

[To be read at a RSE/NLB Conference at the Royal Society of Edinburgh on 'The Bell Rock Lighthouse, the Stevensons and emerging issues in aids to navigation' on 4 February 2011]



Proof copy of an engraving by J. Horsburgh after a drawing by J.M.W. Turner c.1823

Fig. 1 Bell Rock Light House during a storm from the North East

A grand design – Creation of the Bell Rock Lighthouse 1807-11

Professor Roland Paxton MBE FRSE

School of the Built Environment, Heriot-Watt University

Institution of Civil Engineers' Panel for Historical Engineering Works

Introduction

The Bell Rock Lighthouse, Scotland, off Arbroath, ranks as one of the seven wonders of the industrial world and the world's oldest sea-washed rock lighthouse in continuous service [Figs 1 & 2]. It was built in stone from 1807-11, is 36 m (118 ft) high, 11 miles out to sea on a rock surface up to 5 m (16 ft) below high water and cost £61,331.

The lighthouse's height and extraordinary exposure called for a 'grand' design which was achieved by the eminent civil engineer John Rennie and Robert Stevenson under their respective Northern Lighthouse Board appointments of December 1806 as *Chief Engineer*, and *assistant engineer for executing the work under his superintendence* [NAS:NLC/1/1].

Based on contemporary sources, the lecture demonstrates how this seemingly impossible task was achieved, when civil engineering was in its infancy, and identifies and reviews the key contributions and innovative aspects of the lighthouse's design and construction.



Fig. 2 Part of chart (1, pl. III) showing the lighthouse and stone sources
 Each of its 90 courses was prepared at Arbroath. In its mortars, Italian pozzolano, Aberthaw lime and Roman Cement from Kent were used

Design

The lighthouse's design was empirical and based on John Smeaton's successful Eddystone Lighthouse. When designed in c.1757 Smeaton, realised that the stability of a sea tower was dependent on having sufficient weight, and fixity at its base, to resist the force of the sea.

