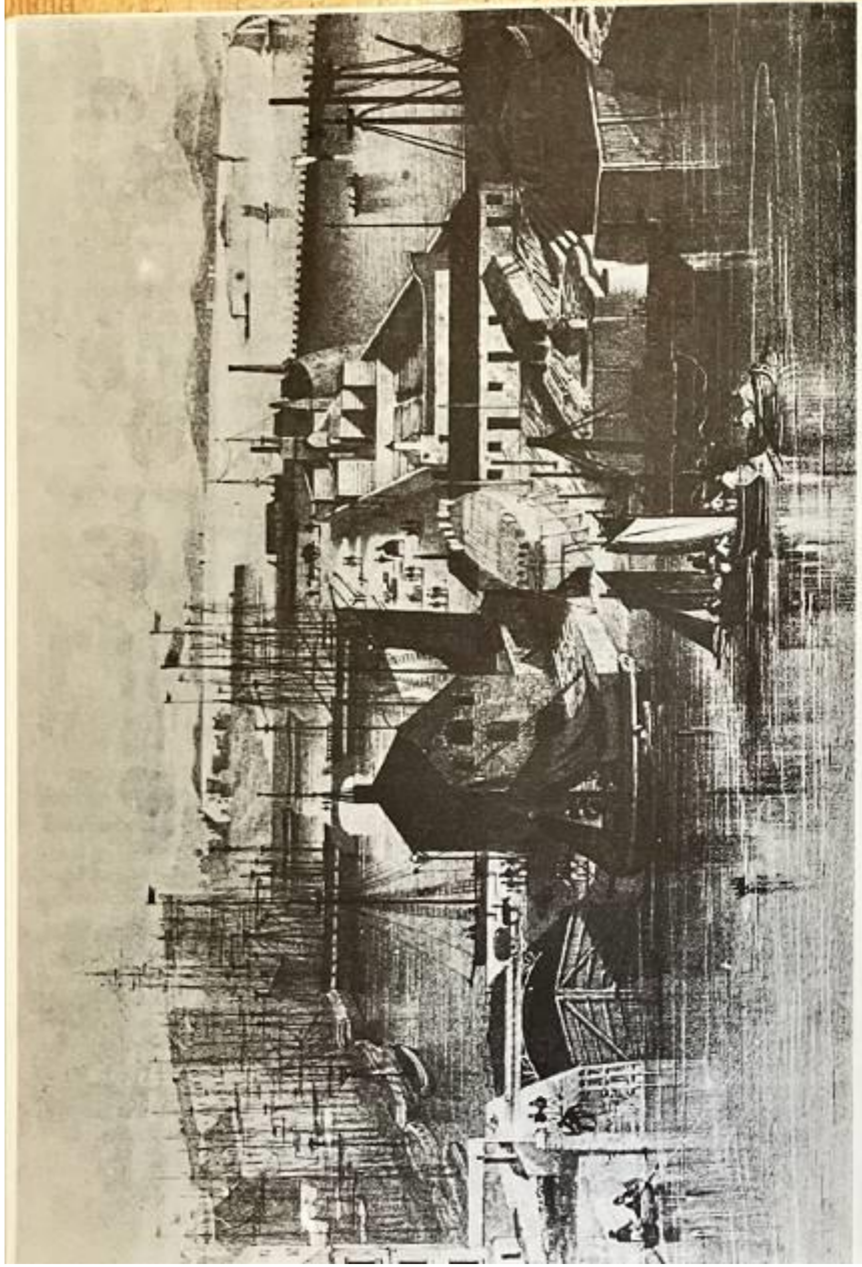


Fig. 9–Leith Docks from the Signal Tower 1838. Photo by courtesy of City of Edinburgh Libraries, Leith Branch.

HISTORICAL ASPECTS OF LEITH DOCKS

by

John Kerr, C.Eng., F.I.C.E., Chief Engineer, Forth Ports Authority

Introduction

Leith, the port of Edinburgh is one of the oldest seaports in the United Kingdom, first being mentioned as far back as the early 14th century.

From the beginning of the nineteenth century the port developed as a system of enclosed docks. In 1938 the Leith Dock Commission changed this pattern of development and instituted the construction of the East and West Breakwaters to form a large tidal basin within which new quays could be developed to suit shipping demands. A new entrance lock was completed in 1969. This transformed Leith into a deepwater port with impounded water and the ability to offer a 24 hour service to shipping.

Early Development of the Port

As mentioned in the introduction the Port of Leith dates back to about 1329, where quay walls were erected along the banks of the Water of Leith, accommodating shipping trade.

The inadequacy of accommodation for the growing shipping trade was finally recognised in the late 18th century when the distinguished civil engineer of that time, John Rennie was employed to examine the ground and furnish designs for docks and extended piers, which would be suitable for the growing trade requirements.

