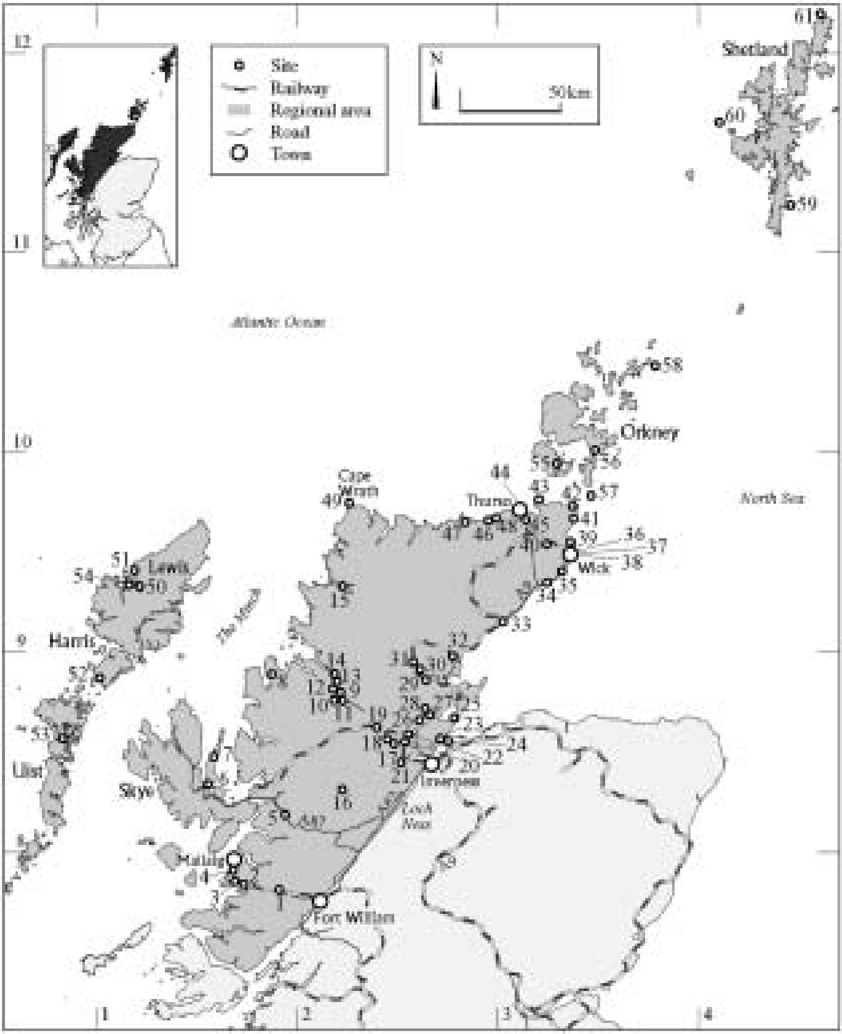

Site
Railway
Regional area
Road
Town
N
50km
Shetland
Orkney
Cape Wrath
Thurso
Wick
North Sea
Lewis
Harris
Uist
Skye
Inverness
Mallaig
Fort William

Highlands West and North, Hebrides, Orkney, Shetland

1. Glenfinnan Viaduct
2. Loch nan Uamh Viaduct
3. Borrodale Bridge
4. Morar Dam, Inverness-shire
5. Shiel Bridge, Glenshiel (Loch Duich)
6. Suishnish Pier, Isle of Raasay
7. Raasay Road, Isle of Raasay, Skye
8. Aultbea Clapper Bridge
9. Braemore and Inverbroom Estate Structures, Wester Ross
10. Gleann Mór Footbridge
11. Corrieshalloch Gorge Suspension Bridge
12. Auchindrean Bridge
13. Inverbroom or Croftown Bridge
14. Inverlael Bridge
15. Kylesku Bridge
16. Mullardoch Dam
17. Moy Bridge
18. Contin Bridge
19. Little Garve Bridge
20. Conon Bridge (Railway)
21. Lovat Bridge, Beauly
22. Dingwall Canal
23. Fortrose Harbour
24. Chanonry Point Lighthouse
25. Cromarty Harbour
26. Evanton or Culcairn Bridge
27. Alness Viaduct
28. Alness Bridge
29. Easter Fearn Bridge
30. Bonar Bridge
31. Oykell Viaduct, Invershin
32. Fleet Mound
33. Helmsdale Bridge
34. Lybster Harbour
35. Whaligoe Steps
36. Wick Bridge
37. Wick Harbour and Pulteneytown
38. Wick Railway Station
39. Ackergill Lifeboat Slipway
40. Greystones Bridge, Watten
41. Freswick Bridge
42. Meal Mill Bridge, John o' Groat's
43. Dunnet Head Lighthouse
44. Meadow Well, Thurso
45. Thurso Bridge
46. Sandside or Reay Harbour
47. Strathy Bridge, Sutherland
48. Dounreay Nuclear Establishment
49. Cape Wrath Lighthouse
50. Callanish Standing Stones, Isle of Lewis
51. Carloway Broch, Isle of Lewis
52. Water Tower, Leverburgh, Harris
53. Uist Causeways
54. Bernera Bridge
55. Underground Oil Tanks, Lyness Base, Orkney
56. Churchill Barriers, East Mainland – South Ronaldsay, Orkney
57. Pentland Skerries Lighthouses
58. Start Point Lighthouse, Orkney
59. Mousa Broch, Shetland
60. Ve Skerries Lighthouse, Papa Stour, Shetland
61. Muckle Flugga Lighthouse

5. Highlands West and North, Hebrides, Orkney, Shetland

Introduction

The basic transport infrastructure of this sparsely populated and extensive area was revolutionised under the direction of the Highland Roads Commission from 1804–21. Individual works noted are Aultbea Clapper Bridge (5-8), possibly PIC Commission; Conon Bridge (1809, 1830, 5-20); Helmsdale Bridge (1811, 5-33); Telford's epoch-making cast-iron arch at Bonar Bridge (1812, 5-30), destroyed by a flood in 1892; Lovat Bridge (1814, 5-21); Contin Bridge (1816, 5-18); Fleet Mound with its land reclamation (1816, 5-32); Greystones and Old Hall Bridges, Watten (1816, 5-40); Shiel Bridge (1817, 5-5); Alness Bridge (1817, 5-28); and Easter Fearn Bridge (1817, 5-29). Harbours improved with Commission funds included Dingwall, with its canal (1817, 5-22) and Fortrose (1817, 5-23).

Before these improvements, such works as there were few and far between, bridges noted being Inverlael (ca.1796, 5-14) on the Contin to Ullapool road; Little Garve on a military road to Poolewe (5-19); Evanton, designed by Smeaton (who had also drawn up proposals for major bridges over the Beauly and Conon in 1772), now sandwiched between later widenings (ca.1777, 5-26); Freswick Bridge (ca.1726, 5-41); Meal Mill Bridge, John o' Groat's (5-42) attributed to Cromwell's men; and Thurso Bridge (1800, 5-45). Bridges developed from the 1870s are represented by Sir John Fowler's iron estate bridges at Corrieshalloch Gorge (5-11), Auchindrean (5-12) and Gleann Mohr (5-10); followed by Inverbroom (ca.1900, 5-13), and Strathy in reinforced concrete (1932, 1994, 10-47).

Railway development is represented by the West Highland Railway extension to Mallaig from 1897–1901, built by 'Concrete Bob' McAlpine, with its impressive mass concrete viaducts at Glenfinnan (5-1); Loch nan Uamh, with its entombed McAlpine horse and cart (5-2), and Borrodale Bridge (5-3). Works on the single-track extension north of Inverness, which became the Highland Railway, and the Dingwall and Skye Railway, which became part of the Highland Railway in 1881, are represented by Conon

Bridge (1862, 5-20); Alness Viaduct (1863, 5-27); and Oykell Viaduct, Invershin (1867, 5-31). The line did not reach Wick until 1874 (5-38).

Other maritime works include Cromarty Harbour designed by Smeaton (1783, 5-25); Whaligoe Steps (ca.1640, 1812, 5-35); Lybster Harbour (1810, 1824, 5-34): Wick Harbour, an instructive case study which exercised the skills of Telford, Mitchell, Bremner, and D. & T. Stevenson (1811–77, 5-37); Ackergill slipway (1910, 5-39); Suishnish Pier, Raasay (1878, 5-6); Sandside Harbour (ca.1835, 5-46); Sandsayre Slip, Shetland (1854, 5-59); the Churchill Barriers, Orkney (1945, 5-56); and the Murchison Oil Production Platform (1979, 3-25).

Lighthouses are represented by North Ronaldsay with 1789 stone and 1853 brick towers and a remarkable stone ball seamark dating from 1809 (5-57, 5-58); Pentland Skerries (1794, 5-57); Start Point (1806, 1870, 5-58); Cape Wrath (1828, 5-49); Dunnet Head (1831, 5-43); Muckle Flugga (1854, 1857, 5-61); Kyleakin (1857, 5-5); Chanonry Point and Cromarty (1846, 5-24, 5-25); and, by way of contrast from masonry towers, Ve Skerries, constructed in pre-stressed concrete and erected with the use of helicopters (1979, 5-60).

The eminent Sir John Fowler left a remarkable legacy of what can be considered civil engineering works from the 1860s, which he created for the enjoyment of his estates at Braemore and Inverbroom. These include, from ten works identified, a tunnel-section byre reminiscent of the Metropolitan underground railway in London which he engineered, and a 1000 yard stag retention wall near the summit of Beinn Dearg! (5-9–5-13).

Power and water supply are represented by Morar Dam hydro-electric works (1948, 5-4); Mullardoch Dam in Glen Affric (1952, 5-16), Britain's largest concrete gravity dam; Dounreay Nuclear Establishment with its evocative sphere (1974, 5-48); Meadow Well, Thurso (1823, 5-44); and Leverburgh Water Tower (1920s, 5-52). The underground oil tanks at Lyness Naval Base, Orkney, represent a notable civil engineering achievement (5-55). Orkney tide and windmills have received only a passing mention, being now no longer operational (5-58).

Ancient works involving remarkable engineering skills in their setting out and erection and considered worthy of inclusion are Callanish Standing Stones (5-50); and Carloway and Mousa Brochs (5-51, 5-59).

An unusual work is Calum Macleod's Raasay road (1976, 5-7), constructed single-handedly in a 'fearsome terrain' based on know-how gleaned from a copy of Aitken's classic *Road-Making* in *Civil Engineering Heritage Scotland – Lowlands and Borders*.

West Highland Extension Railway

HEW 0021

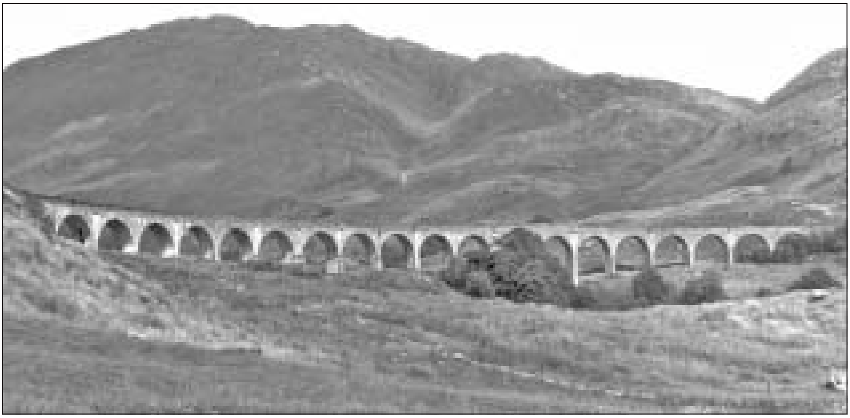
The West Highland Railway, originally worked by the North British Railway, is one of the world's most scenic railways. It could also be said to be the last considerable piece of railway building in Britain, its single track snaking north-west 140 miles from Craigendoran on the Clyde to the fishing port of Mallaig. The 100-mile Craigendoran to Fort William section was begun in 1889 and opened in 1894, and the 40-mile Mallaig extension, was begun in 1897 and completed in 1901.

The Craigendoran–Fort William section was engineered by Formans & McCall, and the main contractor was Lucas & Aird, a prominent London firm whose driving force was John Aird, an MP of crofting stock. The summit is at Corrour, 1345 ft above sea level on Rannoch Moor. The methods of crossing the waterlogged moor on brushwood were developed from traditional experience. Spectacular viaducts include Glen Falloch (NN 3170 2020) 145 ft high, and two in the great Horseshoe Curve above Tyndrum (NN 3350 3620).

Financially the line fared precariously during construction and had to be rescued on one occasion by a director, J. H. Renton, using his private fortune. In gratitude his head was sculpted on a massive rock at Rannoch Station by navvies using only the tools of their trade. It is still there.

The Mallaig extension, built to support the fish trade, struggles westwards through inhospitable mountainous country and winding inlets of the sea. The line has gradients as steep as 1 in 40 and curves of 12 chains radius (800 ft) both of which impose drastic limits on speed of trains. Much of its length is on embankment, bridges or hewn out of the living rock in cuttings and tunnels. Today the line is a major tourist attraction with many steam 'specials' in addition to regular services.

In engineering terms the line is renowned for the early use of mass concrete in bridge construction. The structures were originally planned to be constructed in masonry, but the local rock (mica schist) was too hard and difficult to dress. Concrete offered a cheap alternative solution. In consequence of his usage of this material Robert McAlpine became known as 'Concrete Bob'. The line's most notable elements are Glenfinnan and Loch nan Uamh viaducts



The late Peter Russell

Glenfinnan Viaduct

and Borrodale Arch. The railway was designed by Simpson & Wilson, consulting engineers, and the contractor was Robert McAlpine & Co. [1–3]

1. Glenfinnan Viaduct

HEW0021/01
NM 9099 8135

This spectacular viaduct winds round the hillside, far back and above the Jacobite memorial tower. Its 21 semicircular arched concrete spans of 50 ft, largely completed by 1898, cross 100 ft above the Finnan on an 800 ft radius curve. The width between parapets is 18 ft. Each span has a joint at the crown to allow shrinkage movement of the concrete. The two ‘King’ piers are hollow.

