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The Bell Rock Lighthouse Railway [Draft 2/10/2012]

Introduction

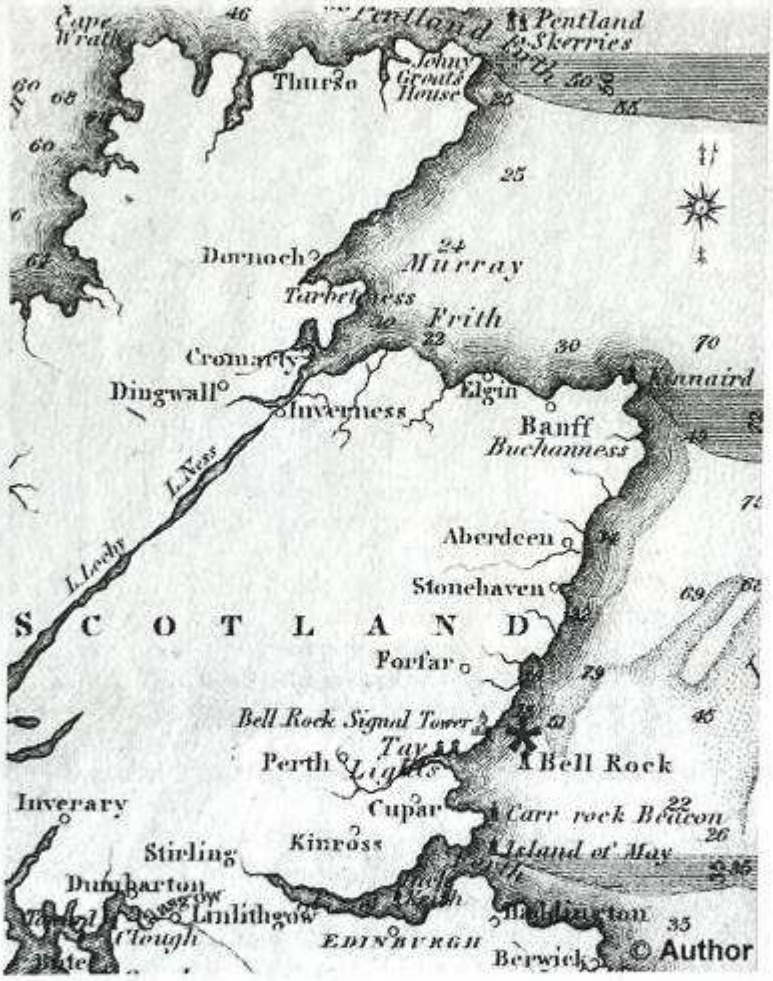

Fig. 1 Map showing location of the Bell Rock

In 1806 an Act of Parliament authorised the erection of the Bell Rock Lighthouse. It is located within the tidal range of the sea eleven miles out to sea from Arbroath, Scotland, on a hard sandstone reef several hundred yards long, submerged up to 15 ft at high water (Fig.1). [1, 2]

From 1807-11 this 118 ft tall lighthouse was built in stone under the overall design and supervision of the eminent civil engineer John Rennie (1761-1821) as 'Chief Engineer' and Robert Stevenson (1772-1850) as resident engineer (from 1808-42 Engineer to the Northern Lighthouse Board and on the lighthouse's completion, founder of the remarkable Stevenson dynasty of engineers (1811-1952)). [3]

To achieve construction at this hazardous location in four summer working seasons a narrow gauge cast iron railway 'about 800 ft long altogether' (fig. 2) was built connecting the site of the lighthouse with wharves at the rock edge. [4, 5] This enabled dressed stones from Arbroath Work-yard weighing up to 1½ tons to be transported across the rugged rock surface.

The paper describes and investigates from contemporary records, and site inspection, the design, manufacture, erection, operation, innovation, attribution and influence of this unique railway which contributed essentially to the construction of one of 'Seven Wonders of the Industrial World'. [6]