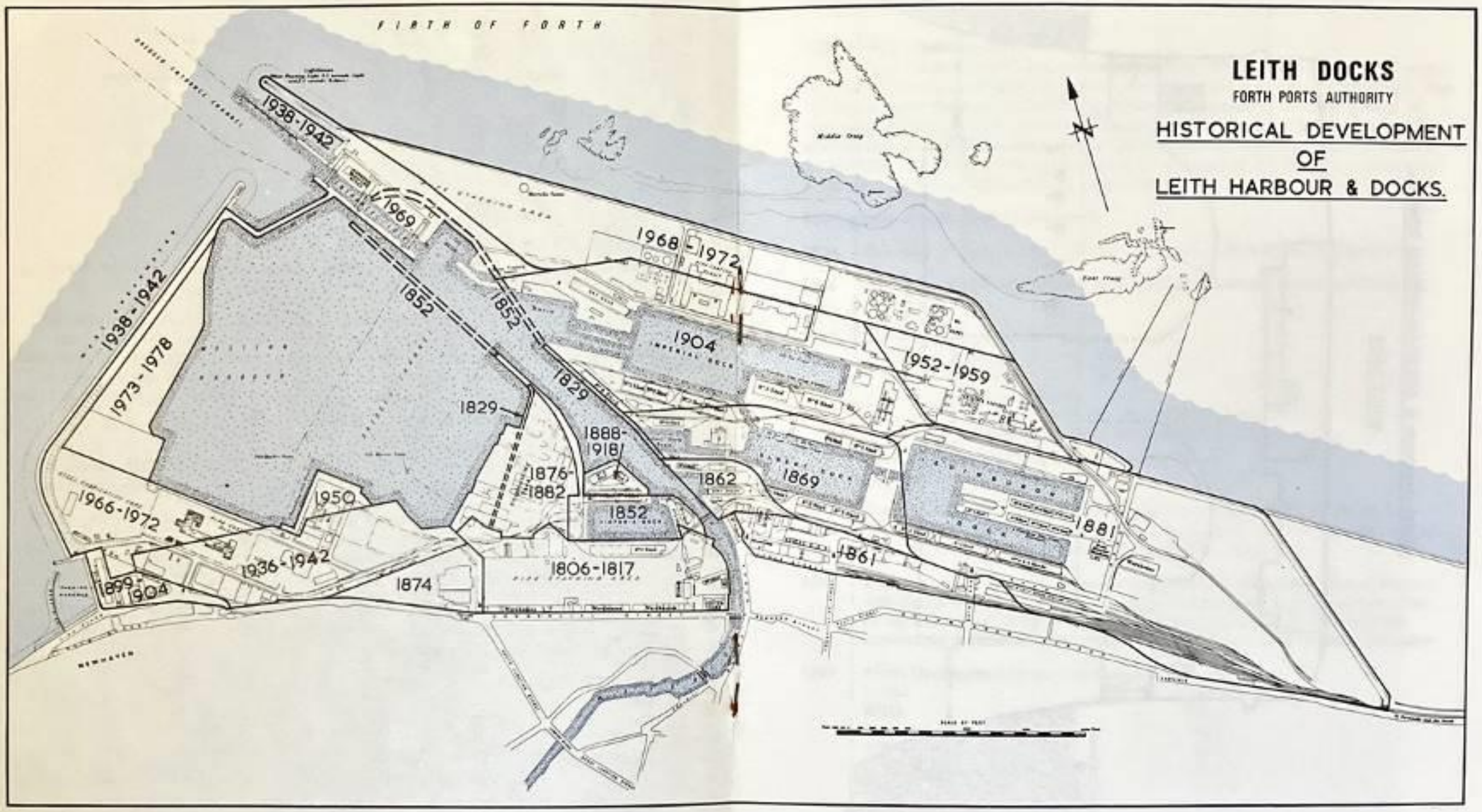
Construction of two wet docks were started under the direction of Rennie, the first, the East Dock, completed in 1806 and secondly the West Dock finished in 1817 (Fig. 9). The two docks were parallel and of the same size.

East and West Old Docks (now infilled)

Length	750 ft
Width	300 ft
Depth	24 ft
Depth on sill	13 ft neap tides.
	17 ft spring tides

Entrance lock	150 ft x 36 ft (still exists)

Construction costs of East and West Docks and 3 dry docks–
£300,000
Engineer–J. Rennie.



LEITH DOCKS
FORTH PORTS AUTHORITY
HISTORICAL DEVELOPMENT
OF
LEITH HARBOUR & DOCKS.
FIRTH OF FORTH
1938-1942
1969
1968-1972
1904
1952-1959
1852
1852
1829
1829
1888-1918
1876-1882
1862
1869
1881
1852
1861
1806-1817
1874
1950
1966-1972
1936-1942
1899
1904
1973-1978
1938-1942