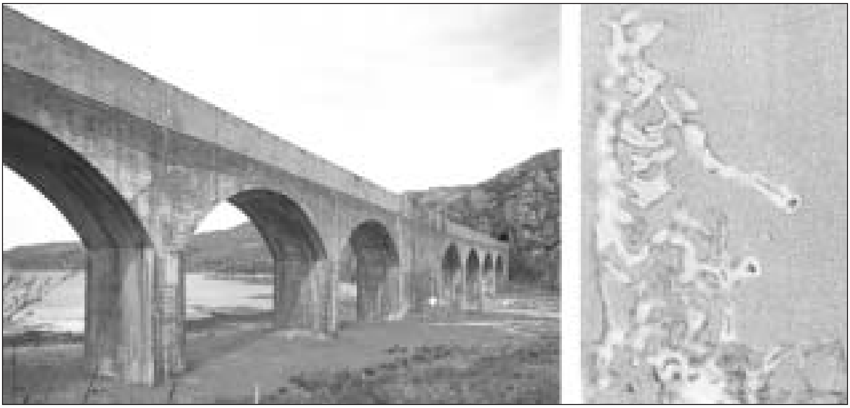
The cost of the viaduct was £18 904. [1–3]

2. Loch nan Uamh Viaduct

HEW 0021/02
NM 7288 8411

The scenic location of this viaduct, at the foot of a rocky mountainside and bridging an inlet to the sea, has been described as Wagnerian. It has eight concrete arches of the standard West Highland Railway span of 50 ft arranged in two four-arch groups on either side of a 50 ft wide central pier. The reason for this unusual arrangement in preference to the more obvious and attractive arrangement of nine arches is not known.

In 2000, Professor Paxton and Radar World, commissioned by Sir Robert McAlpine Ltd, developed an innovative radar imaging technique which penetrated the



Loch nan Uamh Viaduct
Remains of horse and cart in central pier

9 ft thick walls of this pier into its infilled cavity and identified the vertically positioned remains of a McAlpine horse and cart (behind the white spot in the view) which had accidentally fallen into the cavity a century earlier. [1–3]

3. Borrodale Bridge

HEW 0021/03
NM 6975 8549

Borrodale Bridge has three arched spans, the central one of 127½ ft was said to be the longest concrete arch in the world when built. Its soaring unreinforced-concrete arch, built on a curve in plan, exudes confidence. The rise of the arch is 23 ft and its height above the burn is 80 ft. Its arch-ring, composed of concrete comprising four parts sand and stone to one part cement, is 4½ ft thick. The 20 ft side spans were clad in masonry and the bridge was given castellated masonry parapets to mollify a local landowner. [1–3]

4. Morar Dam, Inverness-shire

HEW 2539
NM 6833 9228

A small dam, built by the North of Scotland Hydro-Electric Board in 1948. The power station is built in a cavern excavated in a knoll beside the Falls of Morar. Little more than a doorway and a retaining wall is visible. The scheme initially raised the level of Loch Morar by only 3 ft, but owing to the falls, the operating head for the Kaplan turbines is 16 ft. There is an automatically operated drum gate on the dam spillway. A fish pass enables sea

Ronald Curtis

Glenshiel Bridge

trout and salmon to surmount the dam. The capacity of the scheme is 750 kW, the smallest of the Board's first three projects. [4]

5. Shiel Bridge, Glenshiel (Loch Duich)

HEW 0614
NG 9388 1879

This fine bridge over the Shiel at the south end of Loch Duich, now carrying the A87 road, was designed by Telford and constructed under his direction as engineer to the Highland Roads Commissioners. It formed part of the Kintail Road from Invermoriston to Kyle of Lochalsh. The bridge, one of five built under the same contract, encountered exceptional difficulties in finding skilled workmen, but was essentially completed by 1817.

Crown Copyright: RCAHMS

Kyleakin Lighthouse, and Skye Bridge under construction

Kyleakin Lighthouse – iron bridge approach

Anne Close for Eilean Bàn Trust

The bridge is a random rubble-masonry arch of 65 ft span of pleasing elevation with a string course at road level, tapering pilasters at the approaches and vertical spandrel faces. The surveyor for the Kintail Road, which the Commissioners considered second to none in importance of their roads, was John Mitchell.

About 12 miles west on the A87 road, a 69 ft tall sentinel at the entry to Skye is D. & T. Stevenson's Kyleakin Lighthouse, since 1995 somewhat dwarfed by the Skye Bridge which now even supports the navigational light! When built in 1857 this lighthouse, with its five-span continuous plate-iron footbridge over the rocks, was one of the best examples of its class and exhibited one of the world's first fixed condensing lights. It now forms part of the island nature reserve, of naturalist Gavin Maxwell fame, administered by the Eilean Bàn Trust. [5, 6]

6. Suishnish Pier, Isle of Raasay

HEW 1878
NG 5542 3407

Between 1910 and 1913 Wm. Baird & Co. of Gartsherrie decided to mine a source of iron on the island of Raasay. The mine required a considerable infrastructure to allow the ore to be removed and shipped, and a narrow-gauge railway, crusher, kilns, hopper, pier and other structures were built, mostly of mass and reinforced concrete. Today all are in ruins except the pier which is still used by the Sconser–Raasay ferry.

The pier is a reinforced-concrete structure projecting seawards 380 ft with a pier head frontage 150 ft wide. Unusual features are the movement joint between the pier head and jetty approach, and the use of gravel-filled boxes in the structure to provide mass for the absorption of berthing forces.

The engineer for the Raasay mine infrastructure and pier was Robert Simpson of Simpson & Wilson, consulting engineers, Glasgow. The pier, which is of unique construction, was designed by F. A. MacDonald & Partners and constructed by Robert McAlpine & Sons in 1913–14. The mine labour force included German prisoners during the first world war. Aspects of the installation, such as the pier, diesel-electric power generation and the provision of powerful external electric lighting were state of the art at the time. [7, 8]

7. Raasay Road, Isle of Raasay, Skye

HEW 2540
NG 5840 4800

For many years the people in the north of Raasay had no road to link them with the more prosperous south of the island. All provisions had to be brought by boat from Portree, Skye. By 1925 this situation had become so disadvantageous that the crofters petitioned Inverness County Council for a cart road but unsuccessfully.

By 1966 the lack of a road so troubled Arnish crofter Calum Macleod that he decided to build one himself. It was to be nearly 2 miles long and comprised a layer of stone, gleaned locally, much of which had to be broken by hand, surfaced with gravel and small stones to a finished width of 10 ft. Calum had no experience of road making, and began by buying a copy of Aitken's *Road-making and Maintenance* (1900), for five shillings!

Calum Macleod's road runs from Brochel Castle to Arnish in steep barren country demanding fearsome hair-pin bends, 1 in 4 gradients and a section *en corniche* over the sea. For ten years Calum worked on it single-handedly, alternating month-on, month-off with his duties as an assistant lighthouse keeper at Rona Lighthouse, 8 miles to the north (D. & T. Stevenson 1857). The Council provided tools at the outset, but in the course of the work he wore out two wheelbarrows, six picks, five hammers and four spades.

By 1976 the road was passable for light vehicles and in 1982 was adopted by the Council who spent £115 000

Roland Paxton

Aultbea Clapper Bridge

partly widening it, providing passing places and laying tarmacadam. [9]

8. Aultbea Clapper Bridge

HEW 1695
NG 8738 8898

The clapper bridge at Aultbea on Loch Ewe, probably dating from the early-19th century, formerly carried the A832 over a watercourse flowing into the loch. The bridge, which has been kept in good repair, is approximately 42 ft long and 15 ft wide, with six river and one land openings. These are about 3 ft wide and 4 ft high between the cause-wayed river bed and the stone lintels which are of varying thickness.

This bridge is probably the best Scottish example of this type.

9. Braemore and Inverbroom Estate Structures, Wester Ross

HEW 1556

Sir John Fowler, whose major works included London's Metropolitan Railway and the Forth Bridge, purchased in 1865 and 1867, respectively, estates totalling 40 000 acres at Braemore and Inverbroom, near Ullapool, which he enjoyed for over three decades, his last visit being in October 1897. During this period he applied his engineering skills to developing the estate for the enjoyment of

Braemore House

his family and distinguished guests. His improvements, apart from planting nine million trees and maximising agricultural development, included:

- Building Braemore House on a mountainside 700 ft above sea level. In a letter of 15 July 1867, Fowler refers to the bulk of the stonework of Braemore House as being gneiss obtained from a quarry about $\frac{1}{4}$ mile away. The stone was of a blue colour and ‘wonderfully durable’. For the corners of the buildings and openings, durable sandstone was obtained from Glasgow by sea and carted 6 miles from the head of Loch Broom.
- A $1\frac{1}{4}$-mile long drive up to the house (NH 1997 7927) now demolished, at a more or less uniform gradient of 1 in 30 reminiscent of a railway incline.
- A cattle byre (NH 2000 7940) with the cross-section of a tunnel, similar although not identical to those of the Metropolitan Railway, built into the hillside west of Home Loch. It is about 38 ft long internally and 17 ft wide with an arched masonry roof 14 ft high.
- Enlarging the capacity of Home Loch (NH 2050 7910) by means of two masonry dams for a hydro-electric supply to the house, one of the earliest such systems.

- The generator house (NH 2600 8100), now empty, adjoining the public road below Home Loch. The head of water available was about 600 ft enabling the generators to produce about 60–100 kW of power. It was built of random coursed masonry with ashlar quoins and measured 17½ ft by 12 ft internally. Only the inlet and tail-race pipes built through the walls now remain.
- A 1000-yard-long stone wall near the summit of Beinn Dearg, 3547 ft AOD (NH 2600 8120), said to have been built not so much to keep stags from falling over a dangerous precipice as to provide work for the local unemployed people.
- An embankment with sluices at the west end of Loch Droma (NH 2530 7530) which doubled its extent to about 70 acres, much enhancing its fishing potential. [10]

The bridges are described separately below.

10. Gleann Mór Footbridge

HEW 1556/01
NH 1861 7774

This bridge, of 55 ft span and about 5 ft wide, crosses the wild gorge of Abhuinn Cuileig, a tributary of the Broom which it joins below Corrieshalloch Gorge. Its deck is carried on twin light-arch lattice trusses of wrought-iron or steel 14 in. deep with similarities to the tension ties at the Forth Bridge.

The bridge, probably erected in the 1880s, has been neglected but is a worthy candidate for refurbishment. The view from it is rather less dramatic than a century ago because of tree growth.

11. Corrieshalloch Gorge Suspension Bridge

HEW 1556/02
NH 2034 7801

A footbridge of 82½ ft span in a dramatic setting crossing the gorge about 200 ft deep formed by the headwaters of the Broom near Braemore. The deck is of timber planking 4 ft 8 in. wide, suspended from twin wire-rope cables of 1½ in. diameter.

The bridge was originally erected in ca.1874 and refurbished under the direction of the late Alan Woodhead

Roland Paxton

Gleann Mór Bridge

The late Alan Woodhead

Corrieshalloch Gorge Suspension Bridge

of Sir Alexander Gibb and Partners ca.1977. The site isnow owned by the National Trust who closed the gorge after an inspection of the bridge and viewing platform in 2005. Following a successful public subscription both, which afford views of the dramatic Measach Falls, were strengthened and reopened in 2006.

12. Auchindrean Bridge

HEW 1556/03
NH 1954 8059

This elegant, simply supported, iron truss bridge of bowstring form, the only one of its kind in Scotland, was designed by or under the direction of Sir John Fowler and may have been influenced conceptually by I. K. Brunel's Saltash Bridge. Fowler planned a bridge of similar design for the Metropolitan Railway at Farringdon Road, London, which was never built.

Auchindrean Bridge has a span of 102½ ft and a width of 9 ft. Its timber deck is suitable only for lightweight vehicular traffic. It spans the Broom on an estate road leading to Auchindrean Farm and existed before 1881. The masonry and steelwork contractors are unknown to the authors.

Auchindrean Bridge

Jim Shipway

Roland Paxton

13. Inverbroom or Croftown Bridge

NH 1842 8415

Top: Inverbroom Bridge – before replacement

A former ca.1900-style iron road bridge of 70½ ft span and 12½ ft width over the Broom, used for local access to various clachans at the west side of Loch Broom, and which replaced an earlier timber bridge. The timber deck was supported by three iron or steel trussed ribs about 9¾ ft deep at the abutments and 32 ft deep at mid-span.

The designer, manufacturer and contractor for this bridge have not been determined. It was replaced in 1994 by the present bridge to the design of Highland Regional Council, which has Rennie Mackintosh style ornamentation in its concrete abutments.

14. Inverlael Bridge

NH 1818 8546

A rubble-masonry humpbacked bridge over the Lael, bypassed in 1964 by the present reinforced-concrete bridge alongside. Its arch is segmental, with roughly shaped arch-rings, spanning 44 ft. The width between parapets is 14 ft. Its probable date of construction was between 1792 and 1796 when the road from Contin to Ullapool was made by Kenneth Mackenzie of Torridon for about £4500 at the expense of the British Fisheries Society to connect with their settlement at Ullapool.

By 1809 the road, which had been made at just over half the cost of surveyor George Brown's estimate in 1790, was badly decayed and the rebuilding of some bridges was required. But nothing seems to have been done despite a memorial in the late 1830s by local heritors quoting from the *New Statistical Account* that 'the line chosen was so bad and absurd, and the execution so wretched, that the road has been for many years back not only useless but dangerous, even to foot passengers and riders on horseback'.

Such is the hump of the old bridge that the underside of its arch at the crown is on the same level as the top of the coping stone of the parapet of the present bridge. [11, 12]

15. Kylesku Bridge

HEW 2541
NC 2268 3383

This bridge carries the A894 road over the entrance to the sea inlet Loch a' Chairn Bhaine and was completed in 1984. It is a bold and elegant design of three spans in prestressed and reinforced concrete although the geometry of the bridge is such that the three spans are sometimes read as five. The deck is a box girder of constant depth.