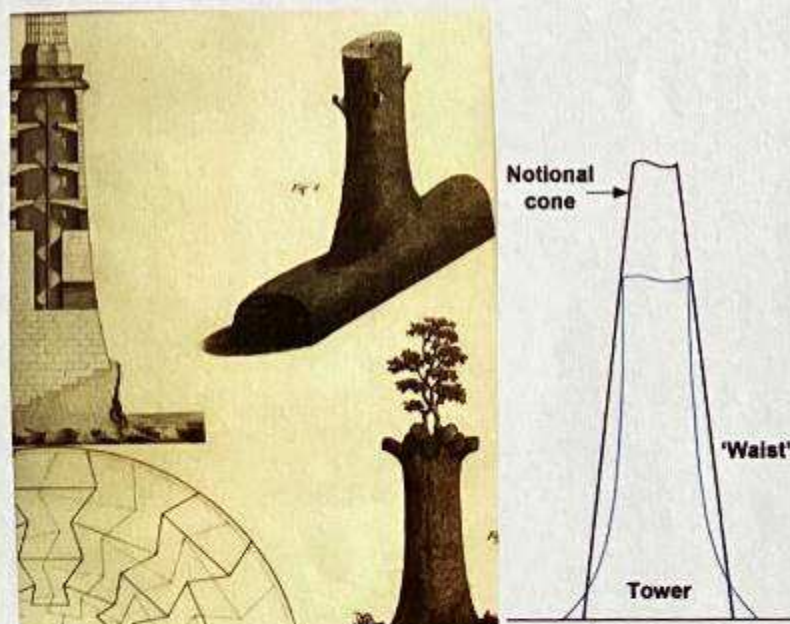
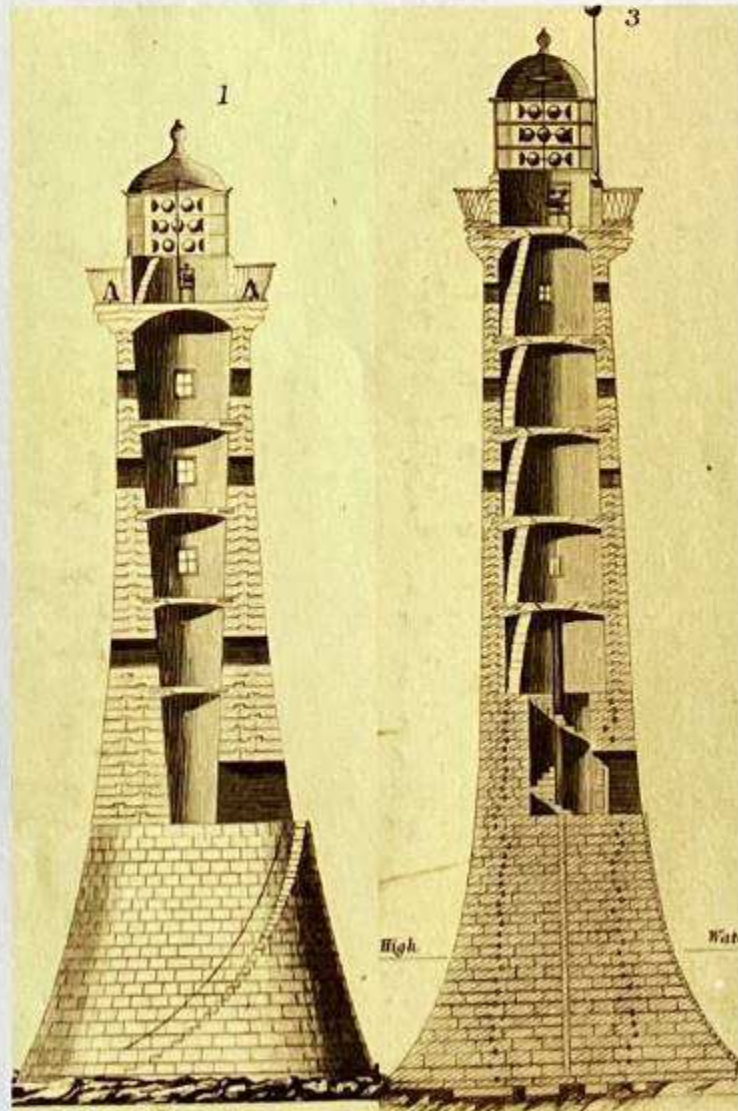


Fig. 3 Smeaton's Eddystone Lighthouse sections and oak tree stump design analogy (2, pl. 13) with author's interpretive sketch of Smeaton's favoured form (incompatible with the rock outcrop)

Notionally he considered this best achieved by a conical stone tower against which horizontal forces would decrease rapidly towards its top. He then developed this idea by advocating a larger base and a diminished 'waist and upper works [Fig. 3 - sketch] to increase the tower's strength and stiffness ... [offering] less resistance to the active power [of the waves], though consisting of a less quantity of materials.' (2, 41),

In concurring with and applying this concept to the Bell Rock tower Rennie specified the implemented base to be '42 feet dia[mete]r, the second course 38 feet, the third 35, the fourth 33 & the fifth 32, forming by these dimensions a cycloidall base which under all circumstances seems the best' [NLS: MS. Acc. 10706/63,65].



Del. J. Andrews for Alan Stevenson, *Civil Engineer and Architect's Journal*, XII (May 1849)

Fig. 4 Robert Stevenson's undovetailed Bell Rock tower proposal of 1800-06 (left) and the as-built design under Rennie's overall superintendence (right) compared