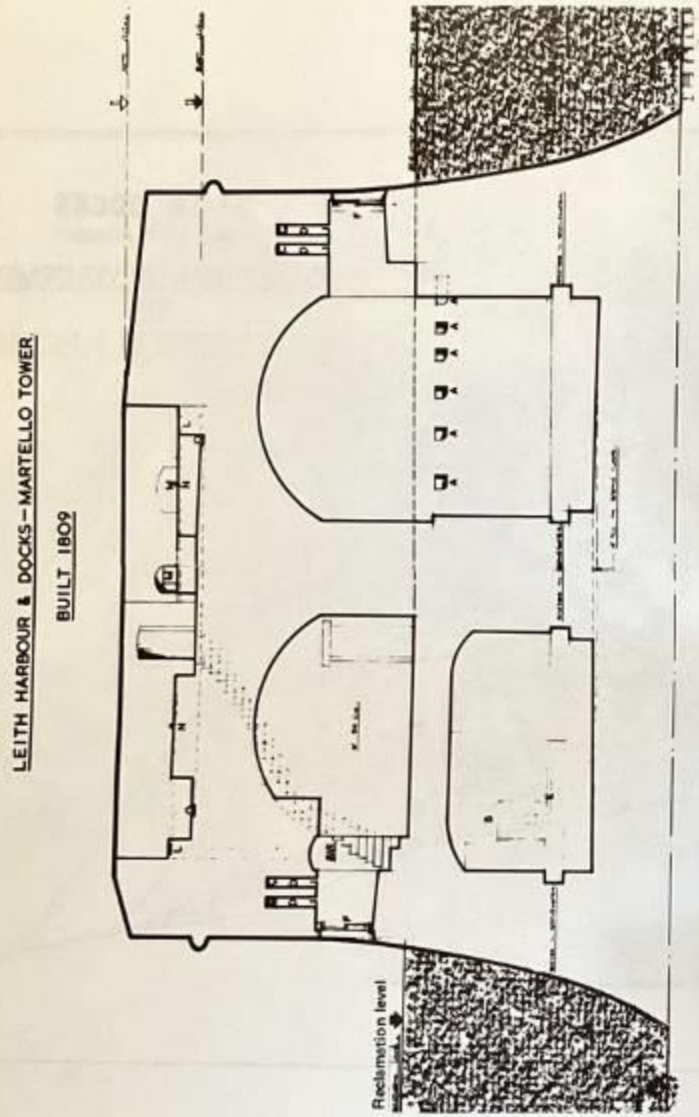


Fig. 10—Martello Tower Crossection.

In 1809 the Martello Tower, now about ¼ mile east of the Entrance Lock, was built for the defence of the Port of Leith against Napoleon. It is reputed to have cost £17,000 and is built of ashlar from Rosyth quarry. It is over 30 ft high with walls about 8 ft thick and has several rooms and what was formerly a powder magazine. Three heavy guns were mounted on its upper platform (Fig. 10).

Leith Dock Commission–1838

Prior to 1838 the port of Leith was controlled by a body of Commissioners with representatives from Edinburgh and Leith city councils, the balance being in favour of Edinburgh. This effectively meant there was domination by Edinburgh in the affairs of Leith Harbour, all dues being levied at that time passed in to the coffers of the capital. This domination ended in 1838 when an act of Parliament set up a fully autonomous Trust to control the affairs of the Harbour. The future development of Leith owned much to this new constitution which sought to improve the facilities for the trade of the Port.

Development of Leith from 1824 onwards

1824 Extension of Eastern Pier 1,500 ft Construction of Western Pier and Breakwater.

1846 Work commenced on a new wet dock (Victoria Dock) and extension of East and West Piers.

1852 Victoria Dock opened

Length	750 ft
Width	300 ft
Entrance Width	60 ft
Depth of Water over sill at MHWS	23.4 ft
Depth of Water over sill at MHWN	20.0 ft

Construction Cost of Victoria Dock £180,000
Engineer—James Rendel.

1859 Construction of a new dry-dock was completed on the East Side of the Harbour, the Prince of Wales Dry Dock. This cost approximately £60,000. It is 382 ft long with a 70 ft entrance. It is no longer in use as a dry dock.

1862 Expanding trade required increased accommodation and James Rendel of London with George Robertson C.E. of Leith submitted proposals to construct new docks on the east side of the Harbour. The site of the proposed dock (Albert Dock) required the reclamation of 84 acres of sand which was formerly Leith race course.

1869 Albert Dock opened by entry of steamship "Florence".

Length	1100 ft
Width	450 ft
Length of entrance lock	350 ft
Width of entrance lock	60 ft
Depth of water over sill at MHWS	25.4 ft
Depth of Water over sill at MHWN	22.0 ft
Construction Cost	£350,000
Engineers	Rendel/Robertson

1876 Important changes in the constitution of the commission, i.e. greater borrowing powers, provided for the construction of another and larger Dock (Edinburgh Dock) to the east of the Albert Dock, access through the latter by means of a connecting channel.

1881 Leith's biggest achievement in dock provision at that time, the Edinburgh Dock was opened by HRH The Duke of Edinburgh. This work actually began in 1874 by building a sea wall of great strength. This embankment, completed in 1877 served to reclaim over 100 acres of ground amid which the new dock was formed.

