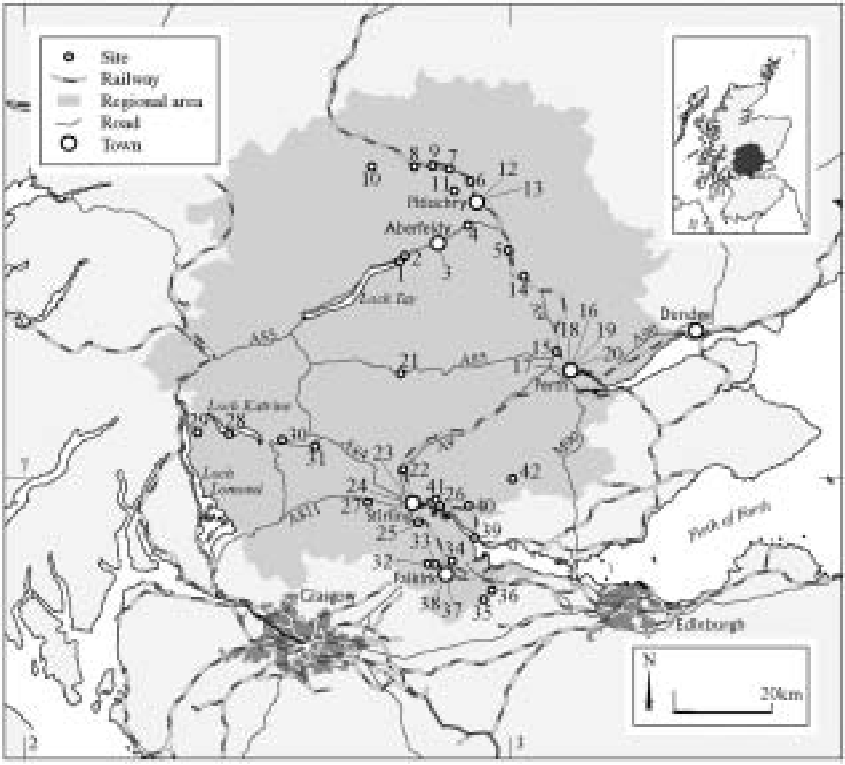

Stirling, Perthshire and Kinross, and Clackmannanshire

1. Kenmore Bridge
2. 'Chinese' Bridge, Taymouth Castle, Kenmore
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4. Grandtully Bridge
5. Tay Viaduct, Dalguise
6. Killiecrankie Viaduct
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16. Perth Bridge
17. Perth Harbour
18. Round House, Perth
19. Tay Viaduct, Perth
20. Friarton Bridge
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22. Faery Footbridge, Dunblane
23. Auld Bridge, Stirling (Old Bridge)
24. William IV or 'New' Bridge, Stirling
25. Bannockburn Bridge
26. Cambus Footbridge
27. Gargunnock Footbridge
28. Loch Katrine and Aqueducts
29. Loch Arklet Reservoir
30. Glen Finglas Reservoir
31. Loch Vennacher Reservoir
32. Dunipace Bridge, Bonnybridge
33. Dunipace or Larbert Weir
34. Carron Ironworks Weir
35. Slamannan Railway – Iron Aqueduct
36. Slamannan Dock
37. Falkirk Tunnel (Canal)
38. Falkirk Wheel
39. Kincardine Bridge
40. Gartmorn Dam, Alloa
41. Tullibody Old Bridge
42. Rumbling Bridge

6. Stirling, Perthshire and Kinross, and Clackmannanshire

Introduction

This mainly inland area has a rich abundance of bridges of which there are 28 listed or two-thirds of the total entries. The bridges are of all types beginning with the medieval Stirling (1500, 6-23) and Tullibody (1555, 6-41); to Rumbling Bridge (1713, 1816, 6-42) where one bridge can be seen on top of another, and Wade's at Aberfeldy (1733, 6-3). These were followed by Perth (Smeaton) (1771, 6-16); Dunkeld (1809, 6-14), Telford's largest Highland bridge; Bridge of Earn (Rennie) (1819, 6-20). More modern examples are represented by the elegant reinforced concrete Faery Bridge (1911, 6-22); Kincardine Swing Bridge (1936, 6-39); Clunie Aluminium Footbridge (1950, 6-13); and the striking Friarton Bridge striding across the Tay valley near Perth (1978, 6-20).

Outstanding Highland Railway viaducts are noted at Dalguise, Killiecrankie, Tilt, and Garry (1863, 6-5/8); and, in the south of the area, a unique iron aqueduct (1840, 6-35) carrying a burn over the former Slamannan Railway. Another early cast-iron bridge at Taymouth Castle (1838? 6-2) is described which has architectural-style pointed arch spans. A historical engineering work of the future is the innovative glass-reinforced plastic footbridge at Aberfeldy Golf Course (1992, 6-3).

Perthshire boasts a major hydro-electric scheme, the Tummel-Garry completed in 1962, with the impressive Errochty, Clunie and Pitlochry Dams (6-10/12). Pitlochry Dam, completed in 1950, is one of the earliest of the North of Scotland Hydro-Electric Board (NSHEB) works.

This chapter contains descriptions of Glasgow's water supply reservoirs, namely Loch Katrine and the aqueduct to Glasgow (1859, 6-28), Loch Vennacher (1859, 6-31), Loch Arklet (1914, 6-29) and Glen Finglas (1965, 6-30). The innovative Perth water supply of 1832 and gasworks of 1825, creations of Dr Anderson of Perth Academy fame, are also represented (6-18).

Towards the end of the chapter the weirs of Britain's once largest foundry, the famous Carron Ironworks (6-33/34), and the Falkirk Wheel are described (6-38). The Wheel is a state-of-the-art work completed in 2002 which links the Forth & Clyde and Union Canals to restore the connection between Glasgow and Edinburgh. It has become an outstanding Scottish tourist attraction.

1. Kenmore Bridge

NN 7715 4555

A notable segmental arch masonry bridge in a picturesque setting with five spans of 20 ft, 45 ft, 55 ft, 45 ft and 20 ft erected over the Tay at the east end of Loch Tay in 1774 and now carrying the A827 road. It was designed by John Baxter, built under the direction of Capt. Archibald Campbell, and funded by Lord Breadalbane and a grant of £1000 from the Annexed Estates Fund. From here in 1842 Queen Victoria viewed the magnificent scene westwards which was compared by Sir Walter Scott 'to a mirrory plain of molten silver set in a frame of mountain-arabesque'.

This is a good early example of a Scottish stone bridge with the dual ornamental and weight reduction provision in its spandrels of oculi or circular voids. Unlike Smeaton's more effective engineering provision of longitudinal cavities at Perth Bridge (6-16) you can actually see through these oculi. The building stone is a chlorite schist or slate from a local quarry. [1]

2. 'Chinese' Bridge, Taymouth Castle, Kenmore

NN 7824 4673

Taymouth Castle dates from 1801–42 and was the home of the Marquis of Breadalbane, where Queen Victoria was received with much splendour in 1842. By this time the present cast-iron bridge over the Tay, supported from the stone piers of a 'Chinese' style hump-backed timber bridge of the third quarter of the 18th century, almost certainly existed as an enhancement to the castle grounds, which now form part of a golf course.

It is an elegant 9 ft wide bridge of three arches in the Tudor–Gothic style carrying a timber deck. The arches span 45 ft between the earlier masonry piers 9 ft wide and have a rise of about 6 ft. They are pointed at the crown and sharply curved at the haunches, the section between these points being very nearly straight.

The cast-iron ribs have flat plate cross-sections and a minimum of diagonal angle-bracing near the haunches. The spandrels are filled with slender cast-iron ornamental panels, some cracked. The parapet railings, about 4 ft high, are of similar design. This design, seen also in the


Jim Graham

'Chinese' Bridge, Taymouth Castle

windows and masonry of the nearby castle, suggests that the designer of the bridge may have been Gillespie Graham the architect for the 1838–42 extension and embellishments to the castle in the run up to the royal visit. [2]

3. Aberfeldy Bridge

HEW 131 H
NN 8513 4929

This five-arch bridge, now carrying the B846 road over the Tay, was built in 1733–34 as part of a system of military roads in Scotland amounting to about 250 miles. It is the most 'architectural' of 40 bridges planned and laid out under General Wade's direction from ca.1725. Although generally known as 'Wade's Bridge' it was designed by William Adam and built of a grey-green chlorite schist from nearby Farrockhill quarry.

The nearly semicircular arches are of 30 ft, 35 ft, 60 ft, 35 ft and 30 ft span and the roadway is 14 ft wide. The bridge is carried on some 1200 timber piles shod with iron. It is said that the stones were prepared and numbered at the quarry before being sent to site and that the cost of the bridge was £4095. The timber centring of the main arch may have been struck too early as there is a sag of about 3 in. in the parapet. A small dam downstream of the bridge reduces scour to the bridge foundations.

The bridge is ornamented and elegant as befits the work of Adam but Southey, perhaps reflecting Telford's view on their visit in 1819, wrote, 'At a distance it looks well, but makes a wretched appearance upon close inspection. There are four unmeaning obelisks upon the central arch, and the parapet is so high that you cannot see over it.' The roadway surface may have been raised later as the parapet comment now only applies locally at its upward sweeps or 'juts'.

Nearby is a historical engineering work of the future. It is a suspension stayed footbridge over the Tay mainly in glass reinforced fibre plastic, including its cables, which was erected in October 1992 for Aberfeldy Golf Club. It was constructed mainly by student labour from the University of Dundee supervised by the designers, Faber Maunsell. The main span is 63 m, an overall length of 113 m and a width of 2.1 m. The towers are 18 m high and the cables are of parafil fibre sheathed in low density polyethylene. [3]

4. Grandtully Bridge

NN 9122 5327

This is one of very few wrought-iron girder road bridges in Scotland on which the traffic runs between the girders. It is only 13 ft wide, probably dating from the 1880s, and crosses the Tay with three spans of 43 ft, 86 ft and 43 ft. The iron-work is in the form of double triangular trusses with differing details in the side spans.

Grandtully Bridge [postcard ca.1910]

The bridge was designed by Allan Stewart who, as chief assistant to Fowler and Baker, made the calculations for the Forth Bridge and who practised as a consulting engineer in Edinburgh from 1861–94.

Curiously, only the north span has single rivet (no gusset plate) connections of the web diagonals to the main top chord, a practice at variance with that of Sir William Arrol at the Forth Bridge, with which Stewart must have been familiar. This arrangement is not mirrored in the south span which is of conventional construction. Perhaps Stewart became aware of Arrol's precept when the bridge was partly erected.