Design and manufacture 1807-09

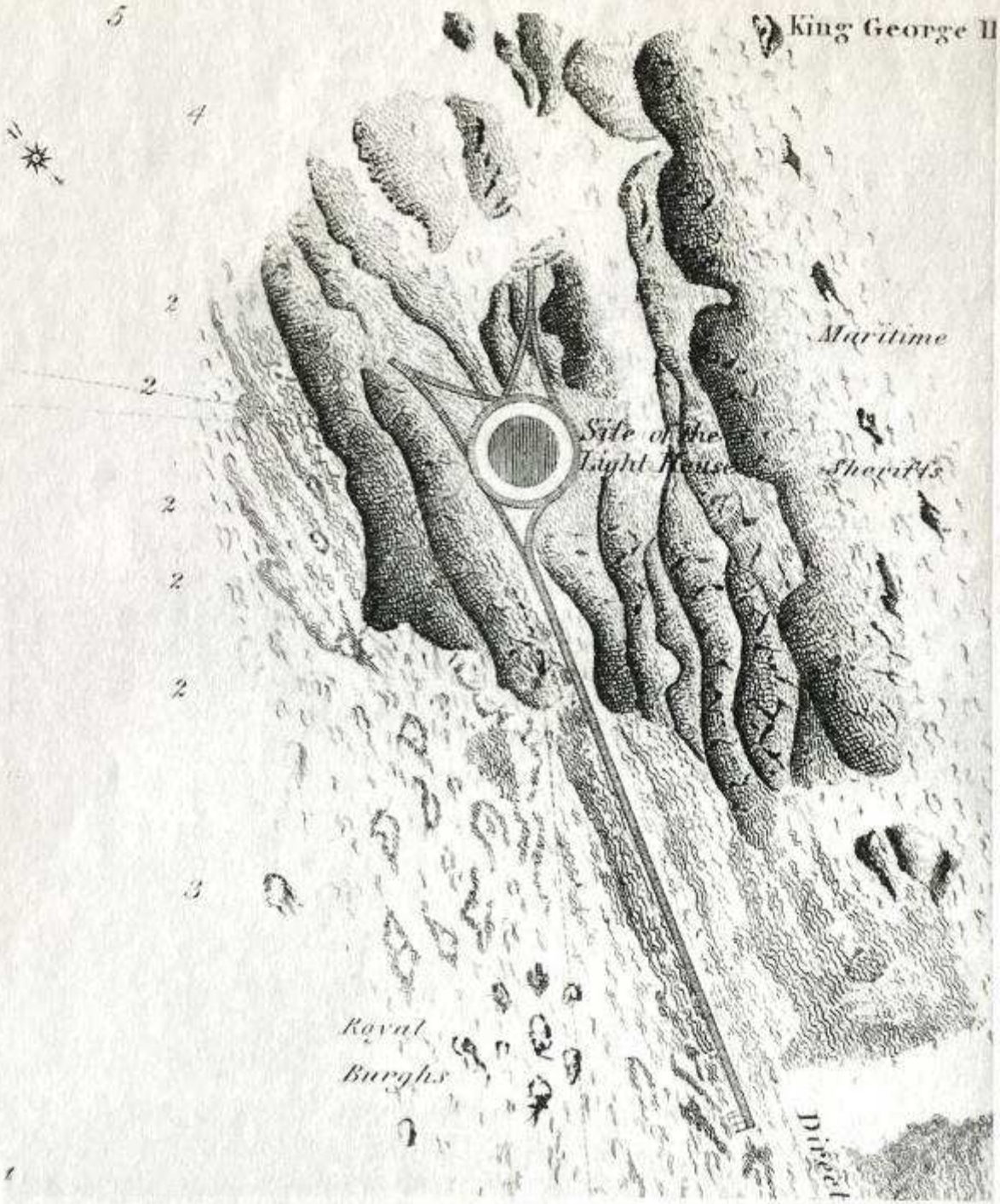

Fig. 2 Plan of railway

The idea of using an elevated railway up to 6 ft above the rock surface, from timber wharves to the south (Pitmilly), the north-east (Duff's) and an another occasional landing and siding to the north was Stevenson's. He was the driving force behind the project for a stone lighthouse first proposed in 1800 and developed in 1807. Stevenson determined the railway's level and location, probably in consultation with his clerk of works and draughtsman, David Logan (1786-1834), who in effect acted as assistant resident engineer.

Research for this paper has revealed that the detailed design of the railway and its associated cranes under Stevenson, was essentially the work of foreman journeyman carpenter and millwright, Francis Watt. But, as this function was not specifically attributed to him in Stevenson's publications in time it was generally credited to Stevenson himself. [2, 7, 8]

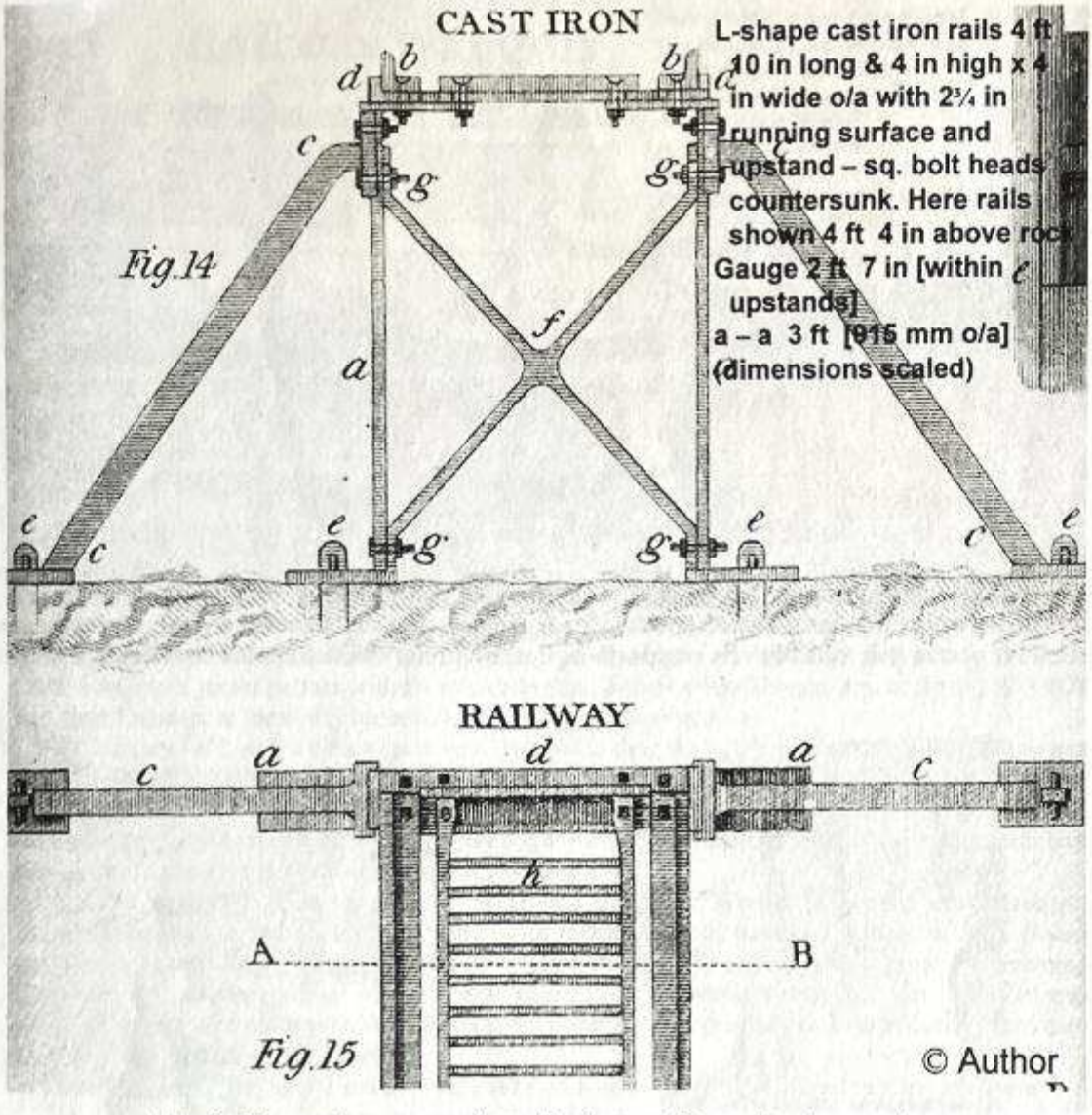

Fig. 3 Plan and cross-section of railway with explanatory notes

Watt's working sketches and drawings for the railway probably no longer exist but a near contemporary engraving published by Stevenson does (fig. 3), to which explanatory details have been added. [9] This shows Watt's design, except for the side braces which were added about a decade after he had left Stevenson's employment. The gauge was nominally 2 ft 6 in and the plate-rail upstand measures uniformly 1¾ in tall on site, a value which should take precedence over that scaled on Fig. 3.