Edinburgh Dock	
Length	1500 ft
Width	650 ft
Length of Jetty	1000 ft
Width of Jetty	250 ft
Width of entrance passage	60 ft
Depth of water over sill at MHWS	25.4 ft
Depth of water over sill at MHWN	22.0 ft

The Edinburgh Dock was constructed with a tongue projecting from its eastern end with a uniform breadth and having a dry dock 300 ft x 40 ft wide constructed at its extremity.

Construction Cost	£500,000
Engineers	Sir A. M. Rendel and G. Robertson

1833-1892 Mr. Peter Whyte C.E. the Superintendent of the Docks and Engineer to the Commission devised a scheme for the formation of an entirely new dock area–the reclamation of a vast track of foreshore suitable for further additions to the dock area and the deepening of the fairway channel from the open sea inwards. A reclamation wall was commenced to be constructed of rubble stone faced with large concrete blocks. The wall was 4,400 ft in length, completed in 1896. *

* see extract from Inst. of Civil Engineers Proceedings

1896 Alexandra Dry Dock was opened

Length	335 ft
Width	48 ft
Engineer	P. Whyte C.E.

The construction of the Albert and Edinburgh Docks made it necessary to have an efficient means of communications between the East and West side of the Harbour. This was effected by the construction of the Victoria Swing Bridge. This hydraulically operated bridge has a clear span of 120 ft and until recently was the largest swing bridge in the U.K. Higher up the Harbour a new swing bridge was opened in March 1898, which took the place of the Old Bernard St. Bridge.

1904 In 1897 after the successful completion of the reclaimed area work began on the Imperial Dock which is now the largest dock at Leith. It was completed in 1904 and opened by Provost Aitken.

Length	1900 ft
Width	550 ft
Length of Entrance Lock	340 ft
Width of Entrance Lock	70 ft

Depth of water over sill MHWS	30.4 ft
Depth of water over sill MHWN	27.0 ft
Construction Cost	£700,000
Engineer	P. Whyte C.E.

1912 Imperial Dry Dock opened

Length	550 ft
Width	70 ft

1936 Construction of the East and West Breakwaters commenced. This enclosed the Western Harbour and provided a new wider entrance to the Port. This increased the dock undertaking by about 230 acres and was completed in 1942.

1955 Two deep water berths in the Western Harbour were completed.

1964 The Government agreed after the Rochdale report on Harbours, to a development scheme to transform Leith into a deepwater port with impounded water. This involved the construction of a New Entrance Lock at the main entrance in the Western Harbour and impounding of the water in the whole harbour.

FORTH PORTS AUTHORITY

1968 Under an act the "Forth Ports Authority" was established and became responsible for the management and development of the Forth Estuary and its Ports. Leith then became part of the FPA along with the Ports of Grangemouth and Granton on the south side together with Burntisland, Kirkcaldy and Methil on the north side of the Forth.

1969 The New Entrance Lock, Leith, was officially opened by HRH Duke of Edinburgh on 28th May.

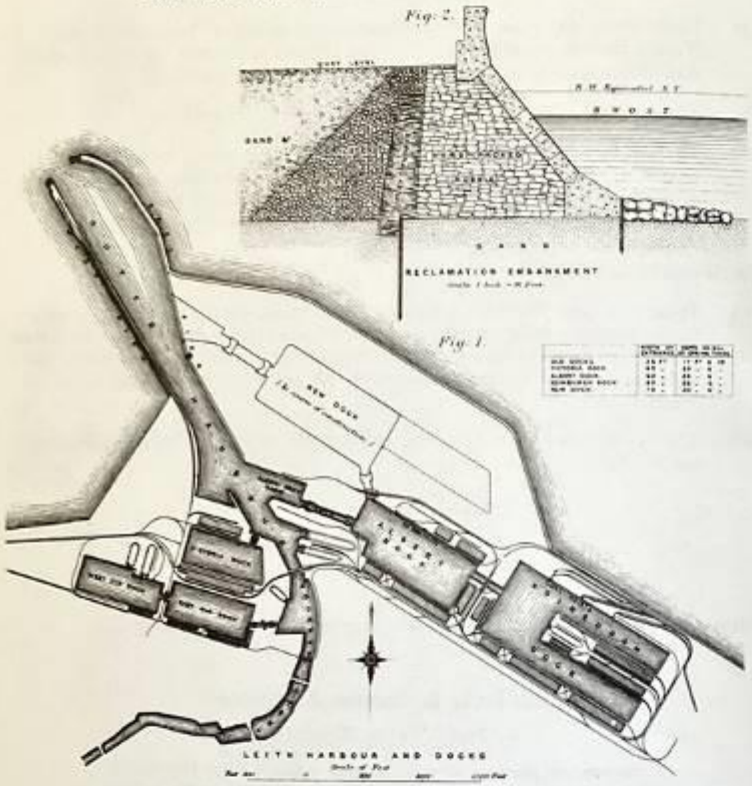
Extract from Minutes of Proceedings of Civil Engineers, Vol. CXXXIX (1900)

"Leith Docks Reclamation Embankment."

By Peter Whyte, M. Inst. C.E.