Highland Railway

HEW 0400

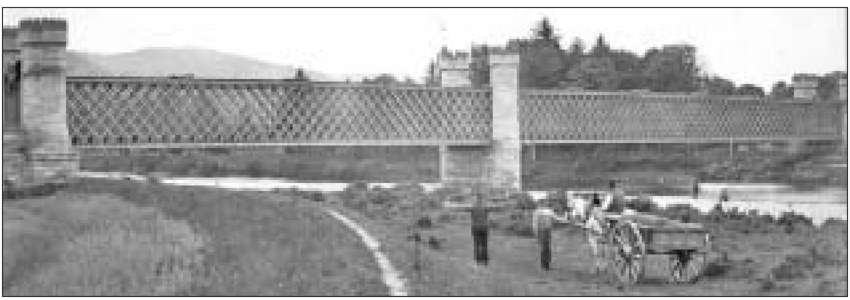
A general description and map of this Inverness-based railway is given in *Civil Engineering Heritage: Scotland Highlands and Islands* (pre 4-18). From its south end, where the line joined the Caledonian Railway at Stanley Junction seven miles north of Perth, the following works built in Perthshire from 1861–63, all engineered by Joseph Mitchell, are of particular note. [4–6]

5. Tay Viaduct, Dalguise

HEW 0400/01
NN 9949 4794

Tay Viaduct, Dalguise [photograph Whyte 1865]

At Dalguise, about six miles north of Dunkeld, the railway crosses the Tay on its original viaduct with two iron girder spans of 210 ft and 141 ft respectively, 16 ft deep and 67 ft above the bed of the river (see figure). The abutment and pier supports have ornamental castellated towers in masonry abutting the ends of the girders, almost certainly



Roland Paxton

Logerait Viaduct – iron tower

a legacy of Telford's influence on Mitchell's practice. In recent years additional diagonal bracing has been added to the top chords of the trusses to improve lateral stability.

The girders are a development in wrought-iron of the earlier American timber lattice trusses of Ithiel Town patented in 1820. The ironwork was manufactured and erected by Fairbairn Engineering Co., Manchester. The contractors were Gowans & McKay.

Other viaducts of similar construction by Fairbairn Engineering are at Blair Atholl and Logierait over the Tay with two spans of 137 ft and side openings of $41\frac{1}{2}$ ft, the latter now carrying a local access road. There was formerly another viaduct over the Tummel just to the east with two spans of 122 ft and side openings of 35 ft.

A fascinating difference between Dalguise Viaduct and the Tummel and Logierait viaducts is that instead of castellated masonry towers the latter two were provided with sets of iron towers reminiscent of locomotive funnels. This use of iron was probably an economy measure on the Aberfeldy Branch which operated, none too successfully in commercial terms, for a century, being closed in 1965. The Tummel and Logierait viaducts were built by Macdonald & Grieve. [6, 7]

6. Killiecrankie Viaduct

HEW 0400/02
NN 9167 6255

Through the pass of Killiecrankie the slopes were so precipitous and steep that the railway had to be supported by retaining walls for a distance of 700 yards with an average height of 26 ft and reaching a maximum of 55 ft.

At the narrowest point there is very limited space alongside the Garry and it was necessary to construct a viaduct on a curve of 20 chains (1320 ft) radius, having ten arches each of 35 ft span, at a height of 54 ft above the river bed. The viaduct is built of masonry and 508 ft long, the drama of the site being enhanced by a 240 yard tunnel at its north end. The contractor who executed this challenging work was Alexander Wilson. [6, 7]

Killiecrankie Viaduct [photograph ca.1890]

7. Tilt Viaduct, Blair Atholl

HEW 0400/03
NN 8738 6519

At Blair Atholl the railway is carried 40 ft above the Tilt on a single wrought-iron lattice girder span of 150 ft of similar construction to Dalguise Viaduct. The masonry abutments were built on timber rafts 3 ft below the bed of the river secured to timber piles. The contractor was Alexander Wilson.

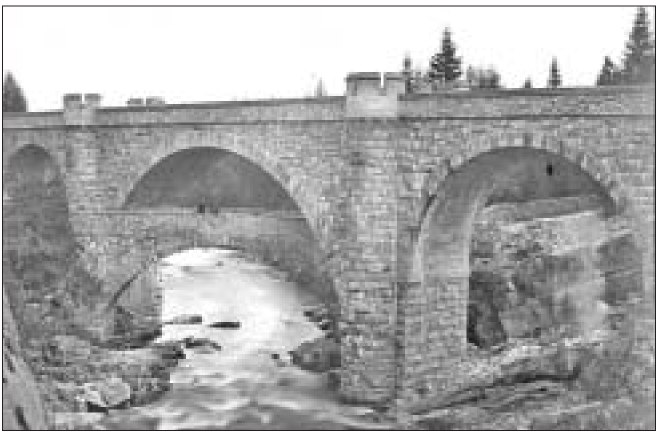
Because of its vicinity to Blair Castle the bridge abutments were 'made somewhat more ornate than was otherwise necessary'. [6, 7]

Top: Tilt Viaduct [photograph Whyte, Inverness 1865]

8. Garry Viaduct, Calvine

HEW 0400/04
NN 8019 6569

At Calvine the railway is carried over the Garry on three masonry arch spans, the centre one being 80 ft and the side spans 40 ft. The track is 55 ft above the bed of the river,



Garry Viaduct [photograph Whyte, Inverness 1865] a large rushing mountain-stream with several nearby waterfalls. The contractor was Alexander Wilson.

The site of the viaduct, within the grounds of Blair Castle, was dictated by the Duke of Atholl to be at the old road bridge. The view indicates that the condition was met with ingenuity on the part of Mitchell and Wilson. [6, 7]

9. Bruar Footbridge (Suspension)

NN 8392 6583

This bridge crossing the Garry opposite the west entrance to the Duke of Atholl's estate at Blair Atholl has a span of 160 ft and is raised well above the river level by a flight of steps at each end. It has an unstiffened timber deck $3\frac{3}{4}$ ft wide with wire mesh between suspenders in place of handrails. The suspender rods are of $\frac{1}{2}$ in. diameter steel, clamped to the cables at about 2 ft intervals. The cables are $1\frac{1}{2}$ in. diameter wire ropes connected by U-bars to short lengths of $1\frac{1}{4}$ in. diameter chain at ground anchorages.

Jim Shipway

Bruar Footbridge

The bridge, probably dating from the early-20th century, was refurbished in 1991 by the 71st Scottish Engineer Regiment (V), who renewed the deck and wire-mesh barriers with materials supplied by the Duke of Atholl.

Tummel-Garry Hydro-Electric Scheme, Perthshire

HEW 2471

The North of Scotland Hydro-Electric Board's Tummel-Garry scheme, with a catchment area of 706 square miles, was completed in 1962, generating 244.8 MW of electricity from the Rannoch (1930), Tummel (1933), Pitlochry (1950), Clunie (1951), Gaur (1953), Errochty (1957), Cuaich (1959), Trinafour (1959) and Loch Ericht (1962) power stations. The consulting civil engineer for the scheme was J. Guthrie Brown of Sir Alexander Gibb & Partners. The scheme utilises the waters of the Tummel and its tributaries and was a logical development of the Rannoch and Tummel Hydro-Electric schemes designed and constructed by Balfour, Beatty & Co. Ltd for the Grampian Hydro-Electric Supply Company from 1931–34.

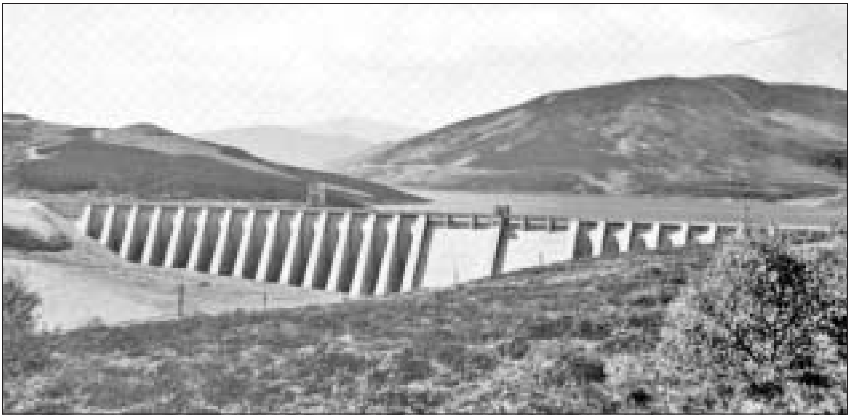
The highest reservoir on the Tummel-Garry scheme, situated on the upper reaches of the Errochty, was created by the construction of Errochty Dam. The Clunie dam was built in the Tummel gorge, the water from which is conveyed by tunnel to Clunie power station. Two miles downstream is the Pitochry dam and power station designed to regulate the flow in the Tummel below Pitlochry and which created Loch Faskally. [8–10]

10. Errochty Dam

HEW 2471/01
NN 7139 6563

Errochty Dam is a 127 ft high, 1310 ft long diamond-headed buttress dam completed in 1957 which formed a new three-mile long reservoir with a top water level 1080 ft above sea level.

A 12-mile long tunnel entering the loch from the north east collects water from the upper reaches of the rivers Bruar and Garry and some of their tributaries. Another tunnel six miles long and 15 ft in diameter takes water from Loch Errochty to the Errochty power station which



Errochty Dam [NSHEB Power from the Glens (1964), 49]

is discreetly situated in a hillside excavation on the shore near the western end of Loch Tummel.

The power station is built of stone excavated from the main tunnel and has three 25 000 kW vertical Francis turbines operating on a head of 610 ft. [8–10]

11. Clunie Dam, Loch Tummel, Pitlochry

HEW 2471/02
NN 8843 6028

Clunie Dam is sited in the gorge of the Tummel about two miles downstream from the natural outlet of Loch Tummel. It raised the level of the loch by 17 ft and more than doubled its length. The mass gravity dam completed in 1951 is 65 ft high and has two 60 ft long automatic drum-type spillway gates for flood control which automatically lower themselves to the extent necessary to pass flood water. A fish pass with 43 pools enables salmon to surmount the dam. The main contractor was George Wimpey & Co.