The main span is 433 ft and the side spans are 236 ft. The deck is curved in plan and continuous throughout, with movement bearings only at the abutments where they can be easily inspected and renewed if necessary.

The waterway at the bridge is nearly 400 ft with strong tidal currents and is of considerable depth. Because of

Kylesku Bridge

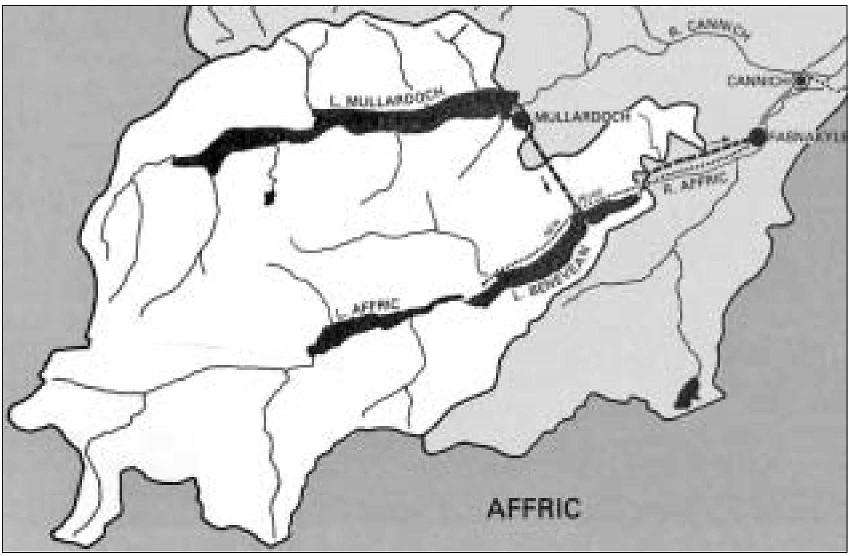
this the bridge was built without temporary supports in the channel by means of cantilevering from the ends. The foundations of the V-shaped main supports are on rock and on dry land. The central section of the bridge was planned by the contractor to be pre-cast on the shore, floated out, and then lifted into position.

The consulting engineers were Ove Arup and Partners, and the main contractor, Morrison Construction Ltd. The tender price was £2$\frac{3}{4}$ million although, because of extremely adverse weather conditions, the out-turn price exceeded £4 million. Construction was achieved within the contract period of 102 weeks. [13]

16. Mullardoch Dam

HEW 1421
NH 2225 3129

In 1928 and 1941 hydro-schemes were proposed in Glen Affric. The first was turned down by Parliament and the second was dropped in favour of the more comprehensive Mullardoch–Fasnakyle–Affric project which was approved in 1947 and officially opened in 1952. A further stage to the north, developing the water power resources of the Beauly and its tributaries, the Strathfarrar and Kilmorack scheme, was carried out from 1957–63 and included the impressive 113 ft high double curvature arch dam at Loch Monar.



Glen Affric catchment area [16]

Mullardoch Dam [16]

The main elements of the Affric scheme consist of Mullardoch Dam, a tunnel from Loch Mullardoch to Benevean, a small dam at Loch Benevean and a tunnel from there to the main generating station at Fasnakyle in Strathglass.

Mullardoch Dam is 157 ft high and 2385 ft long and, with about 300 000 cu. yards of concrete, is the largest concrete gravity dam in Great Britain. It has two wings meeting at an angle of 140° with the apex pointing downstream. Construction began in 1947 and two years into the work it was decided to raise the height of the dam by 20 ft, a change requiring great skill in its execution.

The dam has two spillways each 315 ft long and the level of the loch was raised by 112 ft to form a reservoir $8\frac{1}{2}$ miles long. Water from the reservoir is conveyed through a $14\frac{1}{2}$ ft diameter tunnel, 3 miles long, to Loch Benevean and onward to Fasnakyle Power Station where three 22 000 kW turbo alternators, with Francis-type turbines working under a gross head of about 520 ft, each develop 33 000 hp at 375 rpm.

The engineers were Sir William Halcrow & Partners and the main contractors, John Cochrane & Sons. [14–16]

17. Moy Bridge

NH 4818 5468

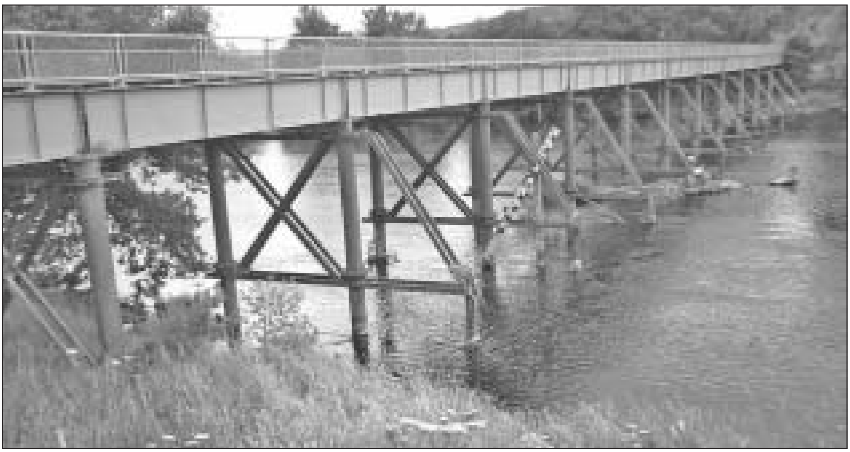
This is an economically designed single-lane road bridge, about 350 ft long, carrying the A832 road over the Conon at Marybank near Contin.

It has 14 simply supported spans each of 25 ft carried on outer riveted steel-plate girders forming part of the parapets. The deck is carried on steel cross-beams bridged by concrete jack arches. The roadway is 12 ft wide with single-lane traffic operation. Masonry abutments flank the girder spans at each end.

The piers are cast-iron columns in pairs with somewhat temporary-looking bracing which may have been added at a later date. Long raking members on the upstream side appear to have been placed to provide extra stability against floods, and possibly floating ice.

The bridge was built in 1894 by Cleveland Bridge Engineering of Darlington. Later work by Crouch & Hogg, Glasgow (date unknown) may have involved extra bracing.

Moy Bridge



Roland Paxton

18. Contin Bridge

NH 4540 5668

An unusual asymmetrical three-span rubble-masonry bridge with spans of 40 ft, 45 ft and 50 ft span designed by Telford and erected from 1813–16 by T. Muirson at a cost of £1163. The long time period was because Muirson was required to rebuild two arches in 1815–16. The bridge connected the Achnasheen and Contin to Dingwall sections of the Loch Carron Road. An earlier bridge of insufficient dimensions was destroyed by a flood in 1811.

Above the bridge's arch springing level its triangular cutwaters translate into narrow pilasters extending up to the parapets. The inclination of the parapet line at the bridge does not quite match that intended by Telford.

The bridge carried the A832 road until bypassed in the 1980s by the present bridge which is curved in plan and affords a good view of the old bridge. [17]

19. Little Garve Bridge

HEW 2542
NH 3964 6288

A rubble-masonry bridge, about 260 ft long, spanning the Black Water, probably built under Major W. Caulfeild's direction in the 1760s as part of the Contin to Poolewe road. It is a fine example of a later military bridge. Loss of stone from the north-west wing wall is giving rise to concern about the bridge's future. The main arch is segmental of 46 ft span and 16 ft rise with random narrow archstones 20–26 in. long. The bridge is 13 ft wide between parapets and attains a maximum height above the river of about 40 ft. There is a segmental flood arch of 24 ft span to the west of the main arch. [18]

Little Garve Bridge

Roland Paxton

20. Conon Bridge (Railway)

HEW 2543
NH 5399 5572

A substantial single-track skew viaduct on the former Highland Railway at Conon Bridge, built in 1862. The structure, which is still operational, is of five segmental arches, each of 73 ft span on a skew of 45° to the river. Each arch is composed of four ribs $3\frac{3}{4}$ ft wide, 4 ft deep at the springing and 3 ft deep at the crown. Unlike a common skew arch these ribs spring from haunches perpendicular to their spans and not their pier lines.

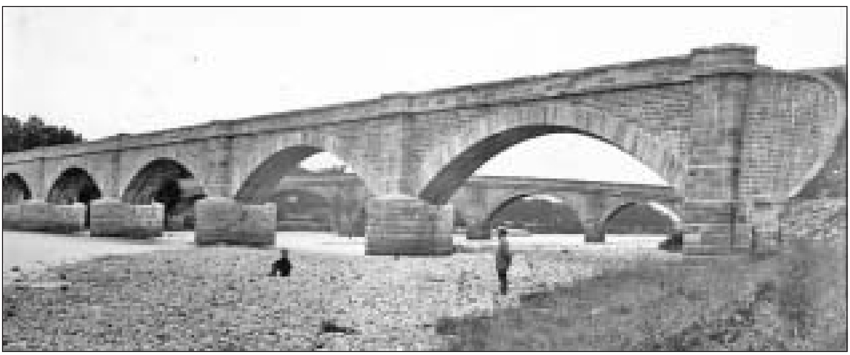
The keystones at the centre of each arch are bonded to the adjacent arch, as are the arch-rings at the haunches. Iron cramps were also inserted occasionally in the arch-ring joints to connect the ribs. The height of the deck is 45 ft from the bed of the river, which is rock, and made an excellent foundation. When the centring supporting the archstones until the keystone was placed was removed, it is recorded that there was no settlement of the ribs.

The designer and builder of the bridge was Joseph Mitchell, engineer to the Highland Railway. He at first favoured an iron-girder bridge at this site, but chose a masonry arch bridge on the grounds of durability.

Immediately downstream on the north side is an evocative high-quality reminder of Telford's former Conon Bridge (1809). It is an ashlar masonry toll house with a two-storey octagonal tower designed by Telford in 1829 and erected under Joseph Mitchell's direction in 1830.

The toll house is of the same genre as the Anglesey toll houses on the Holyhead Road, for example at Llanfair PG (Llanfairpwllgwyngyllgogerychwyrndrobwllllantysiliogogogoch), erected under Telford's direction in ca.1825. [19]

Conon Bridges [photograph Whyte 1865]



Conon Bridge Toll House

Roland Paxton

21. Lovat Bridge, Beauly

HEW 2544
NH 5161 4496

This fine bridge, with its five segmental masonry arches with spans of 40 ft, 50 ft, 60 ft, 50 ft and 40 ft over the Beauly, was built from 1811–14 by George Burn in red sandstone at a cost of £8802. Forming the arch-rings proved to be a hazardous task as his slender centring was often in danger from floating logs during floods.

The bridge was designed by Telford and characteristically exhibits a parapet line on a gentle arc of large radius, its effect emphasised by the pronounced double string course. Other attractive visual features are the archivolts (thin curved stones immediately above and highlighting the arch-rings) and the semi-hexagonal masonry piers rising from the cutwaters to become refuges at road level. The bridge has substantial abutments extending parallel to the river.

The bridge was partly damaged by the great flood of 1829, but repaired soon afterwards under Joseph Mitchell's

Roland Paxton

Lovat Bridge

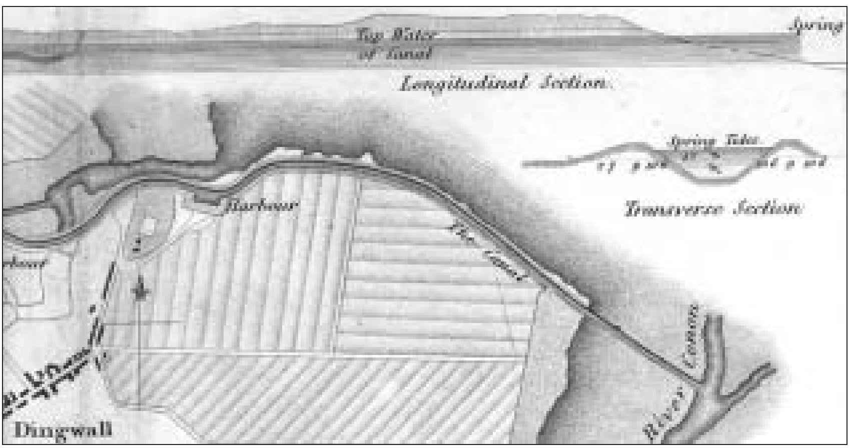
direction. In 1894 two spans had to be rebuilt following the collapse of a pier during severe flooding.

Repairs to the original spans and deck waterproofing were carried out in 1985. Although the bridge no longer forms part of the A9 road, it remains an essential link in the local road network. [17, 20]

22. Dingwall Canal

HEW 2545
NH 5585 5888

This 2000 yard long canal with its two basins and quays connected the Peffrey, Great North Road and town with



Bottom: Dingwall Canal – plan [21]

the Cromarty Firth and was used by vessels of up to 9 ft draught. It was built under the auspices of the Highland Roads Commission from 1815–17 for £3800 by William Hughes, a Caledonian Canal contractor. The engineer was David Wilson.