There are few places where the natural conditions are less favourable to the construction of a port than at Leith. No natural harbour existed there, except a small stream known as the Water of Leith flowing into the sea, in the narrow bed of which the original inner harbour was situated. The harbour and docks have been formed entirely on a long stretch of sandy foreshore, portions of which have been reclaimed by successive stages from the sea. This sand is dry at low water of spring tides, whilst at high water there is a depth of about 16 feet.

LEITH HARBOUR, DOCKS, AND RECLAMATION EMBANKMENT.



The docks and works cover an area of about 350 acres, Fig. 1, Plate 10. The sea-wall, or reclamation embankment enclosing the greater portion of this area, is of somewhat unusual design, consisting of a mound of hand-packed rubble stone, 22 feet wide at the base and 9 feet at the top. The sea-face above the toe-block is formed to a slope of about $\frac{3}{4}$ to 1, and faced with cement-concrete blocks, 6 feet long, 4 feet wide, and 2 feet 6 inches thick, Fig. 2, Plate 10. The toe-blocks are 6 feet long, 8 feet wide, and 6 feet high, and weigh 14 tons. At the back of the wall, a row of sheet-piling was driven down, through the sand, about 2 feet into the clay; and at the toe, a row of greenheart sheet-piling was driven about 7 feet into the sand, in order to keep the sand between the rows of piling in place, and was quite successful. Broken stone spread over it made it resemble a road, upon which the toe-blocks were expeditiously set. Above the sheet-piling, the embankment was backed up to high-water level of equinoctial spring tides with clay puddle, 5 feet thick, so as to make the embankment act as a cofferdam to exclude the water from the reclaimed area. The clay was kept in place by a backing of quarry refuse, stones, earth, &c. A layer of large, rough stones was laid on the sand along the front of the embankment, to prevent the back-wash eroding the sand. The embankment is surmounted by a parapet of concrete in mass, the top of which is 15 feet above high water ordinary spring tides. The embankment was constructed from a stage formed of three rows of piles, 15 feet apart centre to centre longitudinally, upon which gantries and cranes travelled. The gantries spanned two lines of rails by which the materials were brought forward. The reclamation embankment was finished so as to exclude the water in June 1896, and it has stood the gales of two winters quite satisfactorily. Its cost was £50 per lineal yard.

The Paper is accompanied by two drawings, from which Plate 10 has been prepared.

Fig. 11 – View of foundations from South Shore.

THE FORTH RAIL BRIDGE

by

Douglas G. McBeth, B.Sc., C.Eng., M.I.C.E., M.I.Struct.E.

The River Forth

Over the centuries the river has been criss-crossed with ferries, but with the prevailing winds, currents and high seas experienced in the Forth these could be often rather hazardous crossings. However, in the 18th and 19th centuries the alternative was a long circuitous coach trip via Stirling and so the ferries were an important and busy means of communication.

Early schemes for crossing the Forth

Throughout the 19th century various schemes to construct a vehicular crossing were proposed. In 1805 the Scots Magazine published a report on a scheme for twin tunnels and then in 1818 Anderson published his paper on a proposed "Chain Bridge" over the river. However the economic climate wasn't right for an investment of the scale that was necessary to construct a bridge over the Forth.

Railway Construction in the 19th Century

It was in the middle of the 19th century that the railway boom took off as railways dramatically became the prime mode of transport in the country. The railway fever resulted in people investing and speculating in lines all over Britain and abroad. Among the more successful of the many railway companies was the North British Company who along with the Great Northern Railway Company, North Eastern Railway Company and the Midland Railway Company formed the Forth Bridge Railway Company in order to bridge the river.

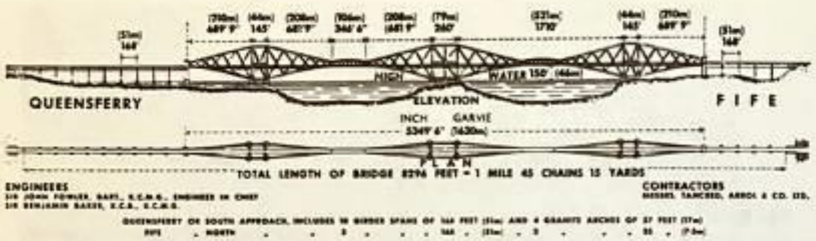
Bouch's Scheme

Thomas Bouch was appointed Engineer and commenced with a scheme for a multiple span bridge, similar to his Tay Bridge design, at Blackness Point. This got no further than a trial caisson in the river and he then proceeded with his scheme for a mighty double stayed suspension bridge at Queensferry. Work started on the bridge but with the collapse of Bouch's Tay Bridge in December 1879 the Company lost confidence in Bouch and the construction was halted. Following the Court of Inquiry into the Tay Bridge Disaster Bouch died a broken man. All that remains of the scheme is an isolated pier in the middle of the river adjacent to the central foundations of the present bridge.