From the dam, water is led to Clunie generating station through a two-mile long tunnel, horseshoe shaped in cross-section, with an equivalent diameter of 23 ft. A vivid impression of the size of the tunnel, the largest tunnel in Britain at the time, is given by the memorial arch of the same section above the power station. Approximately 400 000 tons of rock had to be excavated in its construction. The contractor was Cementation Co. Ltd.

From its outlet the main tunnel trifurcates, in steel, into branches each $12\frac{1}{2}$ ft in diameter serving the three turbines.

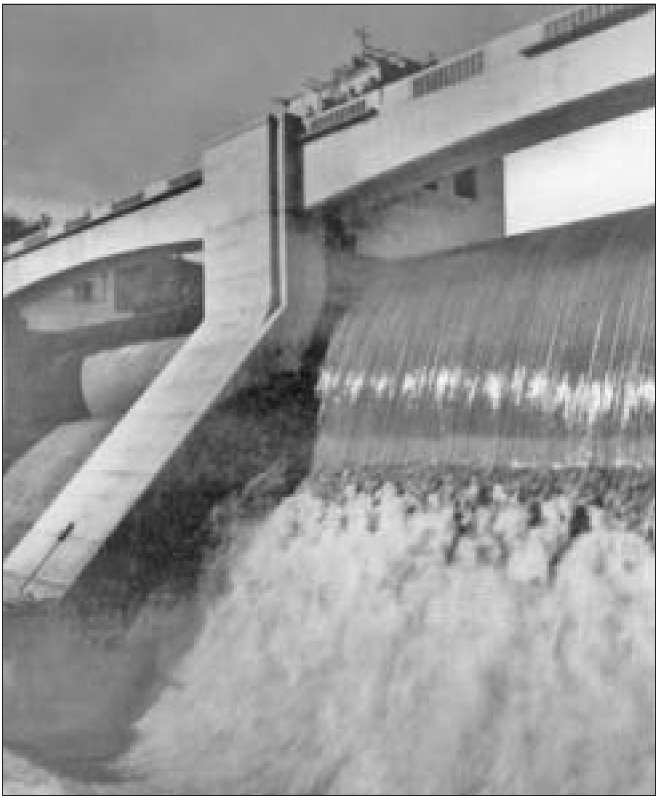
This remarkable trifurcation, now covered over, was made in the workshops of Sir Wm. Arrol & Co. The turbines are of 20.4 MW capacity, each operating on a maximum head of 173 ft. [8–10]

12. Pitlochry Dam

HEW 2471/03
NN 9354 5772

Within a few minutes walk from the centre of Pitlochry are the dam and integral generating station. The dam is 54 ft high and the station was designed principally to benefit the lower reaches of the Tummel by evening out the flow of water reaching Clunie power station.

There are two automatic spillway drum gates at the dam each having a span of 90 ft. These and the fish ladder, 900 ft long with underwater observation chambers from which the fish can be viewed, have attracted much tourist interest.



Pitlochry Dam [8]

The generating machinery consists of two 7.5 MW turbo-alternators.

The construction of the Pitlochry dam, completed in 1950, led to the creation of Loch Faskally and the development of sailing, fishing and various forms of water sports making Pitlochry a major tourist centre attracting about 100 000 visitors each year. In the late 1940s and 1950s, when the works were being planned and constructed, Hydro Board staff and their consultant engineers were often ostracised and refused accommodation such was the fear that the works would blight the scenery and drive away visitors! [8–10]

13. Clunie Footbridge, Pitlochry

HEW 2471/04
NN 9278 5857

The creation of Loch Faskally by the construction of Pitlochry dam raised the water level of the Tummel by about 40 ft, submerging the two-span masonry arch Clunie Bridge. It was decided to replace it by a pedestrian bridge nearby.

The new bridge, erected in 1950, the only one of its kind in Scotland, is unusual in being built of aluminium alloy trusses. It is $310\frac{1}{2}$ ft long with a centre span of $172\frac{1}{2}$ ft and two side spans of 69 ft and is designed for a live load of

Clunie Footbridge [11]

84 lb sq. ft over a deck width of $6\frac{1}{2}$ ft. Although arched in elevation it functions as a cantilever beam bridge constructed of twin 'N' truss girders braced at the deck and arch soffits.

The material for the main members of the bridge is AW10B alloy. Little information on aluminium alloy riveting practice was available at the time of erection and this aspect required careful investigation. As aluminium has a very low modulus of elasticity compared to steel it might be thought that the slender design would be vulnerable to deflection effects or vibration, but this has not proved to be the case.

The consulting engineers were Sir Alexander Gibb & Partners and the contractors P. & W. McLennan Ltd, Glasgow. The aluminium alloys were supplied by James Booth & Co. Ltd. The concrete piers were constructed by Wm. Tawse, Aberdeen. [11]

14. Dunkeld Bridge

HEW 0149
NO 0267 4245

This magnificent bridge is a good example of Telford's dictum that in a bridge of multiple arches the spans should increase slightly towards the centre and the roadway parapet line seen in elevation should be on the arc of a great circle from one abutment to the other (see figure). It is Telford's largest Scottish bridge and its functionality is enhanced by modest embellishment in his favourite Gothic style which is successful in harmonising with its dramatic surroundings.

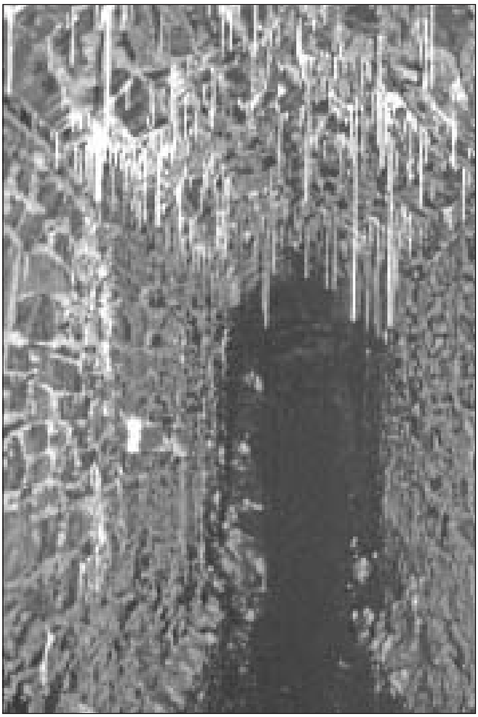
Construction began in 1804, the main contractor being John, Duke of Atholl, and the bridge was opened in November 1808. It cost 'above £30 000'. Until Dunkeld was bypassed by the new A9 road in 1977, the bridge carried the A9 Perth to Inverness road over the Tay. It now serves mainly local and tourist traffic.

The width of the river at this point and its shallowness allowed the bridge to be constructed in two halves, each half being built in a dry channel while the river flow was diverted into the other.

The bridge, about 685 ft long, has seven arches of dressed masonry with spans of 20 ft, 74 ft, 84 ft, 90 ft, 84 ft, 74 ft and 20 ft and the roadway at the centre span is about 54 ft above the water level. Internally it conformed to Telford's practice

Roland Paxton

Top: Dunkeld Bridge



Tayside Regional Council Roads Dept

Dunkeld Bridge interior

for large masonry spans in being constructed with hollow spandrels to reduce the weight on the foundations and allow inspection of the internal workmanship. The piers have typical triangular cutwaters surmounted by semi-circular masonry towers rising to the parapet level where they form pedestrian refuges.

The bridge, which replaced inconvenient and often hazardous ferries, was a toll bridge and the original toll house still stands at the southern abutment. The citizens of Dunkeld strongly objected to the tolls, culminating in riots in 1868. The tolls were abolished in 1879 when the bridge was taken over by Perthshire County Council.

The new A9 bridge, erected in 1976–77 to the north of the town, is 738 ft long with three spans supported on twin steel girders. It was designed by Babtie, Shaw and Morton. [12, 13]

15. Inveralmond Bridge

NO 0948 2656

A substantial three-span masonry arch over the Almond, built in 1827 on the great north road from Perth and carrying the A9 road until it was bypassed in the 1970s. One of Scotland's most sophisticated masonry bridges designed by Jardine with scientifically designed low-rise semi-elliptical arches.

Inveralmond Bridge

Roland Paxton

The arches are semi-elliptical, spanning 55 ft, and the arch-rings deepen proportionally to the calculated thrust from 2 ft at the crown to $4\frac{1}{2}$ ft at the springings. The arch rise, almost flat over the central section, is $9\frac{3}{4}$ ft. The clear width is 30 ft.

The bridge is still used for local access and accommodates a riverside path under its south arch. [14]