The batt fastenings (rectangular cross-section bolts) securing the feet of the railway sub structure to the rock by means of iron and timber wedges were made of wrought iron and 12 inches long with a hole and cottar ('e' on Fig. 3). [10] The sub structure, with its minimal surface area subject to sea action compared with other possible modes of construction, was cross braced (at 'f') and by the horizontal plate to which the rails and grating were secured. Its open aspect longitudinally is evident in Fig. 4. [11]

The basic structural design was influenced by traditional timber construction, but its innovative aspect is essentially in the application of cast iron to this concept and context. The ironwork was empirically designed and little influenced by the state-of-the-art railway practice ongoing at the Caledonian Canal which would have been known to Watt from his time there, as can be seen by comparing Figs 3 - 5 with Figs 6 & 7. [12, 13]

Details of a waggon are given in Fig. 5 [9] They were man powered, of open design and weighed about 224 lb unladen. When not in use they were left upturned on the rock as the tide rose, and generally were not moved much by the sea when the rock was inundated. An ingenious feature was the two-frame chassis which allowed sufficient axle movement for the waggons to be drawn around the tight curves at the tower base.

Courtesy National Library of Scotland
Fig. 4 Part of 'Taylor's Track' and 'Watt's Reach' in July 1810 looking east. Railway up to 6 ft above the rock with its supports bolted to timber baulks below about 4 ft © NLS

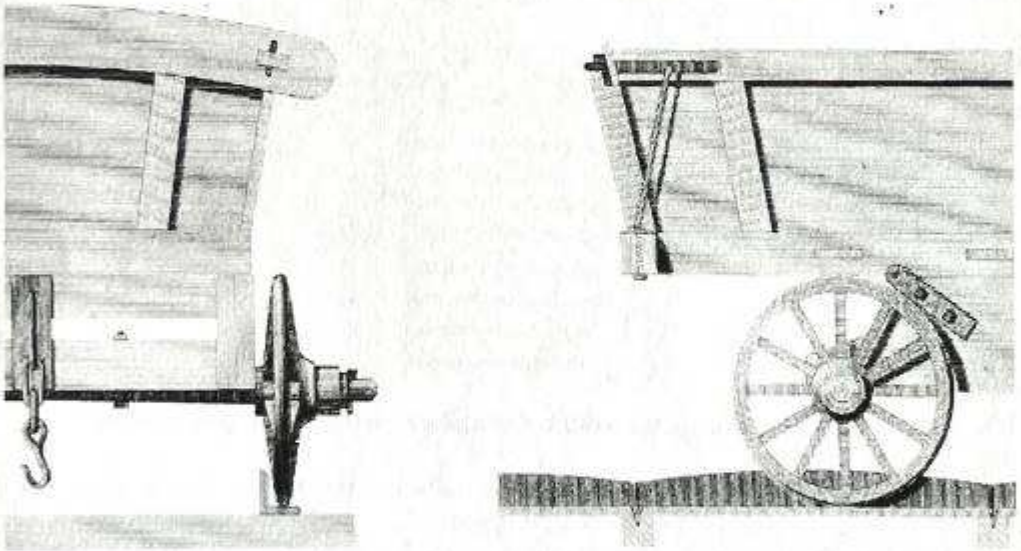

Fig. 5 Caledonian Canal waggon on 3 ft Jessop plate-rails c. 1806

Fig. 6 Caledonian Canal Jessop rail end

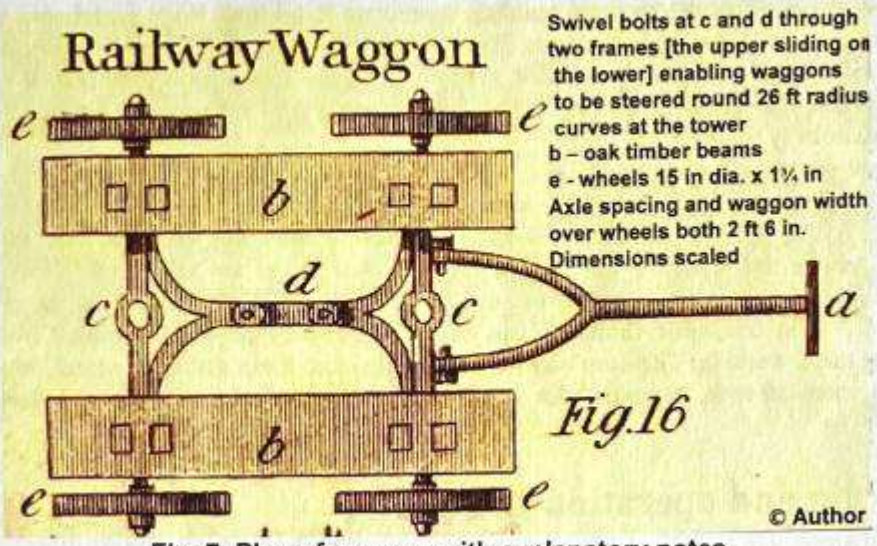

Fig. 7 Plan of waggon with explanatory notes

Watt was engaged by Stevenson in February 1807. [14] By May 1807, prior to the temporary accommodation at Arbroath Work-yard being ready, he was working on details of the railway and cranes, probably at the Greenside Works, Edinburgh, a flourishing private lamp manufactory, in which Stevenson was a junior partner with his step-father and father-in-law Thomas Smith, from 1787-1808 part-time Engineer to the newly formed Northern Lighthouse Board.

On 8 January 1808 with a view to making a start on building the lighthouse in the summer, Stevenson instructed Watt to come from Arbroath to see him in Edinburgh as soon as he had finished 'a proper draft of the crane, of the rock and railway'. [15] Rennie was then pressing Stevenson 'to see a sketch of what was proposed before it was done'. [16] By the end of the month Stevenson was able to inform him that 'the railways were partly fixed upon and modelled'. [17]

On 11 February 1808 Watt wrote to Stevenson from Shotts Iron Works, that the patterns 'I have got almost ready (and) as there is not wood here fit for making them … have got them made at Mr (John) Baird's works in Glasgow'. Here Watt talked to Hugh Baird (1770-1827), canal engineer, 'concerning the cranes and other operations' whom he felt 'agreed in a great measure with (his) ideas'. [18] Watt was still at Shotts on 27 February 1808 when he urged Stevenson to come and see the patterns before they were used. Their making had proved

> 'very tedious … but we have taken every effort of making them in the acceptable manner. I am at a loss to know the most proper way of fastening the rails to the rock as (its surface) is so irregular and for to lay them on strings of wood' (an upwards extension of the timber seen in Fig. 4) will save no (significant amount) of iron work but still increase the friction (the surface area subject to the action) of the water … I think it would be most proper to have (angle) braces of iron (bolted into the rock). 'If you would determine the height of the railway … I think I could execute this method in a more simple manner than the laying of them with wood'. [19] (Fig. 3)

Fig. 8 Model c. 1822 made for Stevenson showing railway in operation

A finely executed model showing building operations at the Bell Rock Lighthouse was made for Stevenson in c. 1822, probably by James Slight (1785-1854) (Fig. 8). [20] Slight later became a civil and agricultural engineer who also modelled structures and machinery as a promotional or design aid. Stevenson had first employed him at the Bell Rock works from 1808 and later on the strengthening of part of the railway by 1819.