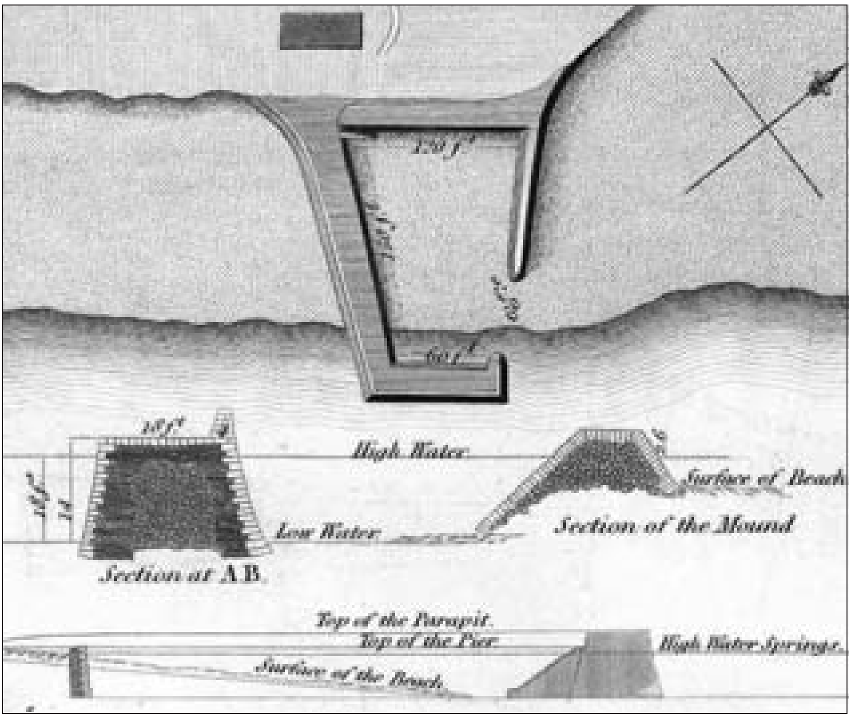
The canal encountered silting problems throughout its existence and was thought to be finally improved in the late 1860s but, within a decade, it had again fallen into disrepair and became disused from 1884. Nothing is now visible of the works at the town end, but much of the canal channel still exists. [21, 22]

23. Fortrose Harbour

HEW 2108
NH 7249 5626

Fortrose Harbour – plan [23]

This harbour, designed by Telford, was constructed under the direction of Highland Roads Commission by John Watson and completed in 1817 at a cost of £4015. It is trapezoidal in plan, 120 ft by 150 ft with piers on two



sides and, although repaired in 1881, remains an excellent example of its genre, largely in its original state.

Other similar small harbours in the vicinity built under Telford's direction exist at Avoch (1815) and Portmahomack (1816). [23]

24. Chanonry Point Lighthouse

HEW 2546
NH 7494 5570

This lighthouse was built in 1846 adjacent to the pier for the ferry across the Moray Firth from Fort George at a cost, including the light-keepers dwellings, of £3570. Its tower is 43 ft high and similar in appearance to nearby Cromarty Lighthouse. Both lighthouses were designed with revolving lights by Alan Stevenson, engineer to the Northern Lighthouse Board, and Chanonry Lighthouse exhibits his innovation of a stronger lantern in bronze with inclined astragals which minimised obscuration of the light beam. The station was automated in 1984. [24]

25. Cromarty Harbour

HEW 2547
NH 7854 6772

The earliest piers of the present harbour were designed by John Smeaton, who is known to have taken his own levels during site investigation. Work probably began in 1781 and by 1785 a 'most commodious quay' had been provided

Cromarty Harbour

Roland Paxton

jointly by the proprietor, George Ross, and the government, under the superintendence of John Gwyn as resident engineer.

By 1783 the curving 230 ft long north pier had been built in typical Smeaton construction, using small squared blocks of reddish sandstone. Smeaton then decided to terminate it and construct a detached pier, or breakwater, 130 ft long almost parallel to the shore and about 70 ft from the north pier head. He considered that this arrangement would provide adequate protection for shipping without too much deposition of sand within the harbour. By 1839 a south pier had been built and in ca.1994 a timber structure connecting it with the breakwater was replaced by the present Bailey bridge.

The harbour is overlooked by Cromarty Lighthouse which, being well above sea level, required a tower only 42 ft high to achieve a range of about 14 miles. The lighthouse was designed by Alan Stevenson, built by David Mitchell of Montrose, and became operational in 1846. Its estimated cost including the other buildings was £3030. The station was automated in 1985. [24–26]

26. Evanton or Culcairn Bridge

HEW 2548
NH 6084 6635

This bridge, probably the most northerly one designed by Smeaton, which he called Altgran, after the river it

Roland Paxton

Evanton Bridge – showing original arch to Smeaton's design crossed (now called Glass), in a report of 1772. His other Scottish bridge projects, not all of which were implemented, were at Glasgow, Coldstream, Perth, Dumbarton, Aberdeen, Edinburgh, Braan, Dumballoch, Banff and Montrose.

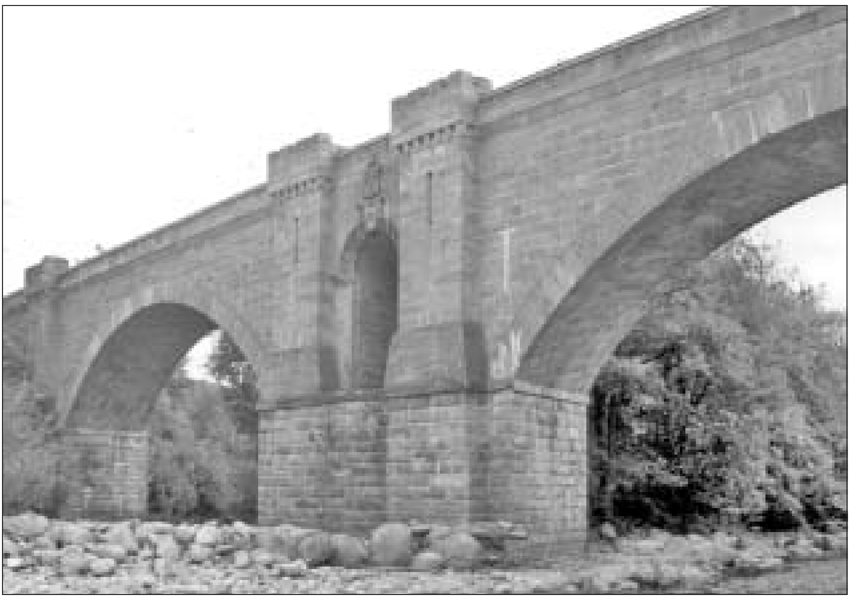
This bridge, replacing a decayed timber one, comprised a segmental masonry arch of 50 ft span, 16 ft wide overall and was erected in ca.1777. Because of later widening to both faces the neat original squared masonry of Smeaton's bridge, with its chamfered springer course 14 in. deep and stone invert, can now only be seen from underneath at low water (see view).

27. Alness Viaduct

HEW 2549
NH 6549 6951

A large and characteristic Joseph Mitchell five-span viaduct, built in 1862–63 with Gothic-style embellishments, carrying the Inverness and Ross-shire Railway over the Alness. Its main spans are two segmental skew arches of 60 ft span with a narrow semicircular arch between, above which is the date 1862 and the company's coat of arms.

Alness Viaduct



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28. Alness Bridge

NH 6415 7160

A bold segmental arch bridge of about 66 ft span with a rise of 20½ ft over the Alness or Averon adjoining a right-angled bend in the B9176 road on what is now known as the Struie Road (formerly the Fearn Road).

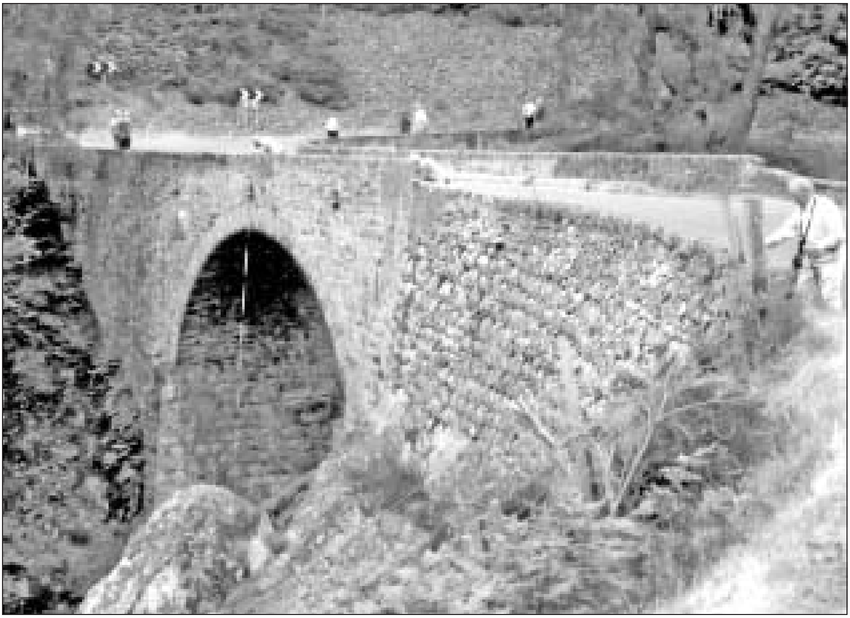
The bridge was completed in 1817 after a slow start in 1812 for the 25½ mile length of the Fearn Road, the poor performance on making which by 1815 was giving the Highland Road Commissioners 'much concern . . . the Alness Bridge will probably need to be taken down and rebuilt' but, fortunately this did not prove necessary. The engineer was Telford, the inspector, John Mitchell and the contractors D. Mackenzie & Ross.

The work exhibits an impressive use of rubble masonry, squared archstones on each face and the usual tapering pilasters adjoining the springings.

The 44 ft span segmental arch road bridge in the town of Alness (NH 6545 6963) over the same river, although undoubtedly influenced by Telford's standard design and usually dated ca.1810 and attributed to him, does not seem to have come under the Commissioners jurisdiction. It is more sophisticated than the usual Highland bridge with a double string course and squared stone in the arch-rings, curved tapering pilasters, spandrels, wing walls and parapets. [27]

Alness Bridge

Roland Paxton



Norman Butcher

29. Easter Fearn Bridge

HEW 0322
NH 6406 8629

A single 40 ft span segmental arch bridge passing 50 ft over the Easter Fearn Burn also on the Struie Road, completed by 1817. The rise of the arch is about $15\frac{1}{2}$ ft and its arch-ring consists of thin random sized stones and the spandrels are of coursed rubble stones.

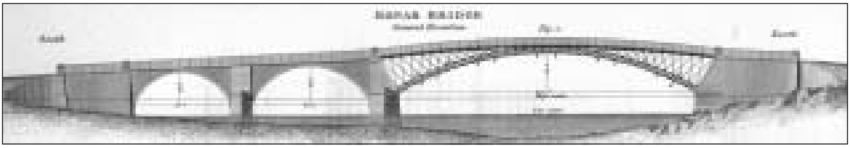
Easter Fearn Bridge with Roland Paxton checking height

The bridge adjoins a right-angle bend in the road and is remarkable for its tall approach walls of coursed large round rubble stones on a splayed base to provide stability. The engineer was Telford, the inspector, John Mitchell and the contractors D. Mackenzie & Ross. [27]

30. Bonar Bridge

HEW 2550
NH 6092 9154

This bridge, the third at this site, carries the A836 road across the Kyle of Sutherland. The first bridge built by Simpson and Cargill, contractors for both masonry and ironwork, incorporated Telford's innovative light prefabricated cast-iron lattice spandrel arch of 150 ft span designed in 1810 and pre-erected by ironfounder William Hazledine at Ruabon in June 1812.



Bonar Bridge – elevation (Telford) [27]

Originally, one arch was thought to provide sufficient waterway if founded on rock but, because of foundation difficulties, this was not possible and, after considering twin rim arches additional masonry spans of 50 ft and 60 ft were adopted to reduce the pressure on the iron bridge pier in times of flood. The bridge was erected in 1812 at a cost of £13 971 (ironwork £3947).

This project, involving the longest such prefabricated span in 1812, constituted an epoch-making iron bridge development. By 1830 at least ten arches of this genre had been erected in Britain as far south as Tewkesbury, of which the second, at Craigellachie, is now the earliest survivor. Many later bridges until the turn of the century, for example Carron (4-5), were influenced in their appearance by the lattice spandrel elevation of this bridge type.

The second bridge, erected after the first had been destroyed in a flood in January 1892, comprised three bowstring steel girders spanning 70 ft, 105 ft and 140 ft. It was designed by Crouch & Hogg, contractor Sir William Arrol & Co. The bridge was built in $10\frac{1}{2}$ months, including sinking the caissons for the two river piers and constructing coffer-dams for the abutments, and opened in July 1893. The contract sum was £13 584.

Bonar Bridge 1893–1973 [postcard ca.1920]

In 1973 this bridge, which had become corroded at its springings, was replaced in 21 months by the present segmental steel tied arch of 340 ft span with a rise of 64 ft, designed by A. A. Cullen Wallace of Crouch & Hogg. Initially the arch was thought by some to intrude on the landscape, but its form is now generally recognised as elegant. The main contractor was William Tawse (North Region) Ltd, with structural steelwork by Redpath, Dorman Long (Contracting) Ltd. The contract sum was £405 000.

In a landscaped garden at the old east abutment, a cairn bears a marble tablet of 1815 from Telford's bridge, a granite plaque from the 1893 bridge and plaques for the present bridge including one for a Steel Design Award in 1974.

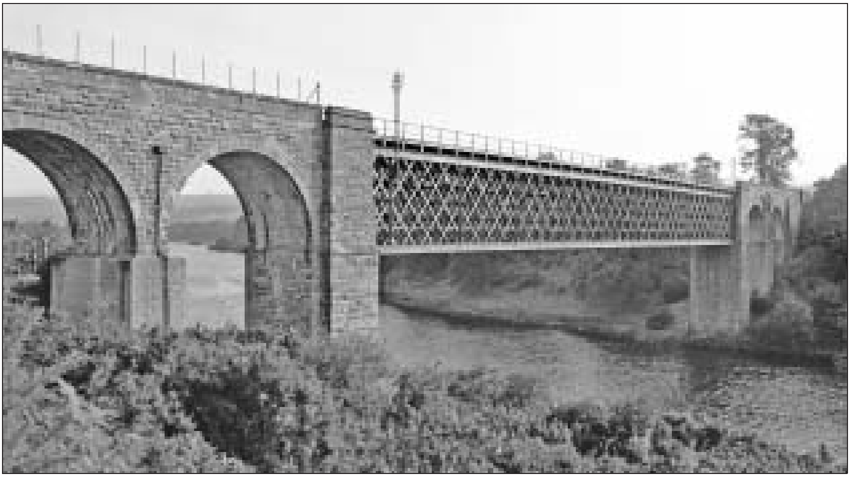
In 1991 the A9 road classification transferred to the route over the new Dornoch Bridge 10 miles downstream. This bridge was the longest in Europe made with the 'cast and push' method. This required the pre-stressed concrete deck to be made in factory conditions on the south bank, taken to site, and to be pushed into position by means of 590-ton rams. The bridge is 2929 ft long with 21 spans, mainly 143 ft, on piers comprising a reinforced-concrete portal founded on two 6.9 ft diameter piles, and cost, including the causeway, £13.5 million. It was designed and built by Christiani–Morrison Joint Venture. [27, 28]

31. Oykell Viaduct, Invershin

HEW 2551
NH 5789 9527

Oykell or Shin Viaduct is an outstanding Scottish example of an early wrought-iron lattice girder viaduct. It crosses the Kyle of Sutherland with a single 230 ft span and is flanked by tall semicircular masonry arches, two to the south and three to the north. The masonry is of coursed rubble with dressed stone arch-rings. The engineer was Joseph Mitchell and his partner Murdoch Paterson.