16. Perth Bridge

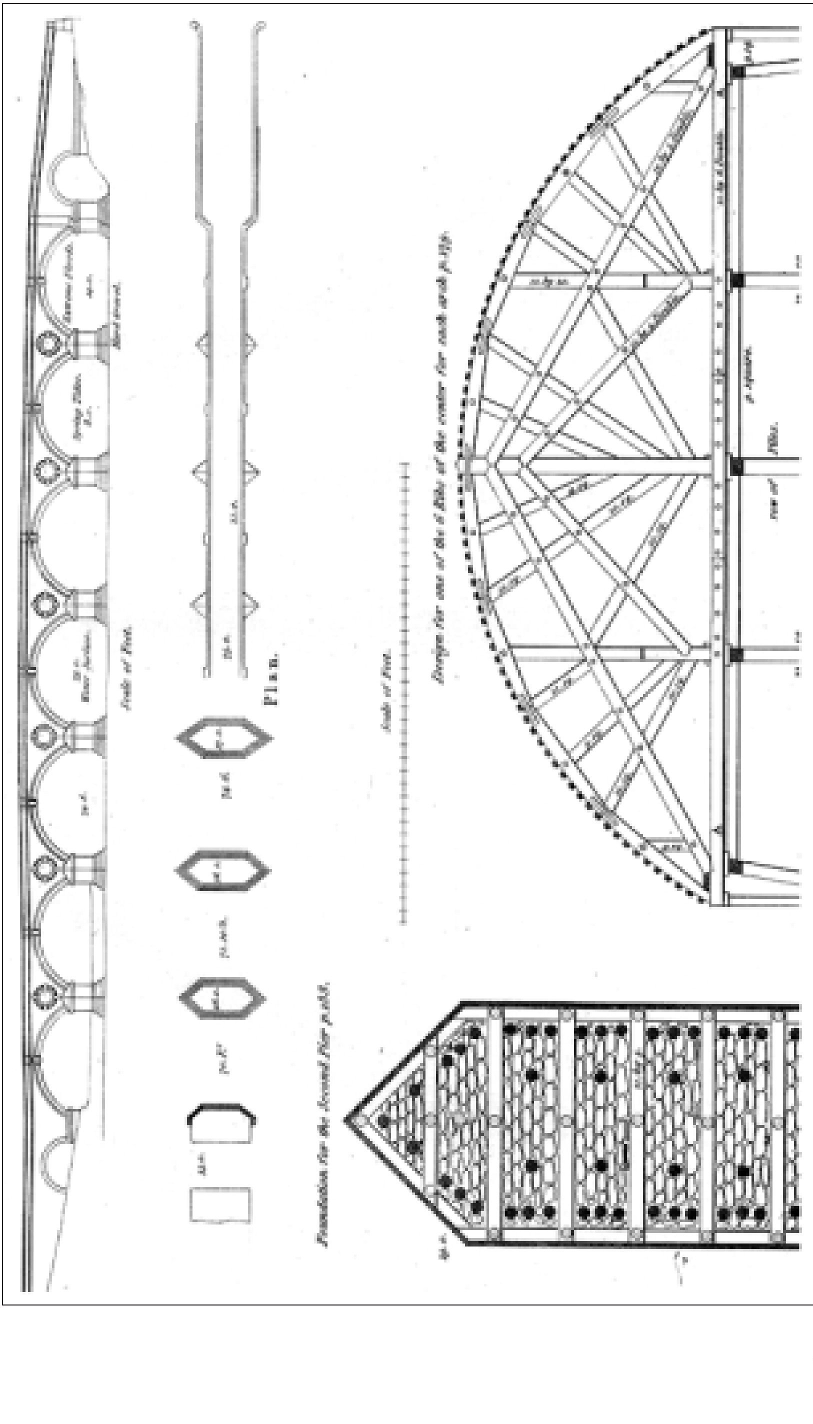
HEW 0318
NO 1212 2388

An old stone bridge over the Tay at Perth was swept away by a flood in 1210. It was rebuilt and either it or its successor often damaged and repaired, being entirely rebuilt from 1599–1617. It is said to have had eight arches and to have been destroyed in 1621 when six arches collapsed in a flood, a disaster ascribed to the town's 'iniquity'. After this the river was crossed by ferries until Smeaton successfully achieved the present bridge from 1766–71.

The bridge has seven masonry arches over the river and two land arches to provide extra flood capacity. The spans increase towards the central arch which is 75 ft wide. The original road was 22 ft wide, but was widened in 1869, none too elegantly, to provide the present cantilevered footways by means of cast-iron brackets and parapets. The masonry of the arches and abutments is pink Perth sandstone. Over the piers the spandrel faces are decorated architecturally by rings of stone infilled with black whinstone suggestive of transverse cavities.

In fact, the internal structure of the bridge is hollow to reduce weight, but by means of longitudinal spandrel walls mounted on the arches supporting the roadway – a technique subsequently adopted by most bridge engineers for large masonry spans. The cavities are bridged over internally by pointed arches, with iron ties placed laterally above them to counter any outward thrust, an early application of this technique.

The piers were founded, some within coffer dams, on timber piles with starlings (a protective timber surround with masonry infill extending up from the foundation to just above low-water level). These measures were based on careful site investigation and trials by John Gwyn the resident engineer, who also determined the as-built



Perth Bridge – drawing (Smeaton) [15]

Roland Paxton

Starling pier protection

position of the bridge and superintended most of its building by direct labour. The cost exceeded £20 000.

This 893 ft long bridge, then Scotland's and Smeaton's largest, now carries about five million vehicles per annum without weight restriction. On the north face of the west abutment is a record of the Tay flood levels from 1814 to the present day. [15, 16]

Traffic conditions were improved with the opening downstream in 1960 of Queen's Bridge, the first long span prestressed concrete structure in Scotland, which cost £150 000. Its 78 ft, 157 ft and 11 ft spans were adopted to suit the four-span Victoria Bridge it replaced on the same line, which was jacked up to clear the new work by 20 in. and to support the formwork for the new bridge. The consulting engineers were F. A. Macdonald & Partners and the contractor, Whatlings Ltd.

17. Perth Harbour

HEW 1069
NO 1188 2195

The Tay has been navigated up to Perth by small boats from at least as early as 1147 with the harbour, consisting of quays along the west shore, in existence for centuries. The modern harbour, opposite Moncreiffe Island, was originally planned by Robert and Alan Stevenson in 1833 with larger quays and a dock at an estimated cost of £48 714.

After a delay the developed scheme, then estimated to cost more than £50 000, was to have been completed by 1854 but in that year the Harbour Commissioners went bankrupt with the work only partly done. The harbour and its debts were taken over by Perth Council but the work remained unfinished for a long time.

The Stevensons also directed a significant improvement of the Tay navigation channel by the removal of fords. By 1841 the water depth at spring tides had been increased from $11\frac{3}{4}$ ft to 16 ft and vessels drawing 14 ft were able to reach Perth in one tide ‘with ease and safety’.

Much of the harbour walling was of timber which has gradually been replaced with steel-sheet piling. Harbour improvements costing £30 000 were carried out in 1955–56. [17, 18]

18. Round House, Perth

HEW 1014
NO 1204 2314

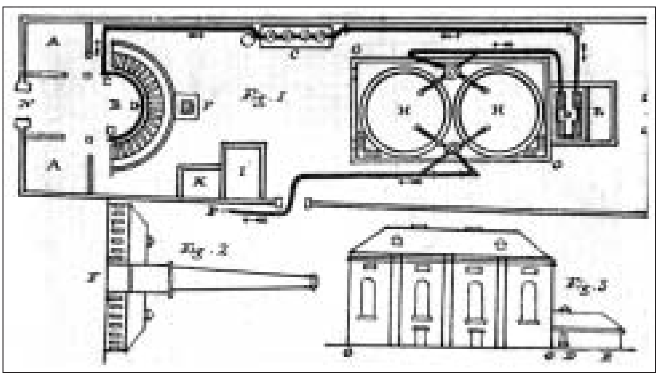
The Round House water tower, built from 1829–32, was part of a water supply scheme for the city designed and superintended by schoolmaster–engineer Dr Adam Anderson, Rector of Perth Academy.

The Round House is built in ashlar masonry in the style of a roman temple. It comprises a circular base with walls 5 ft thick supporting a 146 000 gallon domed storage tank from which the water was distributed by gravity throughout the city. The tank and roof are made from cast-iron sections bolted together. Alongside, to the north, there was a boiler/pump house with a chimney 110 ft high adorned with classical vase-style chimney pot. The scheme also included filter beds on Moncreiffe Island and an intake suction pipe beneath the river from which the water was pumped into the distribution tank.

It is recorded that Dr Anderson once wrote in chalk on the lintel above the south door of the Round House, ‘AQUAM IGNE ET AQUA HAURIO’ (‘I draw water by fire and water’). This piece of classical wit was later inscribed in gilt lettering on a panel above the main door where it can be still be seen, but there is now no longer water in the tank.

Perth Round House and pumping station 1832 [2]

Dr Anderson also designed and superintended the construction of Perth's first gasworks in 1824–25 between Canal and Victoria Streets, adjoining Scott Street. 'The mode of purifying is entirely new and by the novel construction of the retort house and the method of purifying more than double the usual quantity of gas is extracted from the coal' (see illustration with Canal Street



Perth Gas-Works, Perth 1825

Perth Gasworks 1825

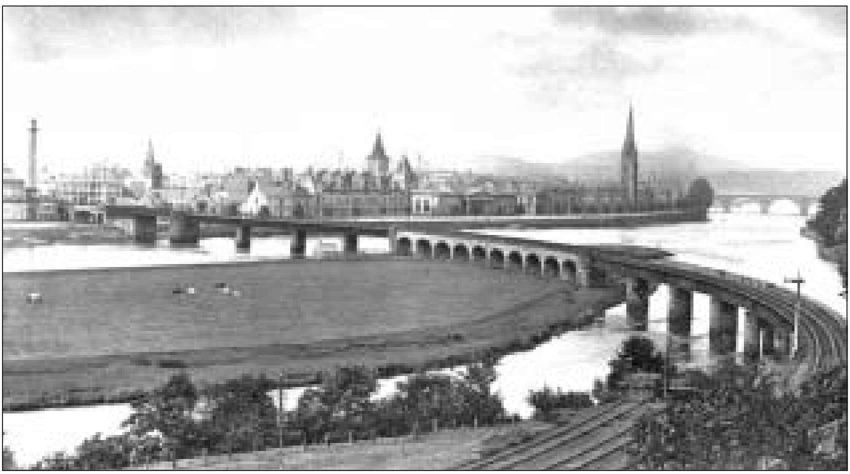
adjoining 'N' and South Street at 'P' and elevations of the former (semicircular in plan) retort house, chimney and gasholder house with two holders). [19]

19. Tay Viaduct, Perth

HEW 1591
NO 1213 2314

The first viaduct on this site, carrying the Dundee & Perth Railway across the Tay, was of bulky timber segmental arches on stone piers erected in 1849. It was replaced by the present iron and masonry viaduct opened in May 1864, designed by B. H. Blyth and erected by Lee & Freeman at a cost of about £27 000. Both bridges incorporated an opening swing-span near the west bank of the river, but in the present bridge it has since been replaced with a fixed span.

The viaduct has an overall length of about 1300 ft and is curved in plan to a radius of 15 chains (990 ft). Its middle section on Moncreiffe Island has ten masonry arches, each of 28 ft 4 in. clear span, carried on 4 ft wide piers. The adjacent sections comprising iron plate-girders spanning about 82 ft are carried on twin $7\frac{1}{2}$ ft diameter masonry piers. The piers are founded on cast-iron caissons filled with concrete. The east section has seven spans and the west section five spans. There is a public footpath along the full length of the bridge on the north side carried on cantilevered cross beams.



Tay Viaduct, Perth – Waterworks on left [photograph ca.1890]

20. Friarton Bridge

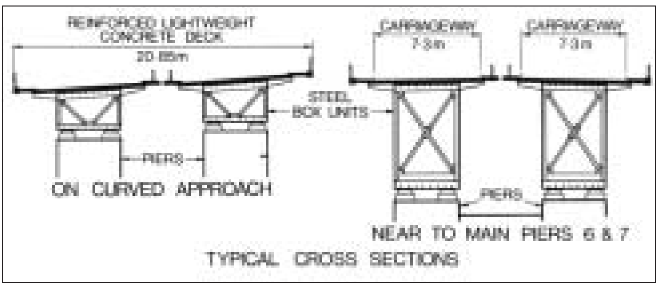
NO 1304 2160

This elegant nine-span steel bridge, erected from 1975–78 on the M85 road, soars some 30 m above the floor of the Tay Valley for more than half a mile with spans varying from 63–174 m. These are many times greater than the Tay Viaduct's spans of 114 years earlier, such had been the development of bridge engineering over this period.