The total cost of the ironwork for the railway amounted to £1002, of which £669 was paid to the Shotts Iron Company for 'cast metal branders, rail road castings, mountings for waggon triangles and sundries'. Ayden & Elwell (Shelf Iron Works south-west of Bradford) were paid £143 for 'rails, stools, sleepers, trusses and branders' for work in 1809. [21] Watt was at the Shelf Iron Works on 25 March 1809 preparing patterns and expected within a few days 'a sett of the castings for the railroad' would be ready. [22] The Greenside Company was paid £190, mainly for small wrought iron items some involving metal working. This sum was for 'batts, bolts, fore-locks and keys, screw bolts and nuts for rail road upon the rock, mountings for small waggon, driving bolts and key, and round and square bolts'. [21]

Erection and operation 1808-10

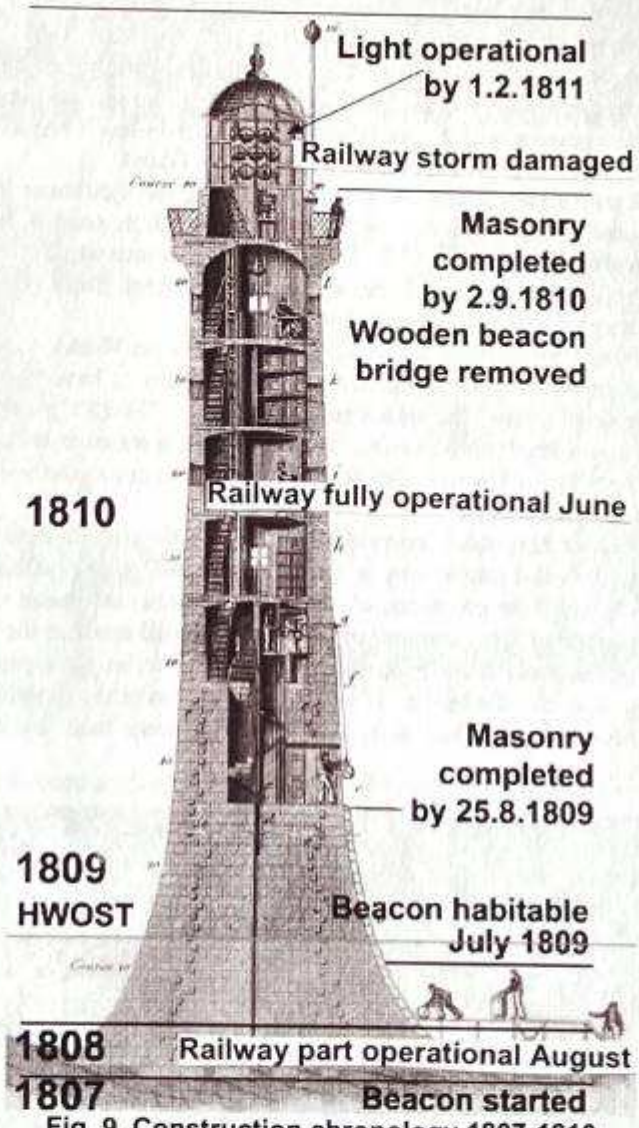

Fig. 9 Construction chronology 1807-1810

The railway and its context relative to the chronology of other operations on the project is indicated in Fig. 9. [23] The Shotts-made ironwork for the railway had been delivered to Arbroath by early May 1808 when intense activity on the erection of the railway was under way for up to about three hours at each low water, tides and weather permitting, the men then having to travel by boat to and from their ship

accommodation. [24] This work included making seats and hand-boring the holes for the batts and screw-bolts to secure the feet of the cast iron supports.

Despite a herculean effort the railway was not ready by 10 July 1808 when the foundation stone of the lighthouse was laid, or before the first entire course of 123 stones was completed on 12 August. These stones had to be placed through the sea from above at high water, before final positioning and fixing after the tide had receded, a difficult and dangerous operation.

The railway eventually began to operate towards the end of August, but only on the eastern (northern) reach from Duff's wharf, when it carried the second entire course of 136 stones weighing 152 tons, including some of about 1½ tons. By mid-September, when work stopped for the season, courses 1 to 5 (of 90) had been laid. Notwithstanding this progress the necessity of bringing into commission the western (southern) reach for greater convenience of operation was much felt.

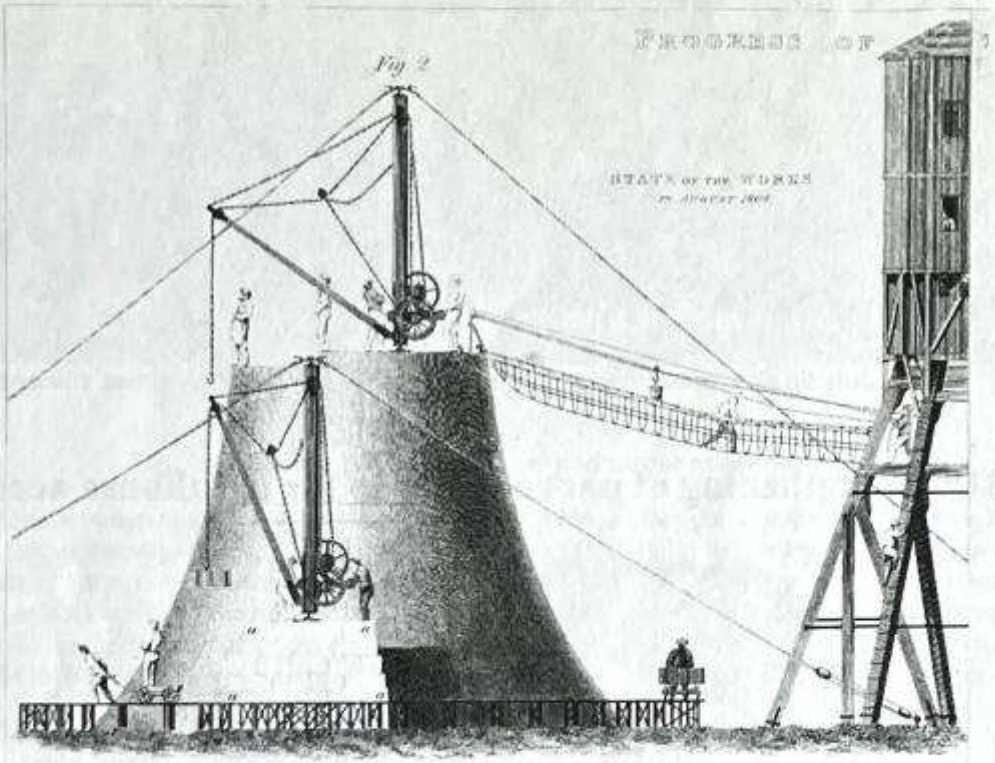

Fig. 10 Work ongoing in August 1809. Note the curved railway, Watt's ingenious cranes and the beacon barrack accommodating up to 29 men