The bridge included the longest of Mitchell's lattice girder spans, 20 ft longer than that at Dalguise Viaduct four years earlier. Unusually, the deck here is on the top of rather than between the trusses. It joins two stations, Culrain and Invershin which are only a $\frac{1}{4}$-mile apart. Culrain Station was built specifically to provide local people with a means of crossing the Kyle as the bridge


RCAHMS: J. Hume

Oykell Viaduct

is the only one for several miles in either direction. A plaque at the bridge reads 'Erected AD 1867 by The Sutherland Railway Co. Mainly promoted by George Granville William, The Duke and twenty first Earl of Sutherland'.

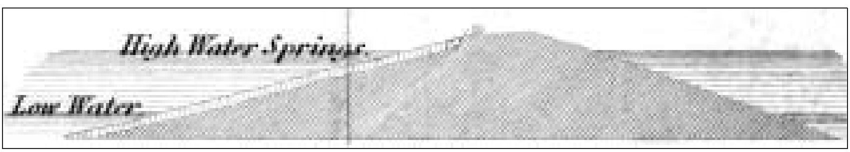
32. Fleet Mound

HEW 0132
NH 7755 9822

In 1813 Telford, who for ten years had been directing a major improvement of the road network in the Highlands, was looking for the means of superseding the inconvenient Little Ferry of the Water of Fleet on the great road from Edinburgh to Thurso. He developed a scheme first projected by local landowner Earl Gower, from 1803 the Marquis of Stafford, for an embankment across the estuary about 3 miles upstream.

The Mound, designed and constructed under Telford's general direction, and implemented by Earl Gower and others as contractors, was almost 1000 yards long, 60 yards wide at the base and 23 ft high. It was built from 1813–16 at a cost of £9290, and was a precursor of Telford's 1300

Fleet Mound cross-section [29]



Roland Paxton

Fleet Mound tidal flap-gates

yards Stanley Embankment of 1823–24 on the London to Holyhead Road.

A unique feature of this project, supported financially by the Marquis of Stafford, was the incorporation of a land reclamation facility at its north end where the Fleet was crossed by the new road bridge, 15 ft wide within parapets, of four arches of 12 ft span, increased to six in 1834. Two timber tidal flap-gates were fitted at the sea face of each arch below the springings which, by preventing sea water from passing upstream at high tide and allowing the river to flow out to sea at low tide, enabled about 400 acres of land to be reclaimed.

At times when the river was in flood, the flap-gates were unable to pass sufficient water out to sea at low tide and a mechanism involving brackets, pulleys, chains and hand-operated winches was devised and installed to lift the flap-gates manually when necessary. Since 1834 the system has been operated by two winches each located within a purpose-built house at each end of the bridge and operating three flap-gates.

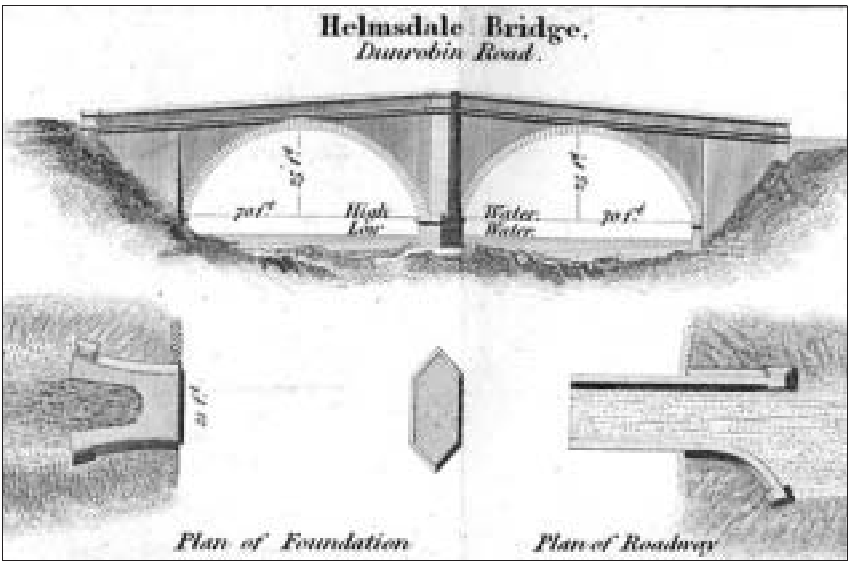
In 2004 the system was modernised. One winch was donated to Dornoch Museum and the other to the Institution of Civil Engineers Museum at Heriot-Watt University where, respectively, they are displayed and interpreted. [29]

33. Helmsdale Bridge

HEW 0258
ND 0259 1538

An unusual elevation Telford bridge of 1810–11 crossing the Helmsdale in twin segmental arch spans of 70 ft with a rise of 25 ft, its elevation being dictated by the width of the opening to be crossed. Its unresolved duality aspect is quite cleverly relieved by parapets which slope upwards from the abutments to form a flat inverted 'V' over the centre pier.

The bridge, which was built by George Burn for £2176, has stepped cutwaters carrying semi-hexagonal pillars which reach to the parapets. These, the string courses and tapered pilasters give the bridge a handsome appearance even though built in random rubble rather than squared masonry. [29]



Helmsdale Bridge – elevation and plan (Telford) [29]

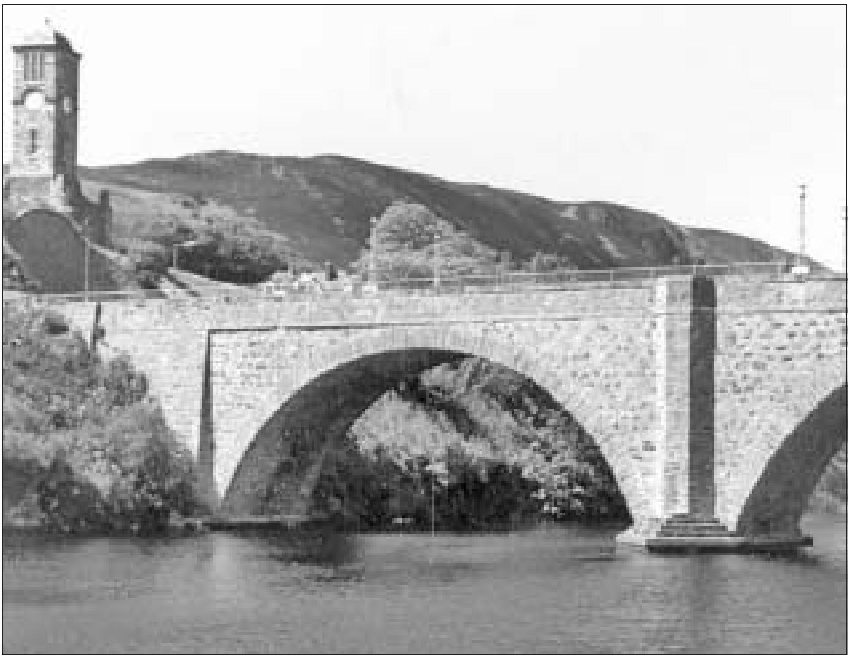
34. Lybster Harbour

HEW 0404
ND 2447 3486

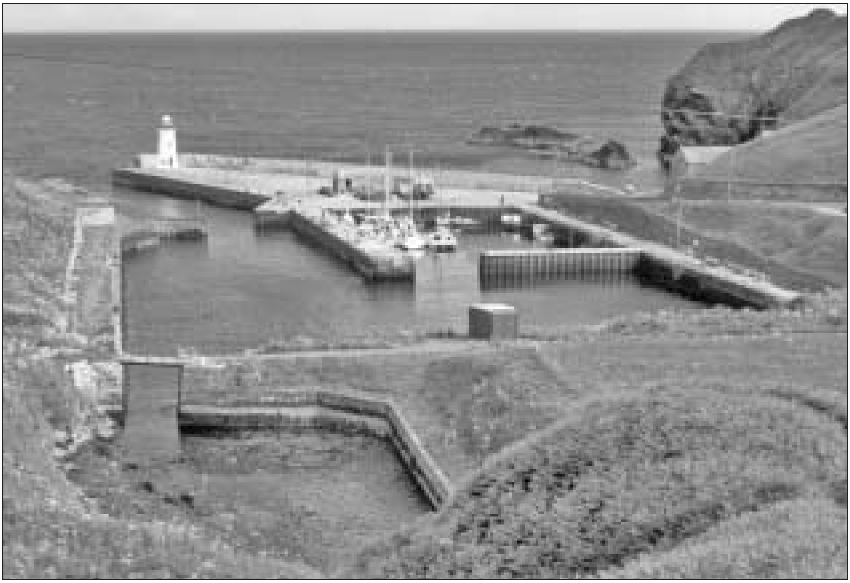
Telford, in a report to the British Fisheries Society in 1790, recommended a small improvement to the natural safe harbour at Lybster, but it was not until 1802 that the village was founded. A timber pier was built in 1810 by General P. Sinclair which was probably replaced by a 90 yard stone pier in 1832. It ran south along the west bank of the Reisgill to the sea. A stone jetty with an adjoining retaining wall was also built on the east side of the harbour mouth in 1832.

After a gale in 1848, in which 94 Caithness fishermen were drowned, the harbour was improved by ca.1852 to accommodate 100 boats, basically to its present form. The contractor was Christopher Moses of Perth under the supervision of Joseph Mitchell, the Fishery Board Commissioners' engineer, a post taken up by D. & T. Stevenson on Mitchell's retirement in 1851. The harbour is also notable as being the location, with a maximum fetch of 600 miles, where the heights of waves were first systematically measured by Thomas Stevenson. The results showed

Helmsdale Bridge



Roland Paxton



Sandra Purves

Lybster Harbour

November–February as the period of highest waves with $13\frac{1}{2}$ ft being attained. [30–32]

35. Whaligoe Steps

HEW 0563
ND 3210 4027

The most remarkable feature of the inlet at Whaligoe is the long stairway of Caithness flagstone steps, said to number 365, winding down the cliff face with five hairpin bends. This is one of the few possible landing places in an otherwise cliff-bound coast and has been used by local people for fishing since at least 1640.

The inlet is very exposed to south-east gales and traditionally, to preserve their boats in stormy weather, the fishermen had to hoist them above wave height on the cliff face. But, with the arrival of the herring boom about 1812, the estate factor David Brodie improved the inlet at a cost of £53 by rock blasting and building a refuge platform for the boats at the bottom of the steps. He spent a further £8 repairing the stairway. The house and curing shed on the brae head were also built at this time. Herring landed here had to be carried up the stairs by the fisherman and his family to be sold at the curing shed, where the fish were cleaned and barrelled.

Whaligoe Steps

The topsail schooners, used to export the barrels to the Continent and the West Indies, were warped stern first into the inlet and the barrels lowered down to them. Standing today in this deserted cove it is hard to imagine that in its heyday, around 1855, 35 boats operated from Whaligoe giving employment to nearly 300 people. Eventually the use of larger fishing boats and the development of safer harbours at Wick and Lybster led to the demise of this unique fishing station.

This harbour was not recommended by Telford who, in 1790, found it 'a dreadful place'. [33, 34]

36. Wick Bridge

ND 3623 5088

In 1665 Wick had a wooden bridge supported on stone pillars which was described at its refurbishment in 1776 as 'with wooden planks upon eleven pillars'. As the first step in the development of Pultneytown for the British Fisheries Society, Telford designed a three-arched masonry bridge about 15 ft wide between parapets which was built about 100 yards downstream of the old bridge by George Burn from 1806–09 at a cost of £2000 including a contribution from the Highland Roads and Bridges Commission. It had spans of 48 ft, 60 ft and 40 ft and a parapet line and stringer curved to an arc of a large radius similar to, but smaller than, Lovat Bridge (5-21).

This bridge was in turn replaced in 1877 by the present wider and flatter road bridge of three segmental arches

George Watson

Wick Bridge

with similar spans built by Murdoch Paterson, with Daniel Miller of Wick as the contractor. [17, 35]

37. Wick Harbour and Pulteneytown

HEW 0599
ND 3691 5061

Harbour development at Wick has always been difficult because of a lack of shelter from the east. In the 18th century Wick had only a rough quay. From 1790 both Telford and Rennie produced plans and estimates for improving the harbour for the British Fisheries Society, but it was not until 1803 that the inner or north harbour was planned and laid out by Telford and completed in 1811.

Expansion of the fishing industry required the provision of an outer harbour. This ‘New Harbour’ was planned in 1824, surveyed by Joseph Mitchell in 1825 and a contract awarded to James Bremner. Soon afterwards much of his partly completed work was destroyed in a storm. With consummate skill he saved the harbour from complete destruction in the teeth of the storm and eventually completed it in 1831 using the ingenious expedient of near vertically laid flagstones. Modifications were also made to the north harbour as part of this improvement. Bremner’s vertical stone construction is still readily visible only on the outer face of the outer harbour.