Fowler and Baker Scheme

Two of the foremost engineers in the country, John Fowler and Benjamin Baker, were eventually appointed to design another bridge for the crossing. They opted for the cantilever scheme known throughout the world for its grandeur. The design was a major innovation in its day. Not only was its cantilever design concept unique but also in its use of steel, then a comparatively new building material, and by adopting tubular sections as the main compression members.

The basic layout of the bridge superstructure was dictated by the topography and geology of the river bed. The North Tower rests on the bed rock at North Queensferry. The Centre Tower utilises Inchgarvie and the South Tower is bedded in dense boulder clay at a depth of about 50 feet below high water.



Each of the towers are built on 4 piers. Those on the two side towers are at 120 feet by 145 feet centres and the piers to the central tower are at 120 feet by 260 feet centres. The towers taper to 33 feet centres at the top 330 feet above the foundations.

The cantilevers are each built out 680 feet from the towers and carry the central simply supported spans, each 350 feet giving a clearance of 150 feet above high water.

The basic dimensions of the bridge are as follows:-

Overall length	8296 feet
South approach	10 spans of 168 feet
North approach	5 spans of 168 feet
Length Portal to Portal	5349.5 feet
Length Tower to Tower	1912 feet
Cantilever lengths	680 feet
Simply supported spans	350 feet
Height of towers	330 feet
Rail level from high water mark	158 feet
Clear headway for shipping	150 feet

Based on researches carried out by Baker all the compression members are tubular and all tension members fabricated in lattice steelwork. The main columns are 12 feet diameter and the bottom booms of the cantilevers taper from 12 feet diameter at the skewback to 6 feet diameter at their extremity.

Construction
The contract was awarded in 1882 to Tancred Arrol and was carried out under the personal supervision of William Arrol.

Arrol had been the contractor for the abandoned Bouch scheme and had already established a working site at South Queensferry. The site, to the East of the line of the South Approach viaduct, was greatly extended to accommodate the works necessary for the new structure. Furnaces were built, hydraulic benders and rivetters built. Rail sidings and stock piles laid out.

Among the more ingenious of the mechanical plant specially designed for the work were Arrol's tube drilling machines. By using these entire rows of holes could be drilled at one go.

An incline was constructed down to the river shore and sections of the bridge were winched down this before being loaded onto one of the eight barges or four steam launches used to transport materials to the working sites in the river.

Labour camps were established on both shores and also accommodation for workers was built in the old castle on Inchgarvie–(where 90 workmen lived during the sinking of the caissons).

Foundations
Fife and the north Inchgarvie piers are founded on rock. During construction it was found that the rock head was very irregular and before the cofferdams could be sealed divers had to cut out protruding edges and the bottom was plugged with cement bags and puddle clay.

The South Inchgarvie piers were constructed by first sinking pneumatic caissons to locate the rock head.

The Queensferry piers were constructed in boulder clay again using pneumatic caissons. These were 70 feet in diameter by 90 feet high constructed of an outer shell of rivetted plates over a cutting edge. Above this edge there was a buoyant collar used to float the caissons into position.

When in place the lower section was concreted leaving a 7 feet working space for excavation. Access to this was achieved by two tubes which were entered via air locks at the surface. The pressure under which the men were working when the caissons were at their deepest was 3 atmospheres (42 lb/ft^2)

When floating the Queensferry, North West caisson into place it was incorrectly anchored, tilted on the sea bed and then flooded. The accident took ten months from December 1884 to rectify and caused a serious delay to the main construction programme.

Piers were filled with concrete, up to the topmost 36 feet which consisted of a core built from Arbroath stone and faced in Aberdeen and Cornish Granite.

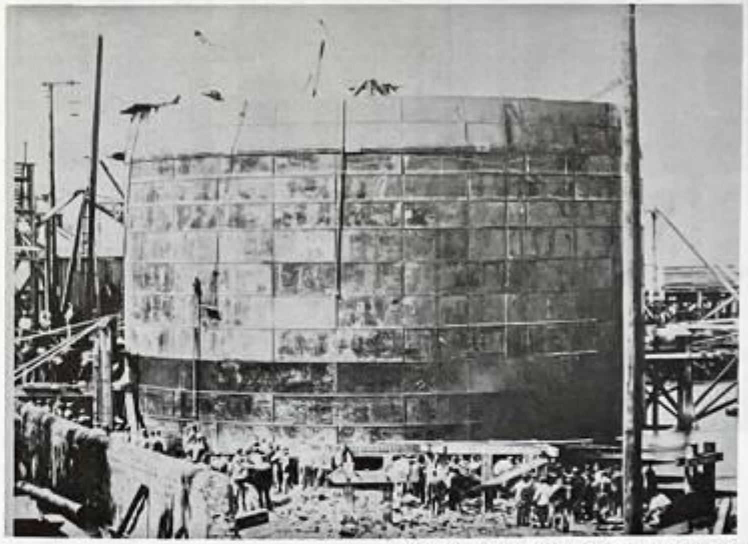


Fig. 12–Caisson in course of construction.