The railway suffered minor damage in the winter gales although this was soon remedied. By 22 May 1809 great exertions were being made on laying the circular track around the tower. Typically a ten-man squad of millwrights, joiners and smiths were engaged on this work under Watt's direction. This number increased to twenty-four at periods from August to November when the temporary beacon barrack alongside the lighthouse became habitable making more time available for 'extending and completing the railways leading to the western creek' (Fig. 10). [25, 26]

Rennie inspected this work in progress on 24 September 1809. Although appreciating that the Stevenson initiative of the additional western (southern) railway reach would facilitate construction at different states of the wind and tide he thought it might not warrant the extra 'heavy expense'. [27] Nevertheless he concurred with this measure in the best tradition of the chief engineer-at-a-distance/resident engineer relationship as practised by Smeaton, Telford and others.

Even with the extended working time it was not until 17 June 1810 that the western (southern) reach became fully operational from Pitmilly wharf serviced by Watt's remarkable jib-crane with its optional mechanical advantage of either 20:1 or 98:1 (Fig. 11). [28] Completion of this reach 'had involved an immense effort in boring the rock, inserting iron-bats and operations, accessible only at the lowest tides … Mr. Watt and his squad had embraced every opportunity day and night – for this work was to the last carried out by torch light'. [29] During the next eleven weeks the most intense period of activity on the project then took place resulting in completion of the tower masonry by 2 September 1810. Following finishing work the light became operational on 1 February 1811.

The total cost of the railway was about £2400 (excluding cranes) of which the labour element was about £1000 (excluding payments to the engineers). Watt received £436 from March 1807 - October 1810, of which about one third can be considered attributable to the railway. Basically he received 7 s per day. Other rates ranged from 2 s 2 d per day for labourers to 3 s 6 d per day for mill-wrights. [30, 31]

Fig. 11 July 1810. Western reach of railway (much curtailed by artist's licence)

1819 strengthening of part of railway for lighthouse access

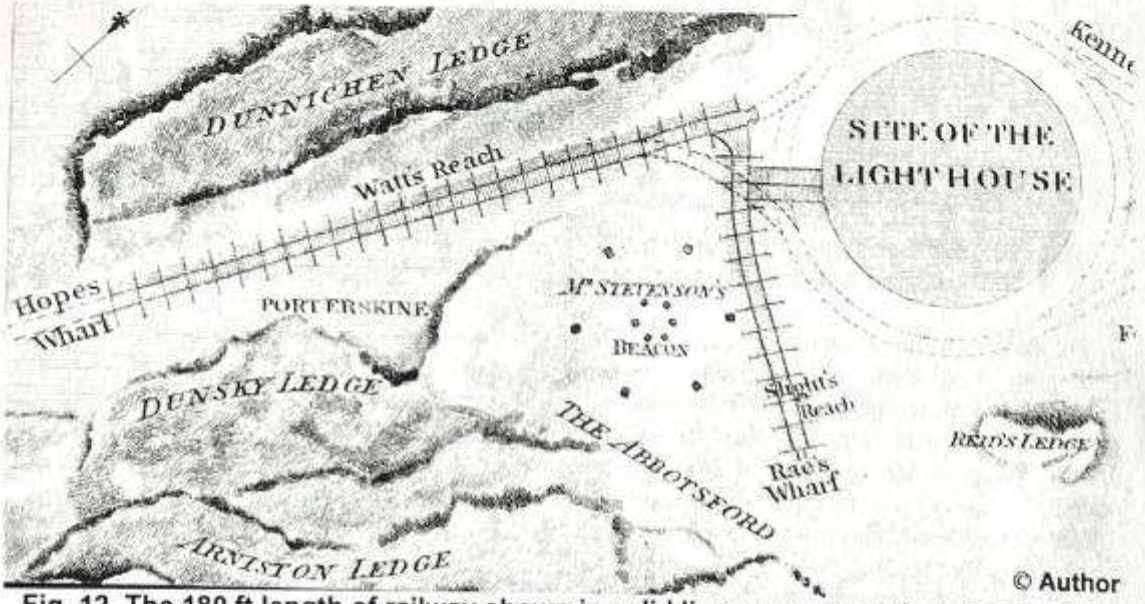

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Fig. 12 The 180 ft length of railway shown in solid lines was strengthened and partly realigned by 1819 as a permanent access to the lighthouse

The railway had successfully enabled completion of the tower by 1810 but any hopes that it might have served permanently were soon dispelled. Stevenson found after a storm on 30 October 1810 that

> 'the railways (were) much broken up on the eastern reach and circular track round the building; while the western railway, extending to upwards of 290 feet has also materially suffered. In several places it had got an inclination to one side, by the force of the N.E. seas which came sweeping round the rock, and it was evident that it could not withstand the gales of winter. The Norway logs, on which these railways were supported, had not only been much reduced in weight by the ravages of the sea-worm (*limnoria terebrans*) but from this cause

also, the rails had got a tremulous motion in heavy seas which had shaken loose several of the bolts'. [31]

Although repaired without too much difficulty, the railway afterwards was repeatedly damaged in storms. This required strengthening to be undertaken from 1815-19 on 'Watt's Reach' and making a realignment, known as 'Slight's Reach', as a permanent access to the lighthouse about 180 ft long overall, only about a quarter of the original railway length **(Fig. 12)**. [32] The work involved provision of the side braces previously mentioned (Figs 3 & 12), the use of strong batt fastenings, and plastering over the feet of the supports with Roman cement to inhibit oxidation. It cost about £1100. [30]