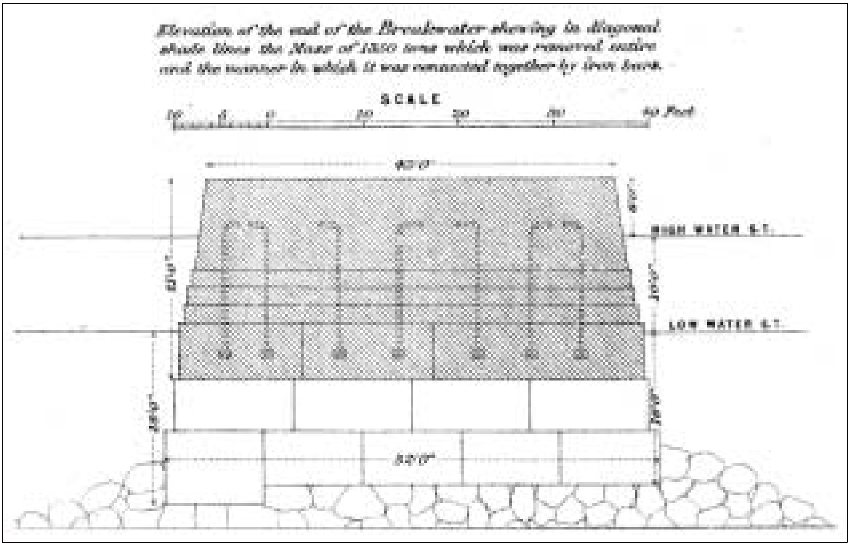
For the Society Telford also planned the layout and designed numerous buildings in the new district of Pulteneytown [ND 3680 5080], named after Sir William Pulteney, adjoining the harbour to the south, in the early

Wick Harbour and Pulteneytown plan [Census plan 1832]

decades of the 19th century, of which Argyll Square survives as a fine testimonial to his planning and architectural skills.

In 1861, in an attempt to protect the harbour from the effects of storms and to provide a larger haven, the British Fisheries Society obtained a report from D. & T. Stevenson which recommended the construction of a breakwater from each shore with a navigational channel opening between them. Work commenced in 1863 on the construction of a stone pier about 50 ft wide using narrow stone blocks weighing 5–10 tons set on edge resting on a rubble mound the top of which was about 18 ft below low water.

By 1868 the southern breakwater had reached a length of about 1100 ft but, in 1870, one-third of its length was destroyed in a gale. An attempt was then made to secure



Wick Breakwater 1876 with reinforced-concrete top, a 1350 ton mass of which was removed by waves [40]

the pier by means of blocks of concrete weighing from 80–100 tons each but this too failed. The upper structure was then rebuilt in Portland cement concrete but further serious damage ensued which was duly remedied. But, in 1877, the whole of the end of the breakwater, weighing 1350 tons, was carried away and the project abandoned to its fate after a total expenditure of £132 000. Its end with the inclined slabs can still be seen at the south shore.

The problem, not then appreciated, was that when the breakwater encountered waves about 40 ft high, the rubble base beneath was susceptible to movement where it was less than about 40 ft below the surface. R. L. Stevenson, Thomas Stevenson's son, who acted as resident inspector in 1868, dubbed the project 'the chief disaster of my father's life', but it did furnish an instructive example for engineers. [36–40]

38. Wick Railway Station

HEW 0600
ND 3607 5089

Murdoch Paterson, a partner of Joseph Mitchell and Company, Inverness, was the engineer who supervised the construction of the Caithness section of the Sutherland and Caithness Railway. All that remains of his 1874 Wick Station is the terminal building whose interior was

John Williamson

Wick Station

refurbished in 1999. The original cast-iron name and date plaque can be seen below the trifoil under the small gable.

This station was also the terminus for a light railway which ran from Wick to Lybster from 1903–44. [41, 42]

39. Ackergill Lifeboat Slipway

HEW 1500
ND 3587 5455

This unusual structure, erected in 1910, is believed to be the first ferro-concrete slipway in Britain. It was built for the Royal National Lifeboat Institution to provide a launching pad for the lifeboat in heavy seas. The boat was normally kept at the top of the ramp ready for immediate use.

Roland Paxton

Ackergill Lifeboat Slipway

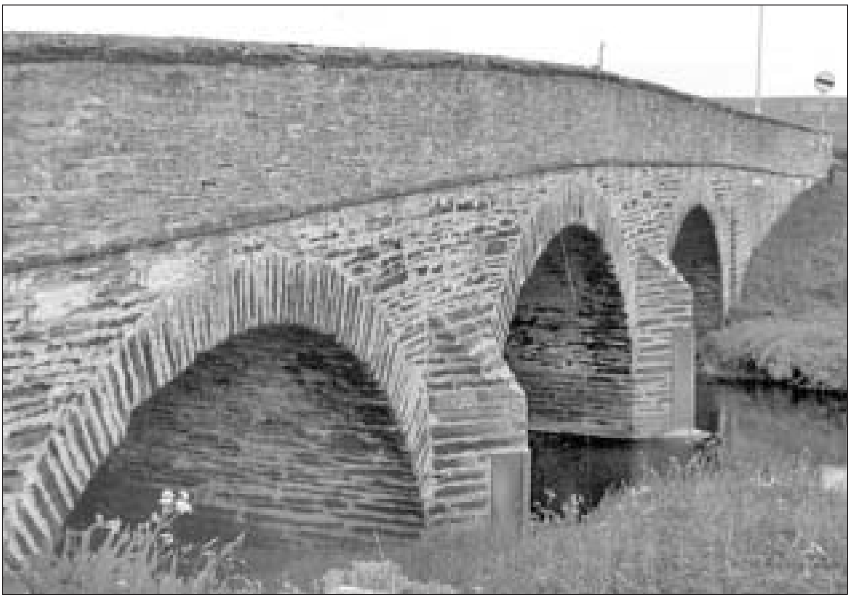
The early use of reinforced concrete rather than mass concrete can be seen in the adoption of a framed structure in the style of earlier timber construction. This is noticeable in the detailing, for example the chamfered edges to the posts and diagonals and the gussets at the joints. It has lasted well in adverse weather conditions as there is little discolouration and no spalling of the cover to the reinforcement. [43]

40. Greystones Bridge, Watten

HEW 1667
ND 2435 5431

Sometimes known as Achingale Bridge, this bridge, carrying the A882 Thurso to Wick Road over the Acharole Burn, is a good Caithness example of a three-arch Telford bridge. Its segmental rubble/flat-stone masonry arches are of 26 ft, 28 ft, 26 ft span. The bridge, built in 1816, was widened from 1931–33 by 6 ft on the north side to provide a roadway width of 24 ft 4 in.

Two miles west of Greystones Bridge, at Watten on the same road, is Oldhall Bridge over a burn, built from 1815–19 under Telford's general direction and now bypassed and deteriorating. It consists of a single semicircular arch



Greystones Bridge

Roland Paxton

George Watson

Oldhall Bridge

about 16 ft wide and 24 ft high with an arch-ring of Caithness flagstones about 2 ft deep, paved invert, random rubble spandrels and approach retaining walls in similar stone. The roadway is 18 ft wide.

Both bridges were erected as part of the improvement of the Thurso road. The surveyor was H. Fulton and the contractor J. Traill Esq. and others. Great difficulty was experienced in letting a contract for this 20 mile length of road which, at the then large sum of £13 365, cost about 30% more than the estimate. [44]

41. Freswick Bridge

HEW 1501
ND 3778 6712

A typical 17th or early-18th century segmental rubble masonry arch bridge, in existence in 1726, of about 13 ft span at the approach to Sinclair of Freswick's house, on what was originally the main coast road. It was subsequently widened on the upstream side. The bridge is unusual in having what is reputed to be a prison cell in the abutment. The Sinclair coat of arms is above its window (see view).

42. Meal Mill Bridge, John o' Groat's

HEW 1502
ND 3720 7335

A narrow segmental stone arch of about 10 ft span reputed to have been built by Cromwell's men in the 1650s and to be the oldest surviving bridge in Caithness.

Freswick Bridge

George Watson

Bottom: Meal
Mill Bridge

Roland Paxton

43. Dunnet Head Lighthouse

HEW 1503
ND 2027 7677

Dunnet Head Lighthouse marks the most northerly point on the Scottish mainland, a distinction gained by a narrow margin over similar structures constructed in the same area such as Cape Wrath and Duncansby Head.

The lighthouse is situated about $2\frac{1}{2}$ miles north of John o' Groat's and consists of an elegant stone tower 65 ft high completed in 1831. Its powerful flashing light, at an elevation of 345 ft above sea level, has a range of about 26 miles. The gallery is supported on stones cantilevered out from the tower top and the cast-iron parapet rail has lion's feet. The station was engineered by Robert Stevenson and built by contractor James Smith of Inverness.

Unlike many Scottish lighthouses, access here for changing crews and supplies is easier by means of a specially constructed lighthouse road. It was built by the unemployed poor of the area for payment of 3/6d a day. A lintel on a store at the northern outskirt of Brough thoughtfully informs the traveller that it is 2 miles 30 rods (165 yards) and 11 yards to the lighthouse. There are neat milestones at 1 and 2 miles from the lighthouse.

Dunnet Head Lighthouse

Roland Paxton

Dunnet Head – Lighthouse road milestone

Roland Paxton

Duncansby Head Lighthouse (ND 4060 7332), with its white 36 ft high tower, became operational in 1924, replacing a fog signal installed in 1914 to try and facilitate safe passage in the tide races of the Pentland Firth. The lighthouse was engineered by David A. Stevenson and is unusual in having a square tower, even the concrete lantern tower of which is square. Its flashing light at an elevation of 220 ft above sea level has a nominal range of 27 miles.

Noss Head Lighthouse (ND 3877 5800), with a white stone circular tower 60 ft high and its light at an elevation of 174 ft above sea level, has a similar range. It became operational in 1849 and was engineered by Alan Stevenson and built by Robert Arnot, Inverness. The original lamp is now in the museum at Wick.

Either here or at Chanonry three years earlier he introduced for the first time a new style of structurally stronger bronze lantern with inclined instead of horizontal astragals. This measure reduced obscuration of the beam of light from the rotating 6 ft diameter lens and became standard practice in the Scottish service. It was also adopted more universally. [45]

Roland Paxton

Meadow Well, Thurso

44. Meadow Well, Thurso

HEW 1504
ND 1171 6835

This well is a good example of small town water supply in Scotland and was the main water supply to Thurso for centuries. In 1818 its cistern was enlarged and the present building was completed in 1823 according to the date on a finial. The hand-operated pump, which is visible within, was installed about 1850. The use of the well for drinking water declined after the town obtained an improved supply of potable water from Loch Calder in ca.1876. It continued in use until the 1920s for filling water carts used to dampen down street dust.

An unusual feature of water supply to dwellings and farms in Caithness was the use of tanks with sides made of local flagstones jointed with lead. [46]

45. Thurso Bridge

HEW 1557
ND 1177 6817

The first road bridge at Thurso, over the Thurso, was built in 1800, replacing local fords, by local mason Robert

Tulloch and had three semicircular arches with oculi over the piers. It served the town well until 1886, when a misguided attempt to widen its narrow roadway resulted in the collapse of the central arch. It was replaced by the present bridge of four segmental arches.

A commemorative plaque on the present bridge states that it was formally opened on 3 May 1887. The engineers were MacBey and Gordon, Elgin, and the contractor was John Malcolm.

The first substantial bridge over the Thurso was built at Halkirk in 1731 by Sir George Sinclair of Ulbster in an attempt to establish an inland market centre there. [47, 48]

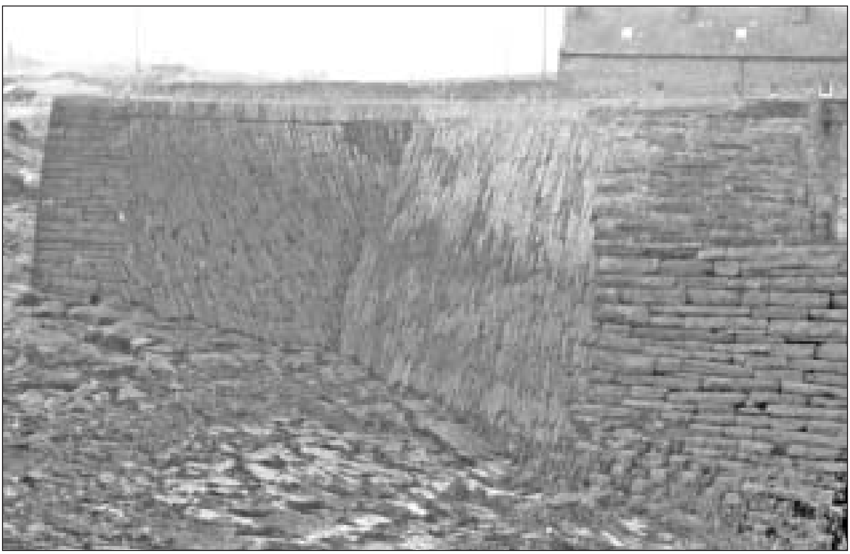
46. Sandside or Reay Harbour

HEW 1672
NC 9582 6607

This 'very neat and commodious' fishing and local coastal trade harbour was completed in ca.1835 for about £3000.

In the planning and construction of this harbour considerable ingenuity was exercised by its engineer James Bremner. He built two piers to improve a pocket in the rocks forming a harbour with a very narrow entrance to the north east. Both piers are backed with near vertically set flagstones to mitigate the effects of wave force, a feature of Bremner's work at various harbours.

Sandside Harbour



George Watson


George Watson

Achscrabster windmill stump

The north pier is constructed almost entirely of these near vertical stones, with a surface of massive lateral stones, and extends out to sea beyond the entrance. The harbour was secured by boom gates, the remains of the machinery for working which, and slot on each side of the entrance, still exist.