The bridge, which is evocative of engineering ability and skill, derives its strength from independent twin 4.3 m wide steel box-girders from 2.7–7.5 m deep. The girders were made at Darlington and Chepstow in lengths of from 10.5–25 m, lifted into place and welded together. Each box-girder carries a 7.3 m two-lane carriageway. The slender reinforced concrete piers on which the girders rest are of 4.5 × 1.25 m cross-section and most are founded on piles up to 40 m long down to gravel or bed rock.

The bridge was designed by Freeman Fox and Partners (Resident Engineer H. Binnie) for the Scottish Development Department. The main contractor was Cleveland Bridge & Engineering Co. Ltd and the civil engineering contractor, Miller Construction Northern Ltd. The cost was about £8 million excluding the multi-level northern approach and junction constructed by Shellabear Price (Scotland) Ltd for about £3 million. [20]

Two miles south of Friarton Bridge is the Bridge of Earn (NO 1304 2160), a finely proportioned masonry bridge now carrying the A912 across the Earn on three equal semi-elliptical arches of 75 ft span. It was designed by John Rennie, built in 1819, and is still in service. His drawing was published in Cresy's *Treatise on Bridge-Building*, Williams, London 1839. Since widening in 1935 the bridge's original façades on each side have been obscured.



Friarton Bridge [Friarton Bridge and Northern Approach Road Project (Scot. Dev. Dept. leaflet 1975)]

Despite a measure of ingenuity, the appearance of the bridge was not enhanced by this widening, which was achieved by means of reinforced concrete continuous girders of varying depth forming cellular construction. Mock voussoirs are inscribed in the concrete arch-ring but this does not exactly follow the extrados of the old bridge which is visible behind like petticoats showing below a skirt.

The Bridge of Earn widening was designed by F. A. Macdonald & Partners, the consulting engineer was Dugald McLellan, and the contractor Murdoch McKenzie Ltd. [21]

21. Dalginross Bridge, Comrie

NN 7736 2191

A three-span steel cantilever bridge erected over the Earn from 1904–05, the first of its kind in Britain. It is 200 ft long with two anchor spans of 52 ft each and a cantilevered centre span of 86 ft and contains 182 tons of steel. The interest lies in two arms of the cantilevered centre span, which meet at a pin-joint at mid-span, without the more usual suspended span joining their ends. This form gives maximum slenderness at mid-span, and offers a convenient location for a movement joint.

The construction is of four tapering plate-girders carrying the roadway, with footways cantilevered off the side girders. The plate-girders have curved soffits giving the bridge a slender appearance, somewhat marred now by some unsightly service pipes.

The bridge, made and erected by Sir William Arrol & Co., was strengthened and refurbished in 2000 and won a Saltire

Dalginross Bridge [22]

Civil Engineering Awards commendation on PHEW's recommendation 'for achieving high quality preservation whilst unobtrusively strengthening Arrol's original structure'. [22]

22. Faery Footbridge, Dunblane

NN 7789 0163

This elegant ferro-concrete arched footbridge, locally dubbed 'faery brig', erected over the Allan Water in 1911 is of the stiffened arch type. It was a bold design for its time and is notable for having been designed and constructed by Considere, early pioneers of reinforced concrete work. The span is 93 ft, the rise of the arch is 11 ft 9 in. and the footway is 4 ft wide.

A plate on the handrailing records that the bridge was restored in 1974 by Leitch & Sharpe, consulting engineers, Glasgow; James Grant & Sons Ltd, contractor, Alloa; and B. J. McKay, Burgh Surveyor, Dunblane.

Considere's practice may have influenced the eminent Robert Maillart in his similar design for the bridge at Toss in Switzerland erected in 1934.

About half a mile downstream 'pontifex' Bishop Finlay Dermoch built a single-arch stone bridge of $52\frac{1}{2}$ ft span in

Faery Footbridge

Jim Shipway

ca.1419, one of very few medieval spans in Scotland exceeding 50 ft (NN 7818 0103). Four centuries later, in 1849, the bridge was widened, some accounts say rebuilt, and again widened with girders on both sides in the 20th century. It still carries town traffic. [23]

23. Auld Bridge, Stirling (Old Bridge)

HEW 0310
NS 7971 9497

This strategically and historically significant bridge over the Forth at Stirling is at or near the site of a timber bridge which was destroyed in the battle of 1297. The bridge, which probably replaced a ferry, is of coursed masonry (Ballengiech stone) of good quality and workmanship, and possibly dates from as early as the 15th century.

It is a tall and handsome structure, with four nearly semicircular arch spans of 38 ft, 55 ft, 56 ft and 48 ft from south to north; the span sizes being determined by the foundation conditions, often the case with mediaeval bridges.

The bridge piers are 14 ft 9 in. thick and there is a slight bend in the line of the bridge of about 2 ft which may also be due to foundation conditions. The roadway, which is 13 ft wide between parapets, is now restricted to pedestrian use. [24, 25]

Stirling Bridges

24. William IV or 'New' Bridge, Stirling

HEW 0311
NS 7974 9447

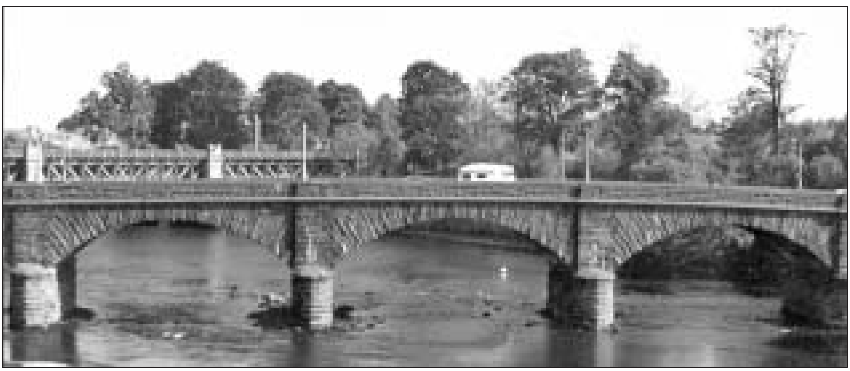
This elegant bridge, built from 1829–32 to the design of Robert Stevenson, was the most seaward road crossing of the Forth for more than a century until Kincardine Bridge was opened.

The bridge, now carrying the A9, has five segmental masonry arch spans ranging from $53\frac{1}{2}$ ft–65 ft with radially oriented masonry in the spandrel faces. The foundation stone was laid in March 1831 and every arch-stone, which increased in depth from the crown towards the springing, was numbered as a guide to its position in the finished work. Stevenson's son David helped to dress at least one of the greenstone archstones.

Some of the foundations were built on platforms on timber piles. The contractor was Keith Mathieson of Stirling and the Resident Inspector was George Middlemiss who had just finished acting in a similar capacity at Montrose Suspension Bridge for Capt. S. Brown. The cost was about £17 000.

Just downstream (see figure) the railway crosses the river on two twin track viaducts, the nearest with three-span open steel trusses of the Pratt type on the former Caledonian Railway to Perth, replacing a viaduct similar to those at Uddingston (4-22) and Ballathie (NO 149 372), and suggestive of a construction date of ca.1900. The other viaduct, alongside downstream, is of three-span iron lattice-girder construction (see figure) suggestive of a ca.1880 construction date, also a replacement structure, on the former North British Railway to Dunfermline. [26]

William IV Bridge and railway viaduct ca.1900



Roland Paxton

Roland Paxton

Downstream railway viaduct

25. Bannockburn Bridge

HEW 1008
NS 8094 9047

This bridge, carrying the A9 road 40 ft over the Bannock Burn about two miles south-east of Stirling, has a span of 24 ft and is of unusual character. According to Southey it was designed by Telford, whose solution for preventing

Roland Paxton

Bannockburn Bridge

Camelon Aqueduct underpass ca.1772

Roland Paxton

inward earth-pressure movement of the tall abutments by means of curved masonry struts is almost playful, but nevertheless effective. The iron beam above the top arch formed part of a later roadway widening to its present 38 ft between parapets.

The bridge was being built when it was visited by Telford and Southey in 1819. Southey wrote, 'Thro' Falkirk we passed under [the Forth & Clyde Canal at Camelon] by an arch so dangerously low that it might easily prove fatal to a traveller on the outside of a stage coach. A new road is making near Stirling [at Bannock-burn] with a bridge which is one of Mr Telford's works and has a huge circle over the single arch . . . the appearance is singular and striking.'

The Camelon underpass referred to by Southey and shown on Smeaton's drawing as 16 ft wide × 11 ft high with 2 ft arch rise was briefly revealed during a lock extension for the Millennium Link Canal Regeneration (see figure). It served for at least four decades before being replaced, first by a bascule bridge and later by a swing bridge. [27, 28]

26. Cambus Footbridge

NS 8533 9408

This bridge, for its time, is a cast-iron segmental arch structure of 65 ft span and 7 ft rise erected across the Devon near its confluence with the Forth, probably between 1825 and 1840. Local opinion favours the earlier date and that the bridge was cast and erected by the Carron Company. Its 12 ft wide timber deck is supported on four ribs thought to be of local design. Each rib is composed of five elements – three 2 ft deep members butt

Cambus Footbridge

Ronald Noble

jointed on transverse diaphragms at third points and two tapered members at the ends on top of the arch-rings.

The bridge, which originally carried horse-drawn traffic, was conserved ca.1975 under the direction of Ronald Noble, consulting engineer, Alloa, as part of a riverside walkway project. [29]

27. Gargunnock Footbridge

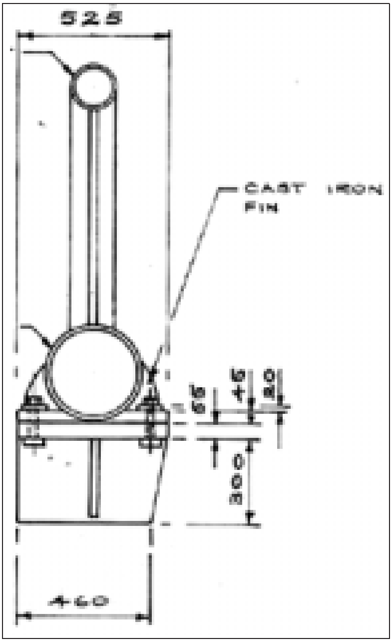
HEW 0922
NS 7061 943

This bridge is a blend of ancient and modern, some parts having had an earlier existence in an iron bridge with timber deck over the Kelty Water at Drymen (NS 5350 9630). Central Regional Council Roads Dept. recognised the uniqueness of the cast-iron trusses, which were to be scrapped, and salvaged them for re-use at the present site.