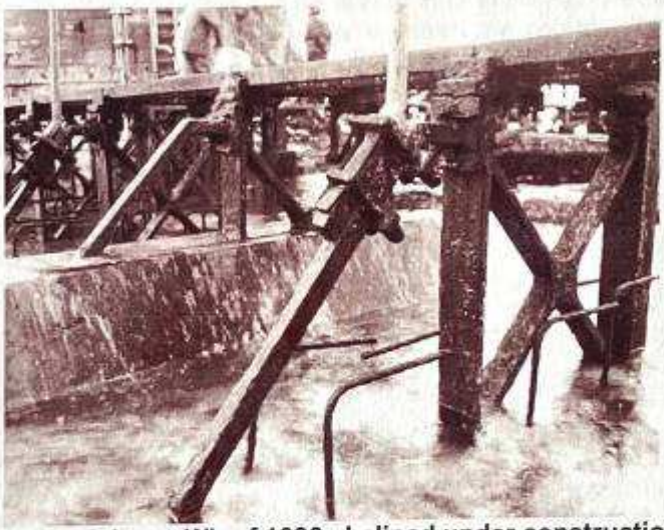

Fig. 13 Fairway Wharf 1986 - helipad under construction

When the author inspected the railway ironwork in 1986, he thought it probably dated from 1819, but on further investigation found that D. Alan Stevenson (1891-1971) had renewed much of it in 1917 **(Fig. 13)**, [34] Stevenson reported that fragments of detached rock had been a source of continual trouble since the construction of the railway requiring 'small repairs … Boulders had sometimes collected as high as the gratings (and had) to be cleared away by blasting …' and that on 19 November 1916 most of Fairway Wharf (Watt's Reach) had been swept away in a very severe gale after about a century **(Fig. 14)**. [35, 36]

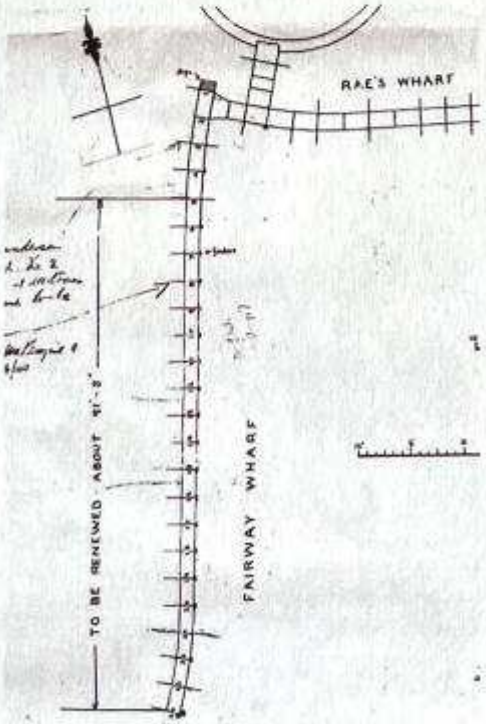

Fig. 14 Fairway Wharf (Watt's Reach) renewal 1917 ©NLB

This replacement painstakingly executed in its original form mostly still exists, continuing to support D. Alan Stevenson's view that 'the long life of the cast iron railways proves the usefulness of cast iron in sea water'. The replacement practice still being followed by the Northern Lighthouse Board. [37]

From a comparison of Figs 12 and 14 it is probable that none of the 1808-10 construction survived after 1917. This may explain why on site now the bolts securing the plate-rails do not have the counter-sunk heads shown in Fig. 3. Some bays of Rae's Wharf (Slight's Reach) may still date from 1819. A bay of this wharf, possibly dating from 1819, replaced in cast iron in 2011 can be seen on the left in Fig. 15. [38] The whole facility as it now exists, with the helipad, is shown in Fig. 16. [38]