Flagstone construction, as here, is a feature of civil engineering work in Caithness. On the road from Thurso to Sandside is Achscrabster flagstone quarry. A feature of this and other local quarries was the use of windmills for power. The surviving Achscrabster stump (ND 0825 6356) shown, one of several still existing, is about 12 ft diameter at the base and 13 ft high, and was probably operational pumping water in ca.1860. [49, 50]

47. Strathy Bridge, Sutherland

HEW 1707
NC 8362 6519

Until demolished between its abutments in 1994 the bridge at this site over the Strathy was of a similar type and span to


George Watson

Strathy Bridge

Etive Bridge, a reinforced-concrete bowstring tied arch of 1932 with a span of about 100 ft and rise of about 30 ft (see 1-25). The original abutments blend in well with the slender modern deck of the present bridge which is a composite beam bridge of steel girders and a reinforced-concrete slab deck. [51]

48. Dounreay Nuclear Establishment

HEW 1708
NC 9860 6715

Dounreay, with its distinctive green sphere, lies 10 miles west of Thurso. The nuclear establishment was built to prove the attractive but, at the time, untried concept that fast reactors could generate electricity and at the same


UKAEA

Bottom: Dounreay Nuclear Establishment 2004

Dounreay Fast Reactor – sphere erection (lower part) [52]

time breed additional fuel. The Dounreay Fast Reactor was housed in the sphere, which was fabricated from inside as illustrated. Around the sphere were fuel fabrication plants, chemical and metallurgical laboratories and fuel reprocessing plants.

Construction started in 1955, with Whatlings as the main civil engineering contractor. Numerous specialist contractors included the Motherwell Bridge Company who built the sphere.

The reactor first became critical in 1959, and over the next 18 years proved itself a useful test bed for experimental fuels and materials as well as a safe generator of electricity. By 1966 sufficient experience had accumulated to justify a much larger prototype fast reactor which was built to the west of the sphere.

Taylor Woodrow was the main civil engineering contractor for this prototype power station designed to supply 250 MW to the national grid. It first became operational in 1974 and began supplying electricity the following year. In 1982 one of the primary advantages of fast reactors was demonstrated when fuel created within the reactor was recovered and returned to the reactor as new fuel.

By this time the energy crisis, which had initially prompted nuclear expansion, had been assuaged by the discovery and exploitation of North Sea oil and gas. As a result, the fast reactor research programme was wound down. The prototype power station ceased operating in March 1994 and radioactive facilities throughout the site are now being decommissioned. [52, 53]

49. Cape Wrath Lighthouse

HEW 1709
NC 2596 7473

Cape Wrath Lighthouse, a 66 ft high stone tower completed in 1828 with its light 400 ft above sea level, is situated on the north-west tip of the Scottish mainland. The name derives, not as one might conclude from the angry waters of the area, but from the Norse word for 'turning point', for it was at this point that the Norsemen are said to have turned their galleys to the north-east to head for home.

The engineer was Robert Stevenson and the contractors, John and Alexander Gibb of Aberdeen. A small quay and store was built at a tidal inlet about a mile east of the lighthouse, connecting by a new road with the lighthouse, which served for bringing in by sea the building materials and equipment and afterwards for servicing the station. The light of 204 000 candlepower flashes at 30 second intervals and has a range of about 24 miles. The station includes a compressed air foghorn, now disused, and a Thomas Stevenson thermometer screen.


Roland Paxton

Cape Wrath lighthouse road and Kervaig Bridge


Roland Paxton

Cape Wrath Lighthouse

Unlike Dunnet Head, access to the lighthouse is difficult. Relief keepers and visitors can cross the Kyle of Durness by ferry and then travel some 12 miles along a 9 ft wide access road, also made in 1828, which can be extremely difficult to negotiate in winter. Numerous bridges on this road were built by Gibb under Stevenson's direction, the largest being Kervaig Bridge of 32 ft span which is illustrated.

A relief crew were first transported to the lighthouse by helicopter on 17 January 1977. This became the regular practice until the lighthouse became unmanned. [54]

50. Callanish Standing Stones, Isle of Lewis

HEW 1718
NB 2130 3302

This ancient monument is arguably the most impressive in Britain after Stonehenge and called for what have come to be recognised as civil engineering skills in its creation. It includes thirteen tall stones forming a circle some 37 ft in diameter on a remote moorland. To the north of this circle stretches an avenue of stones 270 ft long and 27 ft wide, of which 19 stones remain. To the south of the circle there is a shorter, narrower avenue formed of six stones, and to the east and west there are short arms

Callanish Standing Stones

formed of four stones each. Within the main circle is a burial cairn, and opposite the entrance to this stands the tallest stone of the monument, some 16 ft in height. The alignment of the stones relates to astronomical observations. The construction of the monument is generally dated from the Bronze Age, or about 1500 BC, and must have required the organisation of a labour force and tenacity of purpose extending over many years. [55]

51. Carloway Broch, Isle of Lewis

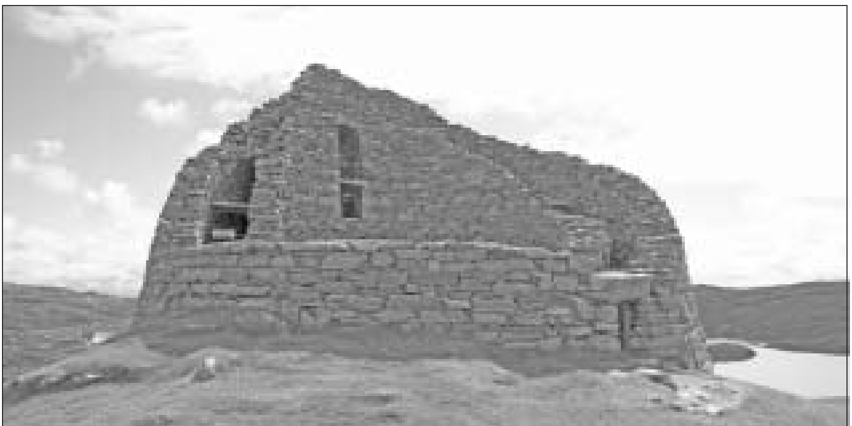
NB 1900 4123

Little is known of the origin and purpose of the brochs; it appears that they were all lofty structures but the original height at Carloway is not known. It certainly required competent building skills to construct.

The remains of the structure are circular in plan with a low narrow doorway giving access to the interior courtyard. A good average internal diameter is 32 ft. The thick walls are built hollow at ground level and the structure tapers to give a conical profile.

Much of the broch is missing, probably because the carefully built drystone masonry was easily pilfered for other buildings, but the form of the structure is clearly

Carloway Broch



seen on inspection. Generally brochs are considered to date from about 200 BC continuing into the Christian era. [55]

52. Water Tower, Leverburgh, Harris

HEW 1810
NG 0130 8730

This concrete water tower stands on a hillside to the east of the B859 road linking Borve and Leverburgh. The circular concrete tank is carried on vertical columns, but there are also inclined members meeting at a point in the centre of the underside of the floor of the tank. The purpose of this unusal arrangement of inclined members seems to be to resist wind forces and to reduce bending moments in the floor of the tank.

It has been suggested that the water tower was originally built to supply water for Lord Leverhulme's fish processing

Leverburgh Water Tower

plant near the shore at Leverburgh and for the housing which he provided for the plant workers. This development took place in 1920–21. On Lord Leverhulme's death in 1925 the local people renamed the local village of Obb as Leverburgh in his honour.

53. Uist Causeways

HEW 1811
NF 8308 5690

There are a series of causeways throughout South Uist, Benbecula and North Uist linking the various islands from Eriskay in the south to Berneray in the north. These causeways have been in place for some years, but the two most recently constructed are those linking Berneray and Eriskay to the Uist mainland about five years ago, with ferry terminals on both Eriskay and Barra for vehicular connection between the islands, the last link in the north–south communication between Barra and Berneray.

All the modern causeways are of the same pattern – heavy rubble fill with gentle side slopes, capped with a concrete road surface and wave barriers culminating in protective parapets, about 4 ft high, of heavy stone. Some are curved in plan, others are straight. Some have a bridge portion to allow the passage of tides.

The oldest causeway is believed to be across Loch Bee in South Uist. It is some 600 yards long and was first built for pedestrian, horse and cart use in the 18th century. It comprised two drystone walls containing a filling of shingle and sand. In the 1930s the causeway was surfaced and, in 1959, was widened and raised. It sustained storm damage in 1983–84 and in 1990 was further improved to full modern two-lane road standard.

The longest of the causeways is the North Ford, which extends intermittently for 5 miles between Gramisdale in Benbecula and Carinish in North Uist, opened in 1960. The project consumed 350 000 tons of rock, and has three bridges along its length, two to allow the passage of boats and one for drainage. It carries a single-track road with nine passing places to each mile of length.

A 400 yard causeway linking the island of Baleshare with North Uist was finished in 1962, completing the initial phase of causeway construction in the Uists. The engineers were Sir Alexander Gibb and Partners and the contractor, Wm. Tawse Ltd.

54. Bernera Bridge

HEW 1812
NB 1647 3419

This structure, linking Bernera with Lewis in 1953, is believed to be the first pre-stressed concrete bridge built in Britain. It has three spans of 108 ft, each of which is formed of three parallel beams of pre-cast concrete segments stressed together and capped by an *in situ* concrete deck slab. The width is 13 ft between parapets. Because of the limited carrying capacity of the roads and other bridges in the area, it was agreed that the bridge should be designed for two-thirds of the full Ministry of Transport loading.

Each span consists of three pre-cast 'U' girders post-tensioned on shore each with two straight and two curved cables of 32 wires by the Magnel–Blaton system. The beams were cast on shore in eight 'U' segments 11 ft 8 in. long, 4 ft 8 in. deep and 3 ft wide and two solid end blocks 5 ft 6 in. long. The completed beams each weighed 52 tons and their erection over water was facilitated by a temporary steel-lattice girder. The abutments and piers are of conventional design and consist of cylindrical shafts 7 ft 3 in. diameter placed 14 ft apart. The piers are founded on a concrete base slab founded on stiff boulder

Bernera Bridge
[57]

clay, and are capped by reinforced-concrete beams on which the pre-stressed beams are carried.

The engineers were Blyth & Blyth, Edinburgh, in collaboration with the County Engineer J. A. Shaw. The main contractor was A. A. Stuart & Sons (Glasgow) Ltd and the subcontractor for the pre-stressing was Stressed Concrete Design Ltd. The cost was £70 111.

While underwater work was in progress, divers reported traces of what appeared to have been a stone-built causeway about 6 ft west of the centreline of the bridge and parallel to it. It was about 7 ft wide and built of hand placed boulders 'some of which were of considerable size'. There is no record of a causeway here, but it may be significant that two standing stones in Bernera overlook the site. [56, 57]

55. Underground Oil Tanks, Lyness Base, Orkney

HEW 1813
ND 2912 9464
(East entrance)

The sheltered sounds around the islands of Flotta, Fara, Cava and Rysa Little made up the Royal Navy's main fleet anchorage in Scapa Flow during both world wars. Close to these sounds, at Lyness on Hoy, an oil depot, naval quarters and stores were established during World War I and were considerably developed in the second war to form the Scapa Flow Naval Base Headquarters, temporary wartime home to thousands of military and civilian personnel. Lyness was finally closed as a naval base in 1957, when it was cleared of many of its wartime buildings, but continued to function as an Admiralty oil fuel depot until 1977.

Conspicuous among surviving structures near the modern ferry terminal is a solitary oil storage tank and pumping station (ND 310946), which together now serve as the Scapa Flow Visitor Centre. This tank, which had a capacity of 12 000 tons, was one of four erected in 1917 when oil-fired warships were coming into service with the Royal Navy. The associated pumping station, also built in 1917, housed the steam pumps which drew the heavy fuel oil from tankers at the pier. Originally coal-fired, the pumps were converted to diesel power in 1936 when, with the threat of another war looming, plans were

Lyness underground oil tanks

laid to massively increase oil-storage capacity. In 1937, Messrs Balfour Beatty & Co. Ltd were contracted to build 12 slightly larger 15 000 ton tanks, bringing the total complement of above-ground tanks to 16 by 1938. Also in 1937 the considerable engineering challenge of creating underground tanks – safer from potential aerial attack – went to Sir William Arrol & Co. Ltd.

The site surveyed for this purpose in 1936 lay beneath the summit of the nearby hill of Wee Fea, some 6100 ft west of the Lyness pumping station and at an altitude of about 295 ft above sea level. An additional pumping station to serve these tanks was designed by Arrol in 1937 and, complete with all its equipment, still stands halfway up the hill at ND 300942. Excavation for the tanks began in 1938, and construction work continued through to 1943 when six tanks had been completed and further work was aborted. The excavated spoil was tipped at the

Lyness foreshore, creating an extension to the quay which, on account of the enormous cost involved (probably about £10 million overall), was ironically nicknamed 'The Golden Wharf'.

The subterranean tanks were arranged in parallel on a roughly north-eastern–south-western alignment beneath Wee Fea. On the northern and southern flanks of the hill, at ND 291946 and ND 285938, respectively, there are two entrances to the complex, some 3200 ft apart. Each entrance leads into an access tunnel of vaulted concrete construction, 10 ft wide and over 1200 ft in length. Within, a tunnel branches at right-angles across the ends of the six tanks which are encased in concrete, each of the six tanks measuring about 778 ft long, 45 ft wide and 48 ft deep. Together, they were capable of storing some 100 000 tons of oil. Filter tanks stand close to the entrance to the north tunnel, through which both the inlet and the outlet pipes passed, the south tunnel evidently being used principally for maintenance purposes. Fragments of the associated pipelines are still visible on the lower slopes of the hill. (G. Stell) [58, 59]

56. Churchill Barriers, East Mainland – South Ronaldsay, Orkney

HEW 1984
HY 4844 0100

Scapa Flow was ideally suited to serve as the wartime fleet anchorage for the Royal Navy in both world wars, but the four main channels on the eastern side of the Flow were known to be weak spots in its defence against enemy submarines and torpedo-carrying craft. In 1915, William (later Sir William) Halcrow was invited to consider the building of permanent barriers across these channels, but sunken blockships were considered to be a more expedient solution. Some of the blockships were later removed or shifted their positions, and their defence inadequacies were exposed in October 1939 when a German U-boat found a way round them in Kirk or Holm Sound, the deepest and fastest flowing of these channels. It torpedoed the battleship HMS *Royal Oak*, with the loss of 833 lives, and escaped by the same route.