A feature of particular interest is that both the top and bottom chord members of the trusses are of hollow circular cross-section, the only known instance of this practice in a Scottish bridge. The castings, which are of uncertain date, possibly mid-19th century, are a tribute both to the pattern-makers' art and to the workmanship of the foundry-men. The original Kelty Water bridge may have been built in 1826 by James Shanks.

The present bridge, re-erected over Gargunnock Burn in 1975, has a clear span of 28 ft 9 in. and carries a footway 4 ft wide. The deck is now of concrete.

Gargunnock Footbridge [County Road Surveyor Stirling 1975]



Gargunnock Footbridge [Central Regional Council Bridges Dept – R. Fraser]

Each truss comprises eight panels, six of which are 5 ft long × 4 ft 1 in. deep, the end panels being rather shorter. They all have diagonal bracing of cruciform cross-section.

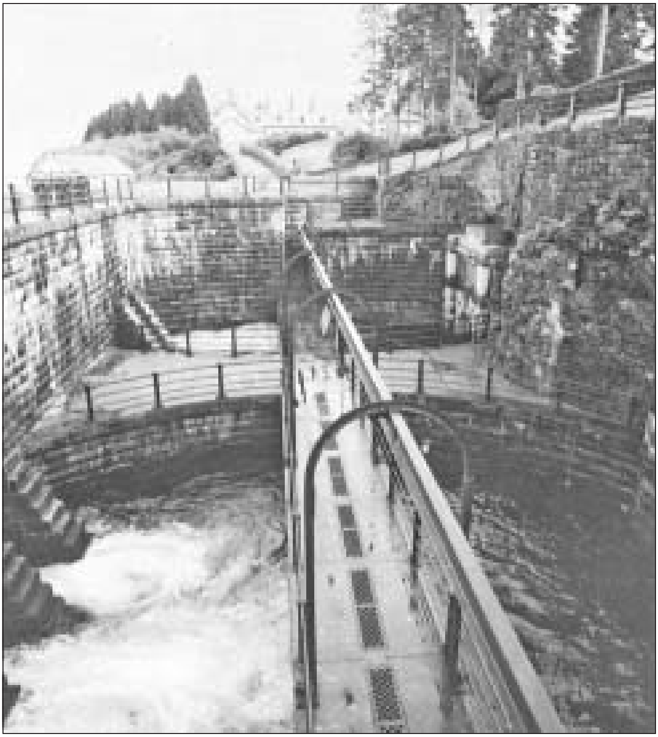
28. Loch Katrine and Aqueducts

HEW 1808/03
NN 4214 0907

For a general description of the Glasgow Waterworks, and Mugdock and Craigmaddie reservoirs, see 4-57.

From 1855–59 the natural summer level of the loch was raised 4 ft by means of a small dam and, by providing a draw-off 3 ft below the natural outlet, the top 7 ft of water was fed through the new aqueduct by gravity to supply 50 million gallons a day to Glasgow.

Under Acts of 1883 and 1885 authority was obtained to raise the level of Loch Katrine a further 5 ft and a new masonry dam was built just below the old one with nine sluices replacing the four previous ones for regulating compensation water. This increased the capacity to 70 mgd (million gallons per day), in addition to which compensation water of 40.5 mgd was provided from other sources.

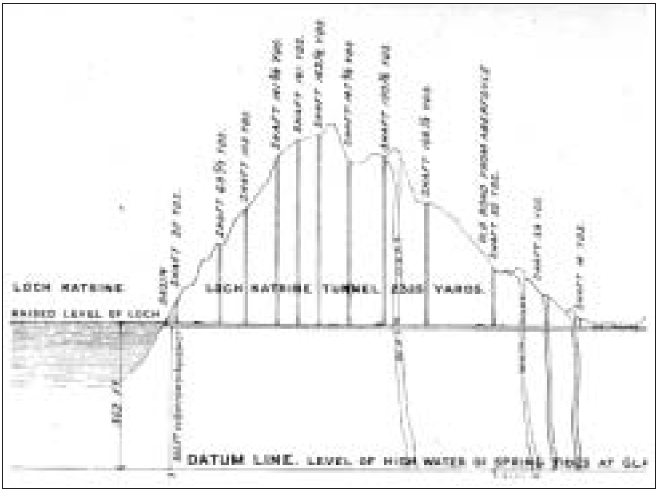


Loch Katrine – aqueduct intake basin, Royal Cottage [Chambers, E.G.W. Water Supply from Loch Katrine. Strathclyde Regional Council 1983]

A third raising of the level of Loch Katrine took place in 1919 when another 5 ft was added. This allowed the city to use a 17 ft depth of water which provided a nine months storage supply assuming no rainfall. The dam at the eastern end was further heightened, and lengthened to 240 ft.

The first aqueduct from Loch Katrine to Mugdock Reservoir at Milngavie was constructed in 1855 to J. F. Bateman's design. It was 26 miles long, of which 13 miles involved hard-rock tunnelling, mostly under spurs of Ben Lomond and just over nine miles of arched aqueduct built in open cut, and cost £468 000, or an average of £18 000 per mile.

The tunnels were unlined, of 8 ft diameter, and laid on a gradient of 10 in. to a mile (1 in 6336). For $3\frac{3}{4}$ miles in total the aqueduct crossed the deep valleys of the Duchray, Endrick and Blane in 4 ft diameter cast-iron pipes having a fall of 5 ft to the mile (1 in 1056). All rock boring had to be done by hand as this was before the time of pneumatic



Loch Katrine Aqueduct longitudinal section – north end [32]

tools. The pipes across the valleys were planned to be laid in a group of three in parallel. At first only one pipe was laid, the others being added later as the capacity was increased from 20 million gallons per day. The third pipe was laid in 1881.

The aqueduct was planned to carry 50 mgd, but actual experience showed it was capable of carrying only 42 mgd owing to friction losses in the unlined tunnels.

Of 70 tunnels, the second longest, immediately after leaving Loch Katrine, is 2325 yards long and 600 ft below the summit of the hill. It was worked from 12 shafts, five of which are nearly 500 ft deep (see figure). The rock was gneiss and mica slate. About 60 drills were constantly in use at each face and on average a fresh drill was required for every inch in depth.

There are 25 substantial iron and masonry aqueducts up to 80 ft in height and 90 ft in span over rivers. The aqueduct bridge in the Duchray Valley comprises a rectangular cast-iron tube 8 ft high and $6\frac{1}{2}$ ft wide, 636 ft long. It is 52 ft above the ground at the lowest part.

The 1885 aqueduct, with a capacity of 70 mgd, was designed and executed from 1886–1903 under the direction of J. M. Gale. He decided not to follow closely the line of the 1855 aqueduct, as the large bridges, particularly in the Duchray Valley, were the least satisfactory feature of the first aqueduct. He adopted a more direct route further into the hills. Although a greater length of tunnelling was involved, this operation was by then facilitated by the newly invented pneumatic drill and the availability of more powerful explosives. A saving in length of about $2\frac{1}{4}$ miles was achieved and, as most of the tunnels were lined with concrete, friction losses were reduced. [30–32]

29. Loch Arklet Reservoir

HEW 1808/04
NN 3561 0940

In 1885 further storage of water in Loch Katrine was planned by a scheme to raise the level of Loch Arklet, and carry the water to Loch Katrine by aqueduct. The original scheme was amended and the work was eventually carried out from 1909–14.

The dam across Loch Arklet's outlet is 350 yards long and made of concrete faced with red freestone from Annan. It is 35 ft high and 11 ft wide at the top. Difficulty was encountered in the construction of its cut-off trench. The water level of the loch was raised by 22 ft and its length increased from 1 to $2\frac{1}{2}$ miles.

The site was remote from roads and the nearest railway was 12 miles away at Aberfoyle. The closest point of access was at Inversnaid, on Loch Lomond. Material had to be brought to Balloch and conveyed by barge up Loch Lomond and then by a specially constructed aerial cableway over the hill to the dam site. The cableway required the construction of a small hydro-generating station for its power supply and this was built at Inversnaid and fed by a pipeline from Loch Arklet.

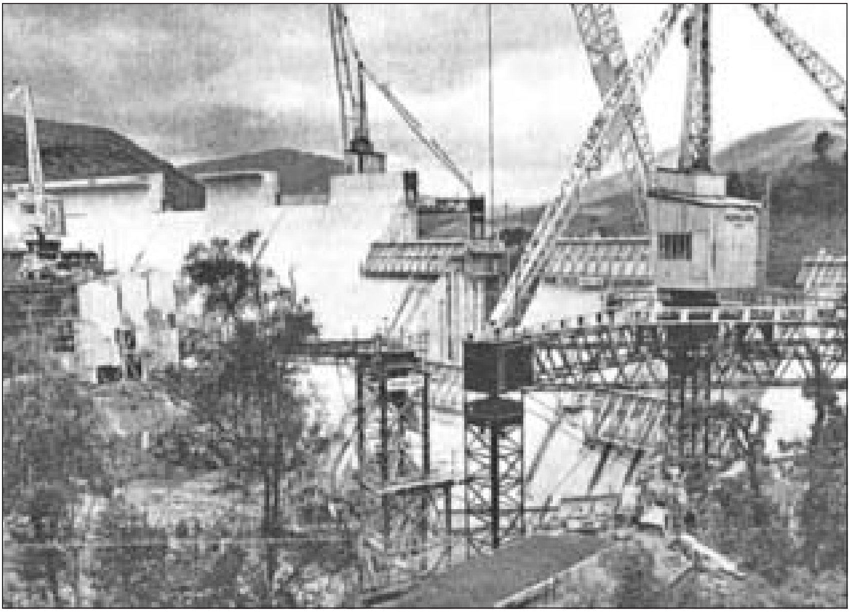
The original scheme was designed by J. M. Gale, but it was brought into service by J. R. Sutherland, both engineers to the Glasgow Water Department. [33]

30. Glen Finglas Reservoir

HEW 1808/05
NN 5299 0791

From 1881–1911 the consumption of water by Glasgow's population had increased from about 37 to 70 mgd which made it necessary to consider further supplies. The first scheme proposed involved damming Loch Voil and Loch Doine, but this met with serious opposition and was abandoned.