As early as 1800, whilst still apprenticed to Edinburgh lamp manufacturer Thomas Smith, who allowed him considerable autonomy in his lighthouse work, Stevenson proposed a design for a stone lighthouse on the Bell Rock which was used in promoting the project until 1806, but the design implemented under Rennie's superintendence differed significantly from Stevenson's [Fig.4]. Rennie insisted on closer adherence to the Eddystone design because of its proven stability. In its 'waist' the implemented design, with its cycloidal curves rising

from the horizontal at about 40° rather than 70°, is about 20% slenderer than Stevenson's proposal. These features, and more robust lateral (dovetailed) connection, minimised possible damage from heavy seas, particularly when building the vulnerable first 9 m, of which up to 5 m was below high water. Stevenson's outside stair was omitted. The shape of the rooms and narrower walls were also influenced by Eddystone practice. In erecting the lighthouse within these parameters and, subject to Rennie's approval, Stevenson exercised considerable autonomy in the detailed design of the masonry, light-room, equipment, finishings and temporary works.

Construction

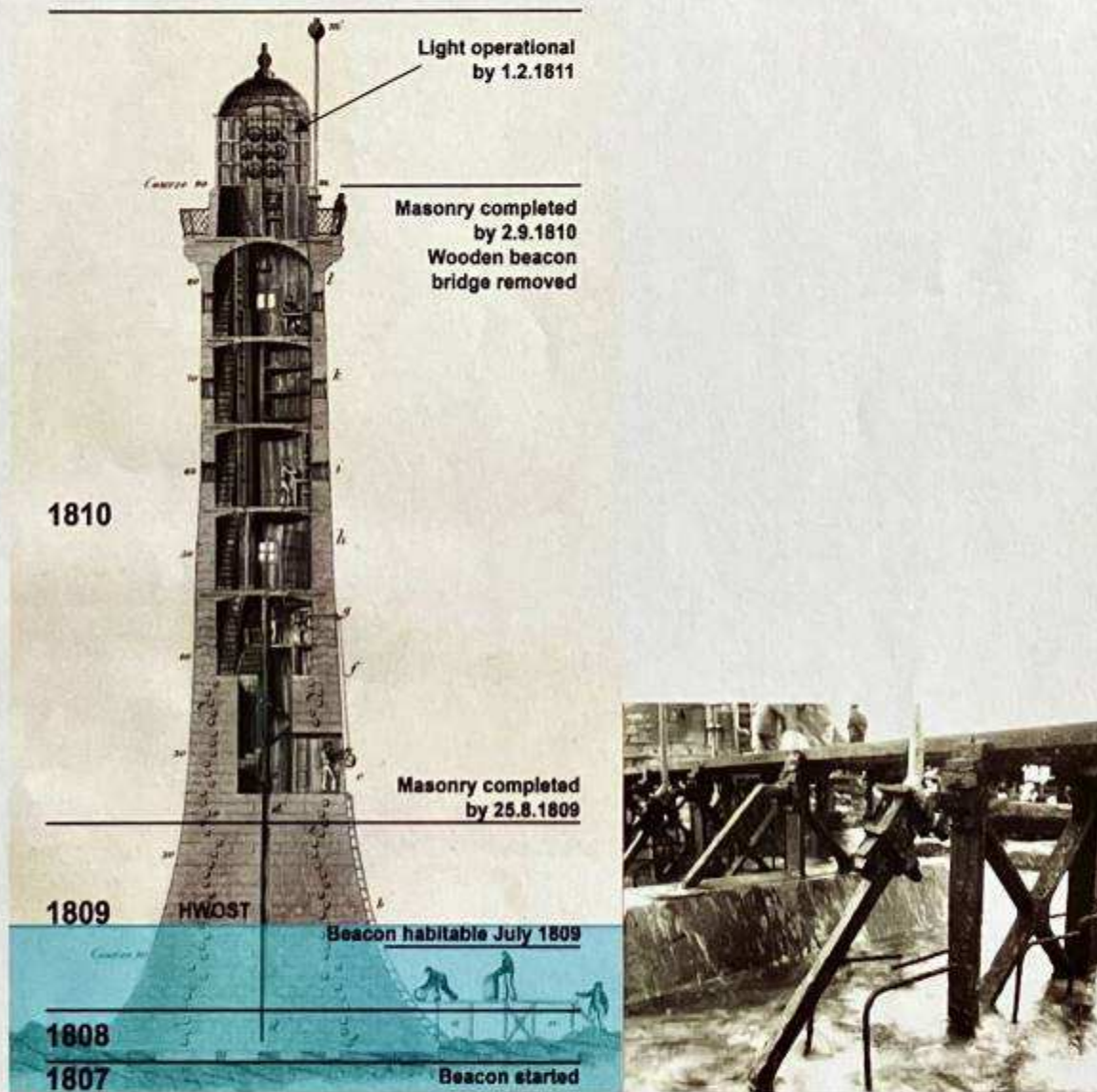