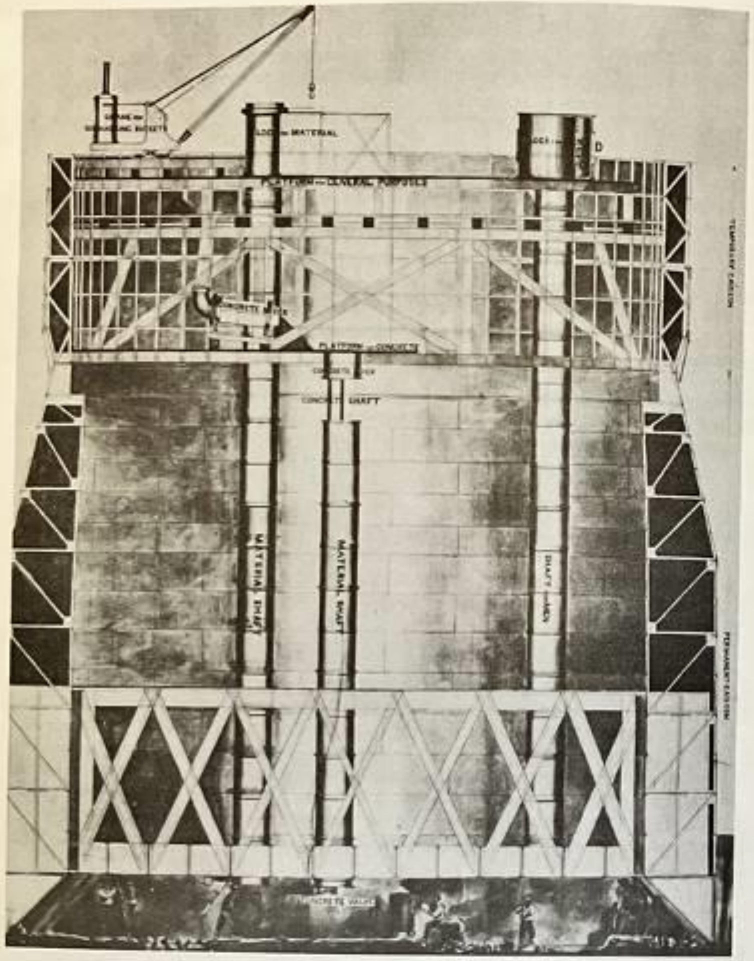


Fig. 13–Interior of caisson.

To the top of each pier was fitted a base plate held down by 48 no 2½" diameter bolts each 25 feet long.

Superstructure

The Forth Rail Bridge was the first major structure in the world to be built in steel. It was manufactured using the Siemens Open Hearth process and supplied by three foundries. Blochairn and Newton (Glasgow); Dalzells Works (Motherwell) and Landore Foundry (Swansea). In total there was 54,160 tons used in the superstructure plus 4,200 tons of rivets (6,500,000).

The initial assembly of the Tubular Sections was carried out on land in the fabrication yards. The bent plates were clamped into place in the tube and predrilled with Arrol's tube drilling machines. Sections were then numbered, dismantled and shipped out to the river to be erected.

From the skewbacks on the piers the main towers were erected with all three being brought up at the same time. All scaffolding and temporary works were kept to a minimum. Erection gantries were constructed so as to climb up the towers as these were erected. These gantries supported small 'Goliath' cranes, and 'Scotch ' derricks. Access to the gantry was by means of a hoist.

Plates were lifted by crane and held in position temporarily with bolts. A tube rivetting cage was assembled round the tubes and teams of rivetters worked in the comparative safety of these enclosures rivetting the tubes. There are approximately 100 rivets per foot on the bridge and to speed erection Arrol invented a hydraulic rivetting machine.

On completion of the towers, work started on the building out of the cantilevers. All six cantilevers were built out together and great care was taken to ensure that cantilevers on either side of each tower were equally balanced. Again temporary scaffolding was kept to a minimum with each section being built out from the section previously erected. Specially designed cranes and gantries crawled out along the members. As with the towers the same method was adopted, of holding the sections in place temporarily and rivetting them in place by the team of men following up. The tube rivetting machines were altered because of the angle of the members. These were winched out along the booms to allow men to work in comparative safety.

To transport materials out to the working positions on the cantilevers, tramways were constructed along the outside of the bottom booms. Plates and structural sections could then be winched out from the jetties at each pier.

The central simply supported spans were also built out from the cantilevers by being connected temporarily at their point of support. The final closure was achieved by taking templates of the members on either side of the gap and forming plates to match. However, due to delays it was discovered, on one span, that when connected, the temperature had dropped and the bolt holes didn't match up. As this was in November and there was therefore little chance of getting a warm sun to help expand the bridge again, it was decided to stack timber on the cantilever, cover the steelwork in naptha and set fire to it! This did the trick and the last plates were bolted together.

The guys temporarily supporting the simply supported spans could then be cut away and the bridge function as designed. In cutting away these guys some of the temporary bolting

Fig. 14–Queensferry columns, looking through the bridge.