An alternative source was found in Glen Finglas which extends into the hills northwards from Brig o' Turk. The



Glen Finglas Dam [34]

Turk was to be dammed and the valley flooded to create a reservoir with a capacity greater than that of Loch Arklet. The waters were to be conveyed to Loch Katrine by an aqueduct $2\frac{1}{2}$ miles long, and the scheme was to provide an extra 19 mgd.

The necessary powers were obtained by an Act passed in 1915 but an effect of the Great War was to increase costs and the scheme was postponed and an additional supply obtained by the third raising of the level of Loch Katrine. The engineer for the original scheme was J. R. Sutherland.

Although the ground for the reservoir and dam had been purchased, the scheme was not implemented until 1963–65 by which time a further increase in supply had become necessary. The concrete gravity dam is 115 ft tall and 720 ft long. The engineers were Babtie, Shaw & Morton and the contractor, Mowlem Scotland Ltd. The cost was about £800 000. [33, 34]

31. Loch Vennachar Reservoir

HEW 1808/06
NN 5979 0645

In drawing water from Loch Katrine for the supply of Glasgow, compensation water had to be provided to the

Teith, and 40.5 mgd was required. This was obtained by storing water in Loch Vennachar and Loch Drunkie.

A dam at Loch Vennachar raised its water surface 5 ft 8 in. above the normal summer level and authority was obtained to draw down 6 ft below that level. Loch Drunkie was raised 20 ft and its water conveyed to Loch Vennachar. The dam at Loch Vennachar had a fish ladder provided to allow the passage of salmon.

These works had to be implemented before any water could be drawn from Loch Katrine, and were carried out from 1855–59. The engineer was J. F. Bateman. [35]

32. Dunipace Bridge, Bonnybridge

NS 8347 8164

A substantial masonry arch bridge over the Carron, on a side road connecting the A833 and A876 roads near Bonnybridge. An inscription on the bridge states that it was built by Thomas Grey, mason, of Lesmahagow and Christopher Cairns, road contractor, of Stirling in 1825.

It is a three-span segmental arch bridge 105 ft long, with spans of 28 ft, 32 ft and 28 ft. The surrounding countryside is flat and to give flood clearance there are ramped approaches with 1 in 25 gradients at each end of the bridge. In elevation the bridge parapet line is on a large radius arc, perhaps influenced by Telford's practice.

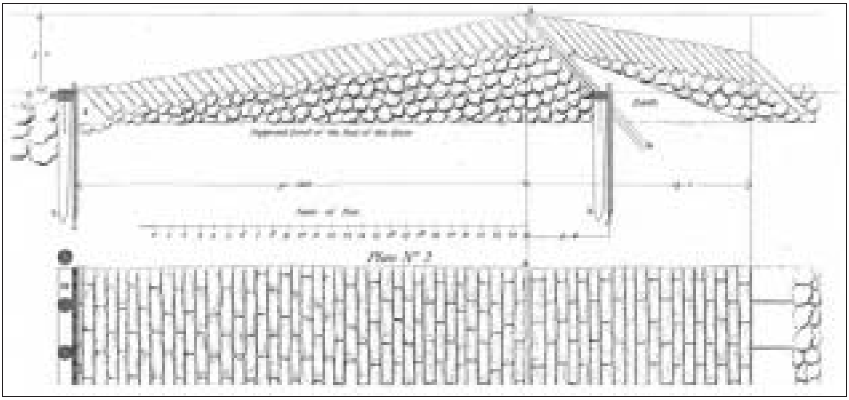
Carron Ironworks Weirs

33. Dunipace or Larbert Weir

NS 8389 8159

There are two surviving weirs on the Carron that were built to provide water power for the Carron Company, then one of the world's most advanced ironworks, much of the machinery for which, with its water power, was designed by John Smeaton. He also designed Dunipace Weir and the former Stenhouse Dam at the Ironworks which were probably the most technically advanced in Scotland at the time. Dunipace Weir is about 300 yards south of Larbert Church.

Dunipace Weir, basically to a Smeaton design of 1773, is about 80 ft long and $6\frac{1}{2}$ ft high and was probably built soon after this date. It is built of quarry rubble and faced with



Dunipace Weir drawing (Smeaton) [36]

squared stone. Differences between the drawing and the as-built weir can be accounted for by site changes during construction. The crown of the dam was designed to be 3 in. higher at the ends than in the middle. The lade to a reservoir at Carron Ironworks, the power source for propelling the early machinery, no longer exists and its intake is now barely discernible. The dam is now neglected and breached. [36]

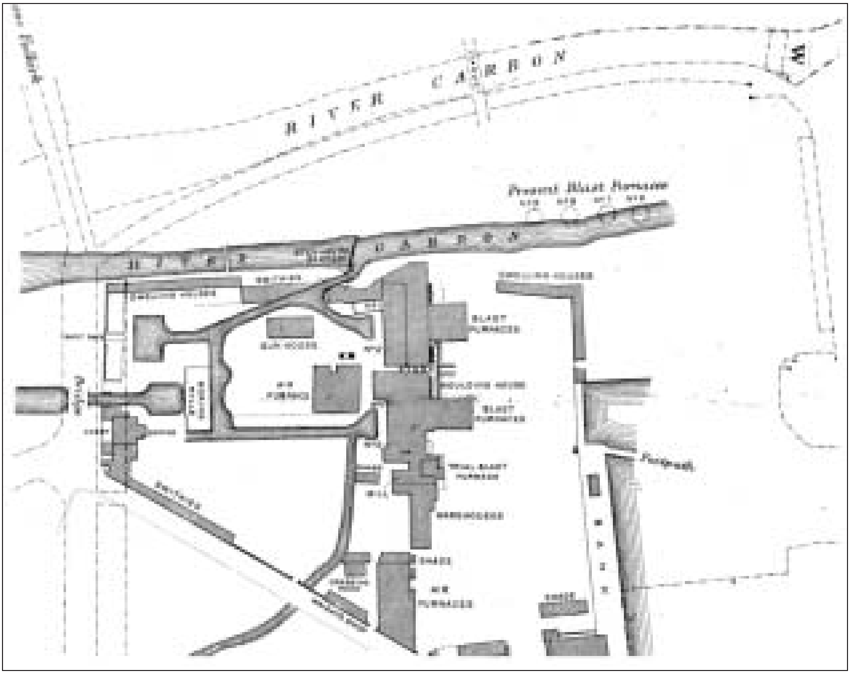
Dunipace Weir

Geoffrey Bailey

34. Carron Ironworks Weir

NS 8791 8232

The Carron Ironworks Weir (at 'W' on the plan and before the realignment of the Carron shown in broken lines) is



Plan of Carron Ironworks ca.1775 (dashed lines show later development) [37]

straight, about 90 ft long, $6\frac{1}{2}$ ft high and 20 ft wide and of generally similar design to Dunipace Weir. It dates from a realignment of the river in the late-18th or early-19th century. An 1815 date is carved on a stone coping at the weir which may indicate its construction date. The intake to the lade and its sluice gate are still intact.

The curved dam shown as Stenhouse Damhead on the plan is presumably the one made to Smeaton's design of 1773. Stenhouse Dam was superseded by Ironworks Weir and its lade into the works. [37]

35. Slamannan Railway – Iron Aqueduct

NS 9447 7419

The Slamannan Railway, which extended from Airdriehill in Lanarkshire through Slamannan to Causewayend on the Union Canal, a distance of some $12\frac{1}{2}$ miles, was made to supply Edinburgh with Monkland coal. The line, now long disused, was opened in 1840 and was followed in 1851 by a $4\frac{1}{2}$ mile branch line to Bo'ness.

Roland Paxton

Slamannan Railway Aqueduct 1840

Approaching the Union Canal there is a deep cutting on the railway at Candie near Avonbridge. This cutting is spanned by a cast-iron trough carrying a burn – Slamannan Railway overbridge No. 25. The trough is supported on an elegant cast-iron sub-structure consisting of three arches

Richard Chown

Slamannan Railway Aqueduct spandrel

formed of angle sections in a semi-elliptical shape, the centre one spanning about 30 ft. The arches spring from circular cast-iron columns in pairs. The engineer was John MacNeill, Telford's former chief assistant. [38]

36. Slamannan Dock

NS 9613 7613

This basin on the Union Canal at Causewayend, near Linlithgow, was commenced in 1836 and opened in 1840 as a trans-shipment facility between the canal and Slamannan Railway connecting with Glasgow. When the Edinburgh & Glasgow Railway opened to Haymarket in 1842 the usefulness of the dock was much reduced, particularly after the Slamannan Railway was connected with the Edinburgh & Glasgow Railway in 1843.

The dock was 150 ft square and the railway tracks ran round the sides of the basin with turning points at the corners to allow the railway wagons to be rotated through 90°. The base of a crane can still be seen. The engineer was John MacNeill, London, and the contractor, Michael Fox (for the eastern end of the railway and probably the dock). The resident engineer was Thomas T. Mitchell. [39, 40]

37. Falkirk Tunnel (Canal)

HEW 0325/03
NS 8825 7874

This was the only canal tunnel in Scotland before completion of the new tunnel at the Falkirk Wheel in 2001. The necessity for the tunnel, which is just south of Falkirk and 696 yards long, arose from the refusal of landowner William Forbes to allow the canal to cross his estate in view of Callendar House. A further objection by him also resulted in a deep cutting north of the tunnel.

The tunnel, completed in 1822, is about $13\frac{1}{2}$ ft wide and driven mainly through solid rock. It is unlined but patched with masonry and brickwork in places. At each end there is a masonry façade with semicircular arch-ring. The work was designed and constructed under the direction of the Edinburgh & Glasgow Union Canal Company's engineer Hugh Baird and the contractor was John Mitchell. The towpath has been renovated and provided with a handrail for pedestrian safety.

Miller had a similar problem at the Falkirk ridge when engineering the Edinburgh & Glasgow Railway from 1838–41 which he resolved by making a tunnel 846 yards in length just to the north-east of the canal tunnel. [40, 41]

38. Falkirk Wheel

HEW 0325/04
NS 8524 8013

The Forth & Clyde and Edinburgh & Glasgow Union Canals ceased to be connected when the Falkirk flight of locks (11 × 10 ft rise; 110 ft rise) on the latter was closed in 1933. In 2002 this connection was restored by means of the landmark 'Falkirk Wheel' boat lift which formed the centrepiece of a £78 million 'Millennium Link' regeneration of the Lowland canals.