Fig. 5 (left). Bell Rock Lighthouse – erection chronology 1807-11 (1, pl. XVI – base image). Slow progress was made before the temporary beacon barrack alongside was habitable. (right) Cast iron [2 ft 8 in gauge] railway over rock surface as seen by author in 1986

The act for the lighthouse [Geo. III. 46 c. 132] was passed in July 1806. In February 1807 Rennie forwarded the base diameter and curvature details to Stevenson, following which the working drawings were prepared at Arbroath under his direction by (clerk of works and engineering assistant) David Logan, son of Peter Logan, buildings operation foreman. The erection from 1807-10 [Fig. 5 (left)] was fundamentally facilitated by the innovations of

cranes, site railways and 4-level temporary beacon barrack, all designed and erected by foreman millwright Francis Watt, but almost certainly conceived by Stevenson and erected under his direction. The beacon barrack comprised a mortar gallery and forge above high water, kitchen, and accommodation for Stevenson, the foremen and 25 men. The first entire course, 123 stones cut to the shape of 10 wooden patterns at Arbroath, was laid on site in August 1808. A year later the masonry was about 60% complete [Fig. 6] and, in September 1809 was inspected by Rennie, on his third visit since work started, who noted with satisfaction 'that the outside of the tower answers fully [to his] every expectation'. [3]