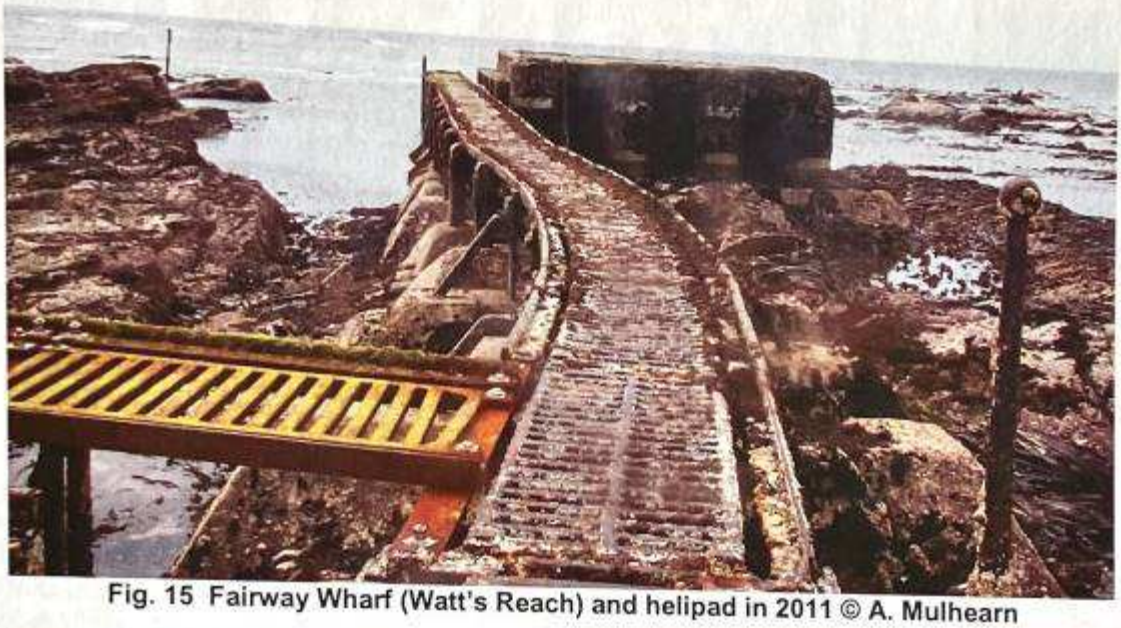

Fig. 15 Fairway Wharf (Watt's Reach) and helipad in 2011 © A. Mulhearn

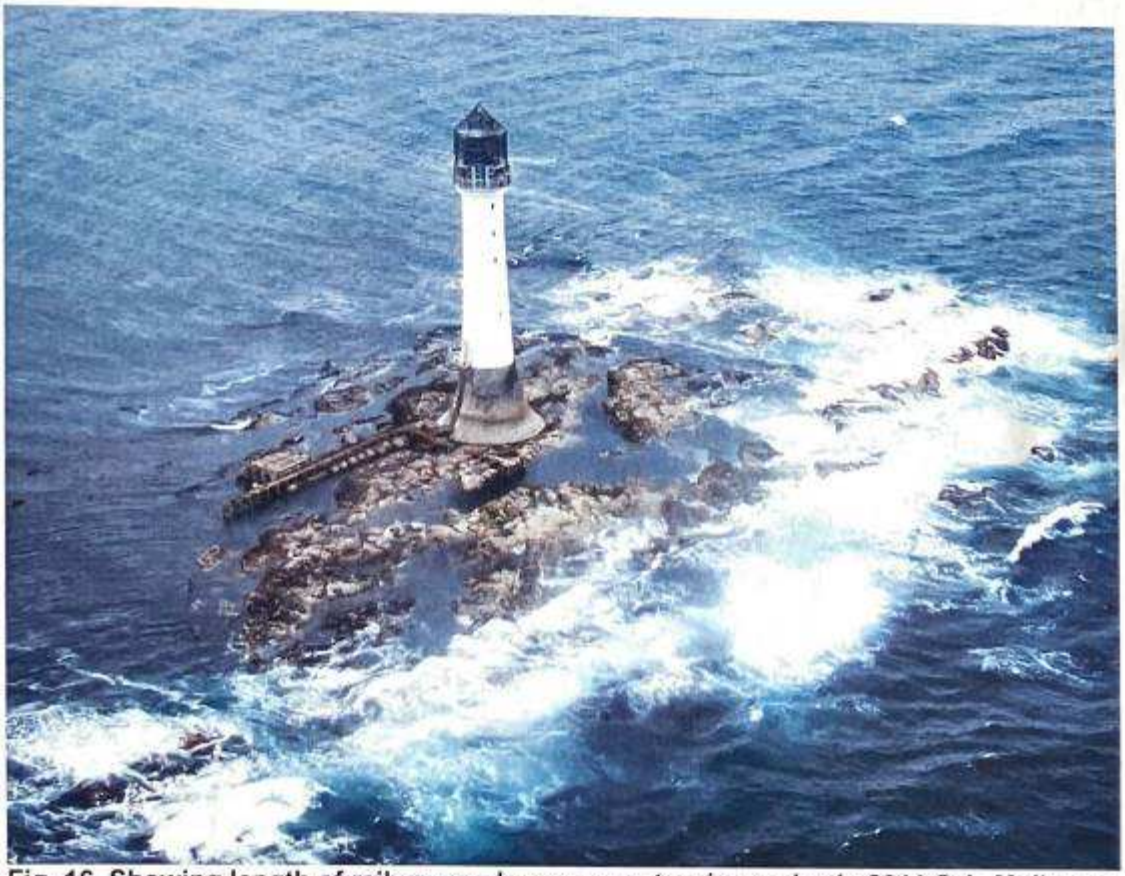

Fig. 16 Showing length of railway made permanent as in service in 2011 © A. Mulhearn

Conclusions

This hazardous-to-construct elevated plate-way, empirically achieved against the ravages of the sea by exceptional courage, determination and skill, made an essential contribution to one of greatest engineering feats in modern history.

The project was all the more remarkable in being effected before the development of such improvements as portable steam-powered equipment, patent timber preservatives, artificial cements and, not least, 'strength-of-materials' design. The latter did not begin to develop in this context until 1844 when a storm wave force equivalent to a pressure of 3013 lb per sq ft was first measured at Bell Rock. This is indicative of the order of hostility to which the railway structure was subjected occasionally (and Rennie's prudence in adopting a pronounced curvature for the lighthouse base). [39]

The railway was designed in detail and erected by Watt to the concept of and under the direction of Stevenson with the approval of Rennie. The 1815-19 strengthening of part was carried out by Slight under Stevenson's direction. The total cost was about £3500, equivalent to at least £2m now.

Fig. 17 Railways projected by Stevenson 1813-26

The railway's success was the catalyst to Stevenson becoming by 1820 the 'great authority' on Scottish pre-steam locomotive railways. [40] His many projects, although mainly unexecuted, showed foresight being more or less on the lines of the eventual network **(Fig. 17)**. [41] A report on one in 1818 also influenced the early introduction of the malleable iron edge rail, a vital break-through in railway development. He advocated the measure 'as likely to be attended with the most important advantages to the railway system', a contention that encouraged Birkinshaw to develop and manufacture his epoch-making wrought iron edge rail in 15 ft lengths from 1820. [42, 43]

Although the railway was not identically replicated elsewhere, its concept had a lasting influence for at least three-quarters of a century in that railways were advantageously adopted in the construction of other isolated lighthouses including Skerryvore (1839-42), Dhu Heartach and its shore station Erraid (1869-72), and Ailsa Craig (1885). [44 - 47]

Other types of project for which the railway concept was adopted to facilitate construction included Hutcheson Bridge, Glasgow (1831-34), designed by Stevenson where wrought iron under-bellied edge rails were used. This application was promoted nationally through Weale's *Bridges* **(Fig. 18)**. [48]

The concept was also adopted on harbour works, for example at Wick Breakwater where stone brought by railway from local quarries was uplifted by jennies on travelling frames moving on railways to open staging through which it was lowered into position (1868) **(Fig. 19)**. [49] Other examples of both practices are illustrated in the plates to Vernon-Harcourt's *Harbours and docks*. [50]

Finally, the surviving railway at the rock, although mainly a painstaking replica dating from 1917, is nevertheless a wonderfully evocative unique exemplification of pre-1820 narrow-gauge plate-way technology and the longevity of cast iron in a hostile environment (Figs. 15 & 16).

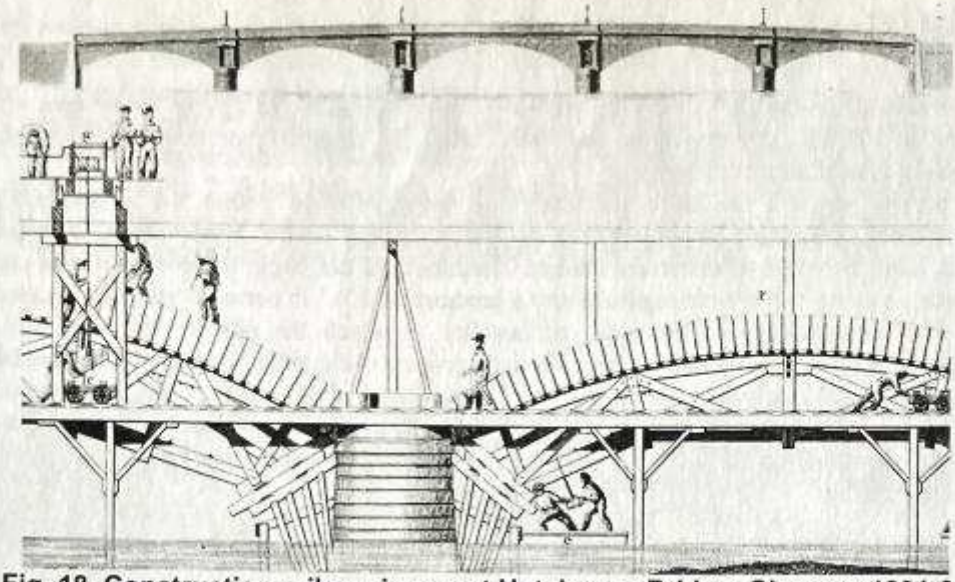

Fig. 18 Construction railway in use at Hutcheson Bridge, Glasgow 1831-34

Fig. 19 Wick Breakwater 1868 – railway and travelling frames © Wick Society

Appendix - Francis Watt (1778-1823?), inventor and artizan

Little is known about Francis Watt which is the reason for this appendix. David Logan, Bell Rock Lighthouse clerk of works (later Chief Engineer of the Clyde Navigation) considered that Watt's applications of mechanical power at the Bell Rock Lighthouse were 'highly unique and valuable' a statement borne out by this paper. [51, 52]