Fig. 15–Fife cantilever.

sheared dramatically with an explosion that caused panic among those still working on the bridge. However, an inspection revealed that there was no damage to the structure and all the rockers and sliding joints were functioning satisfactorily.

The official opening took place on March 20th, 1890 when the Prince of Wales ceremoniously drove the last rivet in the centre of the North span.

Labour
Over the eight years during which the bridge was being built there had been up to 4,600 men working on it. Some specialists in compressed air working came from the continent to construct the foundations, others were full time navvies who moved from job to job "on the tramp". The majority came from the Edinburgh area and were transported to the site either by train to Dalmeny or from Leith by steamer which departed at 4.00 a.m. every morning returning at 7.00 p.m. in the evenings.

A welfare and sick fund was created by the contractor for his employees. Each contributed 8d per week towards this. There were many minor accidents and hospital cases. The total deaths toll on the contract was 57.

Each of the cantilevers was provided with a boat and boatman as a rescue service. It is recorded that these boatmen saved a total of eight lives, 8000 caps and "numerous other articles."

Painting
The painting of the Forth Bridge has become a legend. It is true that when work finishes at one end then it has to recommence at the other. In all there are 145 acres of surface area to paint in the most awkward of locations both outside and inside the members. It takes from 4 to 5 years to paint the entire structure.

The specification was for two undercoats of Red Lead followed by two of Red Oxide. The same Red Oxide paint is used today in this continuous operation.

Costs

Bridge and railway connections	£2,549,200
Abortive work on Bouch's scheme	£ 250,000
Parliamentary Expenses and Fees	£ 378,006
	£3,177,206
Cost of Painting etc.	£ 50,000
Saving on resale of mechanical plant and scrap	£ 120,000

The bridge is still used today for the same function for which it was designed and built. Trains have become heavier but still are somewhat lighter than the test load of 1800 tons that was trundled over the completed structure in January 1890.

An inspection, a few years ago, of the bridge gave it a clean bill of health and confirmed that it will continue to serve its function for many years to come as probably the most famous rail bridge in the world.

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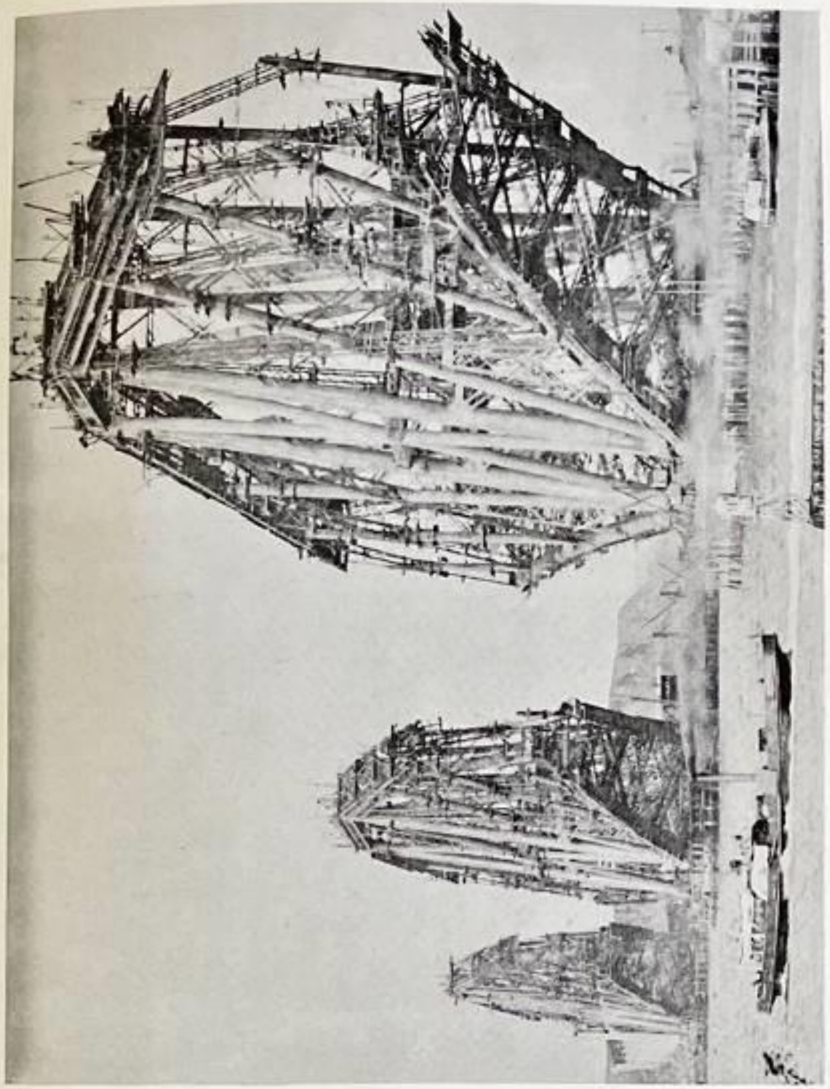

Fig. 16–All cantilevers nearing completion as seen from South Queensferry.

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