This dramatic episode at the very start of the second world war prompted the construction of permanent

Churchill Barrier No. 3

Crown Copyright: RCAHMS

barriers across the four channels, a scheme which was finally authorised by Churchill himself after a visit in person in March 1940, hence their name. On-site preparations commenced in May 1940, and during the summer of 1940 limited experiments were conducted on models in the Whitworth Engineering Laboratories at the University of Manchester.

Not finally breaking the surfaces of the channels until 1942–43, the barriers became recognised as causeways for potential civilian use, and a relaxed interpretation of the Geneva Convention allowed the labour force to be augmented substantially by Italian prisoners-of-war from early 1942 onwards. At its peak in 1943 numbers engaged in the operation reached about 2000. Costing some £2 million, the works were effectively completed in September 1944 but were not officially opened until 12 May 1945, four days after VE day.

The contractors for this feat of engineering and organisation were Balfour Beatty & Co. Ltd, the southern section of the southernmost barrier being sub-contracted to William Tawse & Company, Perth. Founded by George Balfour and Andrew Beatty in 1909 as general and electrical

Concrete block moulds for Churchill Barrier No. 1

engineering contractors, by 1937 the firm of Balfour Beatty had established a major presence on the other side of Scapa Flow, building the additional above-ground oil tanks at Lyness on Hoy.

The barrier scheme was designed and supervised by Sir Arthur Whitaker, Civil Engineer-in-Chief of the Admiralty, and was carried out under the direction of H. B. Hurst who was succeeded by C. K. Johnstone-Burt, Herbert Chatley and J. A. Seath. Until 1942 the Resident Superintending Civil Engineer was E. K. Adamson, and from 1942 until completion it was G. Gordon Nicol, whose notes and photographs preserved in the Orkney Archives in Kirkwall constitute a valuable record of the work of construction. A special feature was the use of five aerial cableways, four electrically-driven, one steam-powered, by John M. Henderson & Co. Ltd, Aberdeen. Nicknamed ‘Blondins’ after the French acrobat and tightrope walker, Jean Blondin, two of the cableways were paired across Kirk Sound, the deepest of the channels.

Designed to absorb a through 4–5 knot tidal current, the structure of the four barriers consists of a core of rubble bolsters cloaked by 5 ton concrete blocks below the water line. Except in the case of the less exposed Weddel Sound, which is of 5 ton blocks throughout, these are in turn overlaid by 10 ton blocks, the outer skin being laid in 'pell-mell' fashion to break the force of the waves.

The barriers measure some $1\frac{1}{2}$ miles in overall length, linking East Mainland to South Ronaldsay via the three islands (north–south) of Lamb Holm, Glims Holm and Burray. The widest and deepest channel was the northernmost, Kirk or Holm Sound between Mainland and Lamb Holm, where the foundations of what became No. 1 Barrier were laid in fast-flowing tidal water up to 59 ft in depth. In total, the barriers consumed about 250 000 tons of quarried rubble overlaid by some 66 000 concrete blocks from the casting yards at St Mary's and on Burray.

The sites of the accommodation camps, rubble quarries, the concrete blockyards and the associated railways are still traceable on the ground, and a chapel on Lamb Holm, cleverly wrought out of two Nissen huts, remains a picturesque memorial to the Italian contribution. (G. Stell) [58, 60–63]

57. Pentland Skerries Lighthouses

HEW 1985
ND 4650 7841

The lighthouses of Orkney represent an important civil engineering contribution to the island and maritime safety. The most historic is the 70 ft tall North Ronaldsay Lighthouse built by the Northern Lighthouse Board in 1789, using local stone and workmen from Leith, only three years after the Board was founded. This lighthouse was closely followed by Pentland Skerries in 1794 to the south at the eastern entrance to the hazardous Pentland Firth. The engineer for both lighthouses was Thomas Smith, who developed, made and installed arrays of facetted mirror-glass parabolic reflector oil lamps.

At Pentland Skerries, Smith directed the erection of two circular masonry towers, 60 ft and 80 ft high, and installed 66 reflector lamps in total. The towers were sited 60 ft apart as a distinction to mariners. In the 1820s they were rebuilt under Robert Stevenson's direction in local stone 100 ft apart, the taller being 118 ft high. In 1848 lenses were introduced. The lower light was discontinued in 1895 on the introduction of group flashing

Northern Lighthouse Board

lights. The light was converted to electrical operation in 1939. [64]

Pentland Skerries Lighthouses

58. Start Point Lighthouse, Orkney

HEW 1986
HY 7868 4350

The earliest tower at Start Point, Sanday, built of masonry under the direction of Thomas Smith began its existence in 1802 as an unlit sea mark with a large ball of stone on top. In 1806 it was fitted with the Board's first revolving light, consisting of an array of Argand oil lamps with silvered copper reflectors, by Robert Stevenson, who formally took over as from Smith as engineer on 12 July 1808.

On completion of Start Point Lighthouse, North Ronaldsay Lighthouse, $7\frac{1}{2}$ miles to the north, was no longer required to be lit. Its lantern was replaced in 1809 by the stone ball, about 5 ft in diameter of squared masonary, from Start Point tower, in which capacity it still serves as a sea mark about $\frac{1}{2}$ mile south-east of the present 139 ft tall structure.

The present North Ronaldsay Lighthouse was built in 1852–53 under Alan Stevenson's direction by Wm. Kinghorn, Leith, at a contract price of £6181. At 138 ft it is believed to be the tallest land-based lighthouse in the United Kingdom. Unusually at that time for a Scottish lighthouse, it was built in brick instead of stone, presumably for convenience of shipping and construction.

Start Point Lighthouse 1870

Northern Lighthouse Board

Other brick towers were built under D. & T. Stevenson's direction at the Butt of Lewis and the Monach Islands and in 1870 Start Point Lighthouse was replaced by the present 75 ft tall brick structure. It was modernised in 1913 and became automatic in 1962. [64]

North Ronaldsay Lighthouses

Northern Lighthouse Board

Orkney also had numerous windmills in the 18th and 19th centuries. These declined in use when new sources of power became available and Peckhole Windmill, North Ronaldsay, is generally believed to have been the last wind-operated grain mill in Scotland. There were also numerous small water-powered mills and Ayre Mill, Kirkwall [HY 443 113], was a large, probably late-19th century corn mill with a kiln at each end powered by tide water impounded in the Peerie Sea. This impounding area has recently been redeveloped as a circular pond.

59. Mousa Broch, Shetland

HEW 2398
HU 4573 2366

This prehistoric round stone tower is located on the small uninhabited island of Mousa off the mainland about 12 miles south of Lerwick. The remains of about 500 brochs have been identified in Scotland, most of which are in Caithness, Orkney, Shetland and the Western Isles, but Mousa Broch is the only one to have survived virtually complete.

Although not strictly civil engineering, a term not known to have been used before 1754, this remarkable structure, which has stood the test of some 2000 years, certainly comes within the definition of harnessing the forces of nature for the use and convenience of man. Other good examples can be seen at Carloway, Isle of Lewis (5-51) and Clickhimin, near Lerwick, Shetland.

The broch is $43\frac{1}{2}$ ft high, and the overall diameter at its base is 50 ft and at the top 40 ft. The wall profile externally is not straight, but slightly curved outward at the base. The local stone is dry-built in carefully laid regular courses. Its entrance is a small rectangular opening facing the sea on the west side.

Internally the circular courtyard is 20 ft diameter at ground level. The walls average 15 ft thick at the ground and the inner face is vertical, the thickness tapers towards the top on the outside. The upper part of each wall is hollow, spanned at intervals by flagstones forming galleries. There is a stair within the wall having a width of 3 ft which ascends spirally to the wall top. It seems unlikely that the broch was roofed.

The date of construction is unknown but it is possible that the broch existed in the first century AD. Brochs are always found near arable land and seldom far from the edge of the sea. They comprise strong towers capable of passive defence but are in no sense offensive structures. Their purpose seems to have been to provide refuge for peaceful cultivators in the face of attacks from seaborne forces.

The point of embarkation on the mainland is via the 200 ft long, 15 ft wide masonry Sandsayre Slip, with a slope of 1 in 27 and external batters of $1\frac{1}{2}$ in. to 1 ft, designed by D. & T. Stevenson in 1854. [65, 66]

60. Ve Skerries Lighthouse, Papa Stour, Shetland

HEW 2452
HU 1038 6540

This 50 ft tall pre-stressed reinforced-concrete lighthouse was constructed in 1979 at a remote and exposed location, mainly as a navigational aid to tanker traffic in and out of Sullom Voe oil terminal.

Construction was achieved in the remarkably short time of four months by means of helicopters. This technique was used only after the practicability of helicopters for lifting


Robert Mackay

Ve Skerries Lighthouse

and positioning 9.84 ft diameter pre-cast concrete manhole chamber rings weighing about a ton to be used as permanent shuttering had been tested.

An unusual design feature was that the tower was prestressed vertically with a post-tensioning force of about 1600 tonnes nearly ten times the weight of the structure. This was achieved by means of Macalloy bars anchored from 10–16 ft into the rock beneath, tensioned from the top by hydraulically operated compressed air jacks. The tower was designed to withstand a wave force of 2 tons sq. ft for the bottom 25 ft tapering off to $\frac{1}{2}$ ton sq. ft at the tower top.

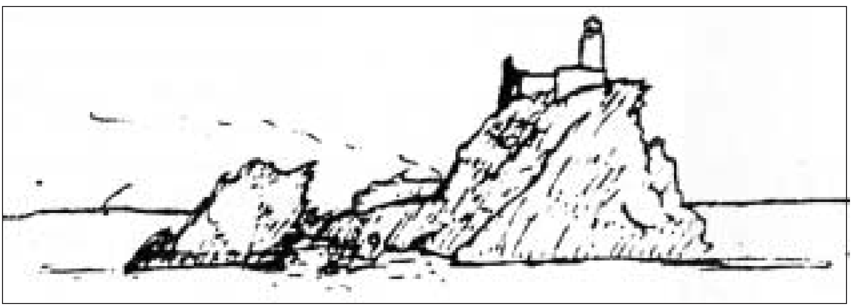
A lighthouse at this site was considered as early as 1863 but not implemented. Using traditional methods it would have taken several years to build. This innovative project, directed by Northern Lighthouse Board civil engineer R. Mackay, was the first of several using the post-tensioning technique in Scotland. [67]

61. Muckle Flugga Lighthouse

HP 6066 1977

Muckle Flugga, off the north coast of Unst, Shetland, is very nearly the most northerly rock in the British Isles. As can be seen from Robert Louis Stevenson's sketch of his uncle David and father's project, it is a pyramid of stone rising some 200 ft above the sea.

In 1853 war with Russia seemed imminent and, to safeguard a much increased naval presence near this unlit coast in this eventuality, the Admiralty commissioned the Northern Lighthouse Board to erect two lighthouses as a matter of urgency. Work had already begun at one site, Out Skerries (completed 1854), and the other site selected



Muckle Flugga Lighthouse – R. L. Stevenson's sketch [59]

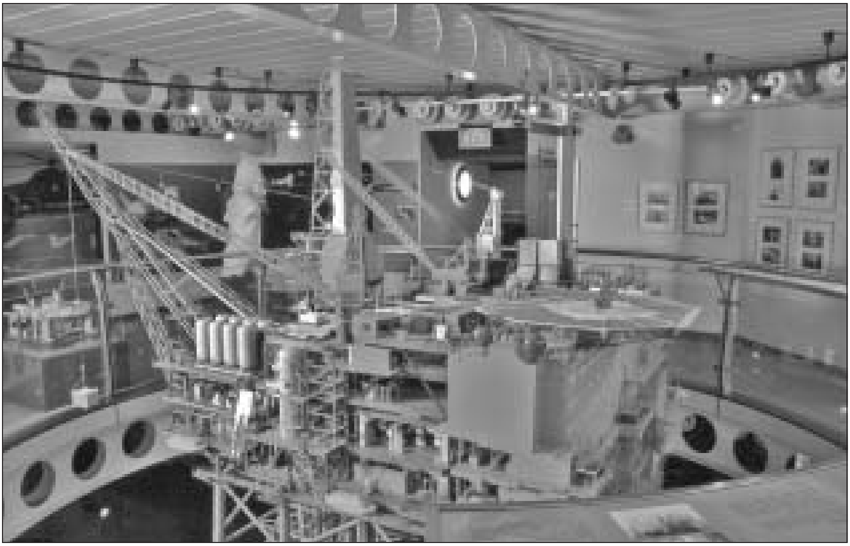
Northern Lighthouse Board

Muckle Flugga Lighthouse

was Muckle Flugga. The Board's engineers were D. & T. Stevenson.

The task of building a lighthouse at Muckle Flugga was daunting because of its remote and exposed location. In August 1854, with men using lifelines, a level platform was cut on top and a flight of rough steps hewn. Under the direction of resident engineer Alan Brebner, materials were hauled up the steps on men's backs including the temporary iron keepers' huts. Cement mortar was used for the first time at a rock station. Amazingly, the temporary light was lit on 11 October.

It was decided to make the light permanent and the present 64 ft high lighthouse was built in brick, an untried experiment in such an exposed situation, but bricks were easier to man-handle than stone blocks. The work was carried out from 1855–57 by direct labour under D. & T. Stevenson's direction with Brebner as resident engineer. The cost was £36 000. The workmen were housed in an iron hut and the materials needed were raised from sea level on a steep railway by means of a 10 hp steam engine. To shelter the station from storm damage, a masonry wall 5 ft high and 2 ft thick was built part way round it.



Maritime Museum Aberdeen

Murchison Oil Platform model at Maritime Museum Aberdeen – platform top

An idea of the exposure of this site can be gained from the fact that half ton stones were thrown up 80–85 ft above high water and on one occasion the protective wall round the station was thrown down and a heavy door broken at a height of 195 ft above the sea. To combat storm conditions, which they have successfully done for one and a half centuries, the tower walls were made $3\frac{1}{2}$ ft thick and the foundations sunk 10 ft into the rock. [68–70]

Our concluding work with its tall, sea-bed anchored, framed tower, is the Murchison Oil Platform about mid-way between the Shetland Islands and Norway, for information on which the reader is referred to the entry at the Maritime Museum, Aberdeen (3-25).

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