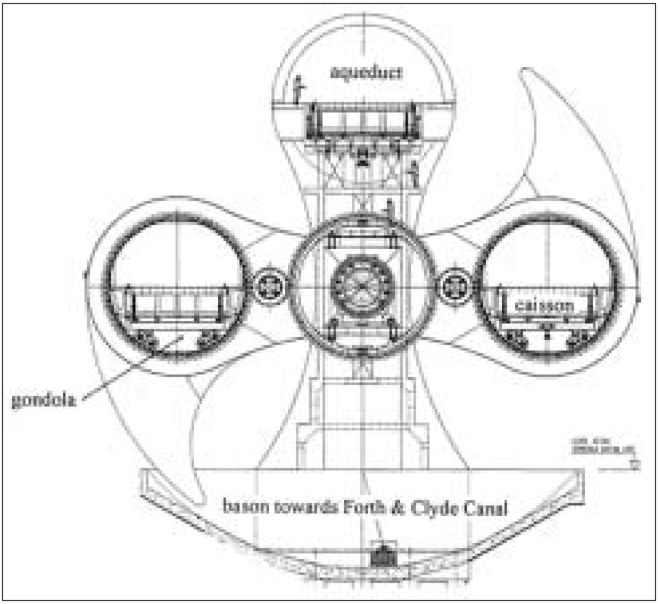
The Wheel comprises two 35 m long rotating arms rigidly connected to each end of a 3.8 m diameter central axle 28 m long. The arms support, within semicircular gondolas, two water-filled boat-carrying caissons with double watertight doors at each end. These allow transfer of the boats between the caissons and the aqueduct above and the basin below.

The total weight to be moved is about 1800 tonnes, but the machine is essentially a balanced unit with the loads to be driven by the motors deriving from wind and friction being a small fraction of this figure. There are also loads caused by the unequal balance of water in the gondolas. The drive system, designed to operate with the worst foreseeable combination of these loads, operates by means of ten hydraulic gearbox units driving one end of the main axle. Under normal traffic conditions they rotate the arms 180° in about four minutes.

Each gondola of the Wheel sits in two circular tracks. When the arms are rotated the tendency of wind and friction to move the gondolas out of position is counteracted by the gears at the end of each gondola holding them horizontal and preventing oscillation. Each gondola, which contains about 250 000 litres of water, will transfer up to four boats at a time in about 15 minutes. The design life of the Wheel is 120 years. It is now one of Scotland's most visited tourist attractions.

The project, which includes two locks above the Wheel and one below, and a 168 m sprayed-concrete tunnel under the Roman Antonine Wall and Edinburgh &

Falkirk Wheel
[43]



Glasgow main line railway, was carried out for British Waterways – Director Scotland, Jim Stirling, and designed by Arup Scotland. The contractors were Morrison Bachy-Soletanche. The steelwork was fabricated by Butterley Engineering, Ripley, Derbyshire. [42, 43]

Although a military project, the Antonine Wall, or Graham's Dyke as it is known locally, made from ca.140–ca.185AD, is mentioned for its major earthworks, the remains of which are still visible in many places. The Wall comprised an earth rampart, ditches, forts and a road and extended over a distance of 36 miles across Scotland from Kinneil to Bowling, more or less on the line of the Forth & Clyde Canal 16 centuries later. One road by which it was served from the south was via Dere Street, from Corbridge via Trimontium (visible from Leaderfoot Viaduct, 2-23), Inveresk and Cramond.

39. Kincardine Bridge

HEW 1561
NS 9256 871

There was no road bridge over the Forth downstream from Stirling until 1936 when Kincardine Bridge was completed at a site where the river is 2400 ft wide at high water. Even

Roland Paxton

Kincardine Bridge

though the Forth Road Bridge, completed in 1964, attracted some of its traffic the bridge still serves as a major artery carrying the A876 road.

In the 1930s the Forth was navigable to Stirling and vessels of up to 2000 tons traded to Alloa with coal, oil and timber. To accommodate upstream shipping a turning section was incorporated into the bridge which swung about a central support to provide twin openings of 150 ft. The circular track and rollers at this support were so finely made by Sir William Arrol & Co. that it required only 2 hp to turn the span. Because of the decline in shipping the bridge is no longer turned. The shipping clearance at high water was when closed, and is now, 30 ft.

Adjoining the turning section there are ten approach spans of 62 ft–100 ft to the north and 16 approach spans of 50 ft–100 ft to the south. The south approach ends in a piled reinforced concrete viaduct 265 ft long. The total length of the bridge is 2696 ft and when built it was the largest swing bridge in Europe and Scotland's longest road bridge. The delay to road traffic in opening and closing the bridge for shipping was 13 minutes.

The consulting engineer for the bridge was J. Guthrie Brown of Sir Alexander Gibb & Partners, and the main contractor was the Cleveland Bridge & Engineering Co. Ltd, Darlington, who subcontracted some work to Sir Wm. Arrol & Co.

In 1885 the Alloa Railway crossed the Forth five miles upstream by means of a single track 1615 ft long viaduct with 15 wrought-iron lattice bow-girder spans of 68 ft, two of 80 ft, one of 100 ft and two opening spans of 60 ft clear. It was designed by Crouch & Hogg. The contractors were Watt & Wilson and the ironwork was executed by P. & W. MacLellan. The bridge was demolished in 1971. [44]

40. Gartmorn Dam, Alloa

NS 9134 9400

In 1710 George Sorocold, a hydraulic and mining engineer from Derby, was commissioned by the 6th Earl of Mar to advise on the drainage of his coal mines at Sauchie north of Alloa. Sorocold recommended that the reservoir with its earth embankment which had been rebuilt by the Earl as early as 1694, now known as Gartmorn Dam, and which was fed with water from a small burn, should have its power capacity increased by means of a substantial additional feeder from Forest Mill on the River Black Devon about two miles to the east.

At Forest Mill, water from the river was diverted for the mill and feeder to Gartmorn Dam at a horseshoe shaped masonry weir some 10 ft high. Construction of the feeder along the north flank of the river valley, and requiring several rock cuts, was a considerable challenge in 1710.

Gartmorn Dam

Ted Ruddock

Sorocold set it out using a large wooden quadrant with a plummet set on a tripod. The feeder was cut soon afterwards. His advice for improved pumping at the mines seems to have been disregarded as an earlier chain and bucket arrangement continued in use.

In 1767 Smeaton was consulted about improving the transport of coal from Sauchie and reported on making the Devon navigable to the Forth.

A lade from the west end of the reservoir supplied water for a waterwheel which drove the pumps at the mines and, later, a colliery winding engine. Downstream the water was again used by various mills and gave Alloa a degree of industrial prominence such that by 1791 there were four mills grinding wheat, barley, oats and rye. The water finally featured in the Earl's pleasure grounds around Alloa Tower near the Forth before being dammed again to provide a scour, via a stone flume, to clear the former harbour of silt.

In 1785 the dam was heightened and surfaced with rough hewn stone, and in 1827 was repaired for £300. The weir at Forest Mill was rebuilt in 1835 for £248 (see figure). From 1820 onwards some of the water was led to Alloa for domestic use through wooden pipes and since 1860 the system has been used solely for this purpose. In 1894 the dam was given a stone face and its crest was raised by a further 2 ft increasing the water area to about 160 acres (see figure). A pump house was also built which is now the Visitor Centre.

The dam itself is believed to be the oldest in Scotland still in use for water supply. It is now located in a country park giving public access to all surviving features of the system. [45]

41. Tullibody Old Bridge

NS 8465 9514

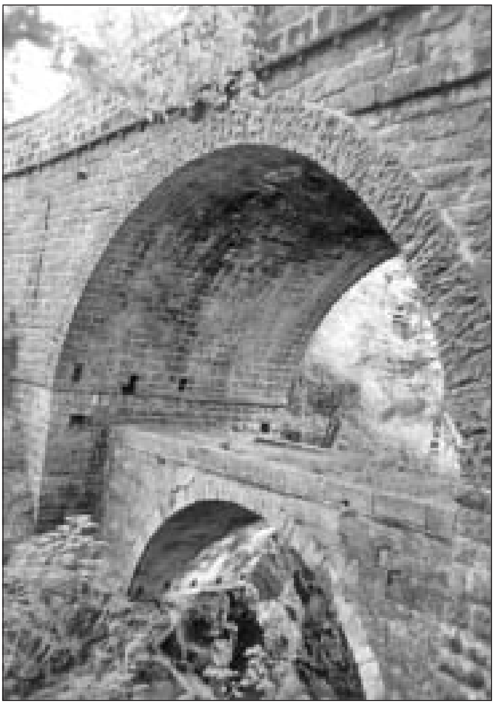
This 16th century bridge over the Devon near Alloa is 442 ft in length, has ribbed main arches of 18 ft span and is $10\frac{1}{2}$ ft–20 ft wide. It has been described as the finest example in Scotland of a fortified bridge in which a series of twists are produced designed to effect the throwing of a body of horsemen into confusion. The eastern part is said to date from before 1555 and an extension westward completed before 1616.

This bridge, now confined to pedestrian use, was bypassed ca.1920 by a single-span steel truss bridge alongside (now demolished). It had arrow-slitted abutment towers designed to harmonise with the old bridge. The trusses were of the Pratt or N-girder type with diagonals curiously in compression instead of tension. This departure from normal practice led to speculation that the girders may have been erected upside down. [46, 47]

42. Rumbling Bridge

NT 0165 9945

This bridge, about ten miles north-east of Alloa on the Dunfermline via Glen Devon to Crieff road over the Ochils from Powmill, improved under the direction of road engineer Charles Abercrombie, was erected in 1815–16. It carries the road more than 100 ft above the Devon on an arch of about 30 ft span and is of particular interest in being built on top of and in having preserved a squared stone masonry bridge. This earlier bridge, built in 1713 by



Roland Paxton

Rumbling Bridge

William Gray of Saline, is 12 ft wide of 22 ft span and 86 ft above the river.

It is recorded in the *Scots Magazine*, that on 19 July 1816 the masons and labourers and others concerned in building the new bridge had a 'grand entertainment of roasted mutton and beef steak with plenty good ale and whiskey on the old bridge with the new arch for covering'. [48]

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