Logan felt so strongly about this and wishing to see that Watt received his due credit, which he did not feel had been sufficiently acknowledged by Stevenson, he took the trouble of preparing details of Watt's innovative cranes developed during the Bell Rock works for publication. These comprised anonymous articles on Watt's jib-crane and arguably his most significant invention, the world's first iron counter-balance tower crane used for erecting the upper part of the lighthouse above the range of the jib-cranes shown in Fig. 10. [52-54]

Logan's articles were first published in the little-known *Caledonian Journal* [52] and then reprinted nationally as front-page features in the *Mechanics Magazine*. [52, 54] The jib-crane article was also reprinted in several editions of Jamieson's *Dictionary of mechanical science*. [55]

Watt was baptised on 18 July 1778 at Greenburn, Newhills, Aberdeen. [56] That he is this Francis Watt in the *Old Parish Records* is attributed from Logan's information that he was born at or near Aberdeen, confirmed by a letter from Watt to Stevenson dated 8 September 1810 written from 'Greenburn by Aberdeen'. [57] Nothing is known of Watt's education which was probably gained at a local school before entering the carpentry trade.

According to Logan, Watt worked as a journeyman carpenter on Fochabers Bridge over the River Spey (erected 1801-1805) and then at the Caledonian Canal works, probably from c.1805 to 1807, under the overall direction of leading civil engineers Telford and Jessop.

Watt was 29 years old when he started work on the Bell Rock Lighthouse project in March 1807 at two guineas a week. He continued in this employment until 31 October 1810, over which period he was paid £436 (about £10 per month). A premium was paid for work on the rock and his greatest monthly

payment of just over £20 was in June 1810. [30] He seems to have had a good working relationship with Stevenson who makes only the broad passing acknowledgement in his *magnum opus* that he 'had profited by (Watt's) ingenuity in reference to machinery' and his 'zeal and intrepidity in erecting the beacon and railways'. [58]

In September 1810 Watt wrote to Stevenson that he was looking for work and hoped 'to get a job soon' [57] Soon afterwards he went to London, it is said in the service of Rennie, possibly working on the Waterloo Bridge.

On 26 November 1812 Stevenson took trouble to ensure that Watt received a copy of the separate printing of his *Account of the Bell Rock Lighthouse* by sending it to London in the hands of 'Capt. Brown who occasionally tells me of your welfare and who will know your address in London'. [7, 59]

Watt was probably still alive in November 1820 as in a letter then Logan makes mention of obtaining Watt's permission to publish details of his inventions. [60] Nothing seems to be known of Watt's work or life in London, but because of his inventive propensity he may have been the Francis Watt awarded the Silver Vulcan Medal of the Society of Arts and ten guineas, for his invention of a screw-wrench for loosening and securing square-headed screw-bolts, his model of which was deemed of sufficient merit to be placed in the Society's repository.

By 21 April 1823 this Francis Watt was very ill, presumably living in Lambeth, London, and died shortly after, on the day that his screw-wrench invention was brought before the Society's Committee (Fig. 20). [61]

A slightly fuller account of Watt which seems to be largely based on Logan's information was published by Robert Mudie, a miscellaneous writer who espoused the cause of promoting engineering talent. Mudie refers to Watt as 'a contriver in cases of emergency' and as 'having great inventive talent' but also as 'a frequenter of alehouses ... (in which) matter he was allowed to have his way only to be always ready at a call'. [62]

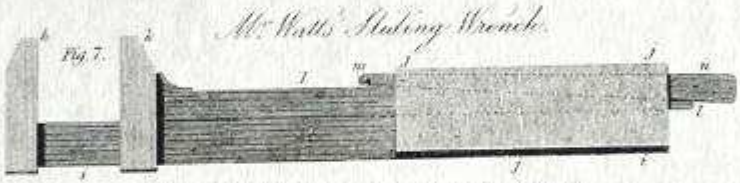

Fig. 20 Watt's screw-wrench 1823

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9. Stevenson 1824, pl X. Drawn by Stevenson assistant George Cumming Scott but not before 1818. Based on site and office knowledge and earlier drawings
10. D. Alan Stevenson, Report on the condition of the landings at the Bell Rock, 7 March 1917, Edinburgh 7. Typewritten carbon copy on NLB paper. Author's collection
11. NLS. MS. Acc. 10706, 218. Original drawing by Scott in c.1820 of operations at the rock in July 1810
12. T. Telford, *Life of ... containing a descriptive narrative of his professional labours*. Edited by John Rickman (London, 1838), pl XX
13. Caledonian Canal plate-rail at ICE Scotland Museum, Heriot-Watt University. Similar but not identical to Kilmarnock & Troon rails, illustrated by the author in *Selected papers* from the First International Early Railway Conference (Durham, 1998), broken by the action of *'The Duke'* Killingworth locomotive in 1816. (It is now known that this 'travelling engine' was sold to the 7th Earl of Elgin, for £70 on 5 Nov. 1824. See author's article in *ICE PHEW Newsletter*. 103 (2004), 4)
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19. NLS. MS. Acc. 10706/73.133
20. Model in the National Museums Scotland, Chambers St., Edinburgh
21. NLS. MS. Acc. 10706/148/88
22. NLS. MS. Acc. 10706/73/185
23. Stevenson 1824, pl XVI. Base image with author's additions
24. NLS. MS. Acc. 10706/73, 147
25. Stevenson 1824, pl IX. Drawn by James Slight
26. Stevenson 1824, 31
27. Paxton 2011, 75
28. Stevenson 1824, pl XVIII
29. Stevenson 1824, 350
30. Stevenson, 1824, 475-480. The approximate costs have been gleaned from this data and 31
31. NLS. MS. Acc. 10706/148, 26-29
32. Stevenson 1824, 395
33. Stevenson 1824, pl VI. Stevenson named the railways and other parts of the rock
34. Author's image showing extended beams for the helipad under construction 1986
35. D. Alan Stevenson 1917, 4
36. D. Alan Stevenson drawing 'Bell Rock. Renewal of Fairway Wharf' 3 April 1917. At NLB
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