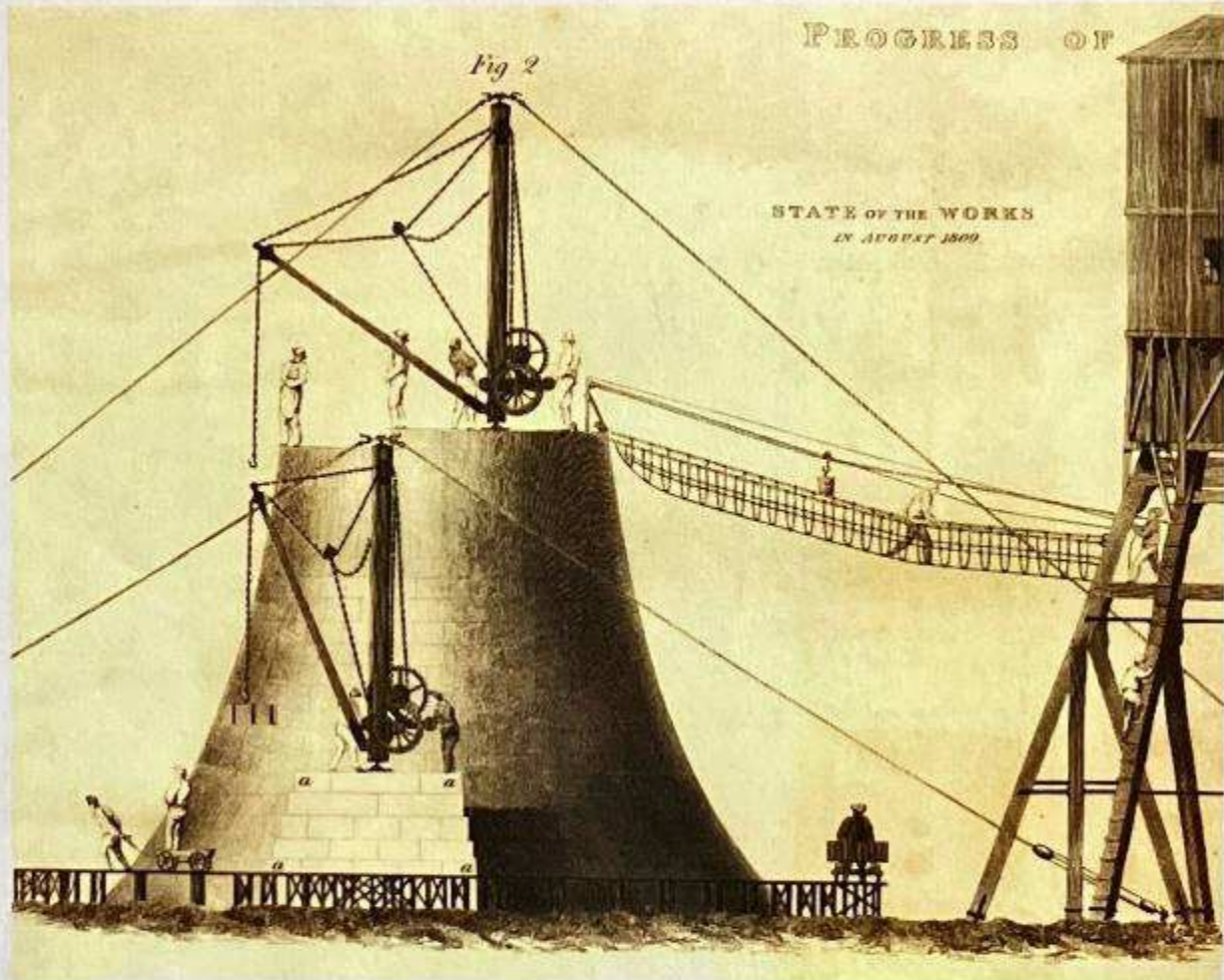
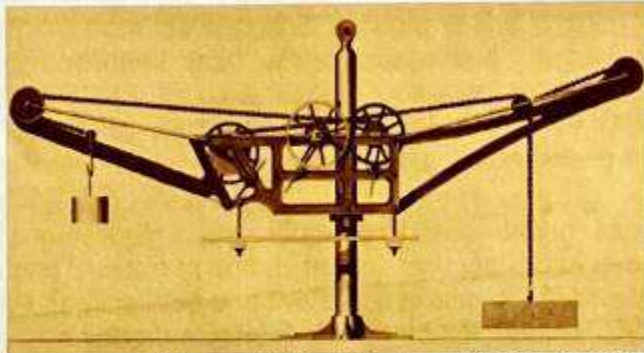


Fig. 6 State of the works in August 1809 (1, pl. IX). Most of the unprecedented temporary works are exemplified in this view

Working from the barrack, the tower was completed by September 1810. Above the height deemed inconvenient to use the jib cranes (a considerable improvement on Smeaton's poles, ropes and pulleys), Watt's innovative counterpoise crane, the earliest-known iron precursor of the modern tower crane, was used to complete the tower. Stevenson's view published in 1824 [Fig. 7 (lower)] is misleading in that the crane shown was not that used in 1810, but presumably an improved variant for the Carr Rock tower in 1817 and the Melville Monument in 1821 (further developed in use by D. & T. Stevenson at Dhu Heartach (1871) and Chicken Rock, Isle of Man (1873). The crane made in 1840-41 for erecting Skerryvore Lighthouse was similar to that of 1810 [Fig. 7 (upper)].

Stevenson's decorative finishing and furnishing of 'The Strangers' Room or Library' can be considered a fitting finale to this grand design [Fig. 8].

On 1st February 1811, the then state-of-the art revolving red and white light from 20 Argand lamps, each with an 457 mm (18 in) silvered copper reflector, was first exhibited and the lighthouse, now with modern lighting, continues its valuable contribution to maritime safety.



[Del. David Logan (NLS: MS. Acc. 10706); 4, 39]

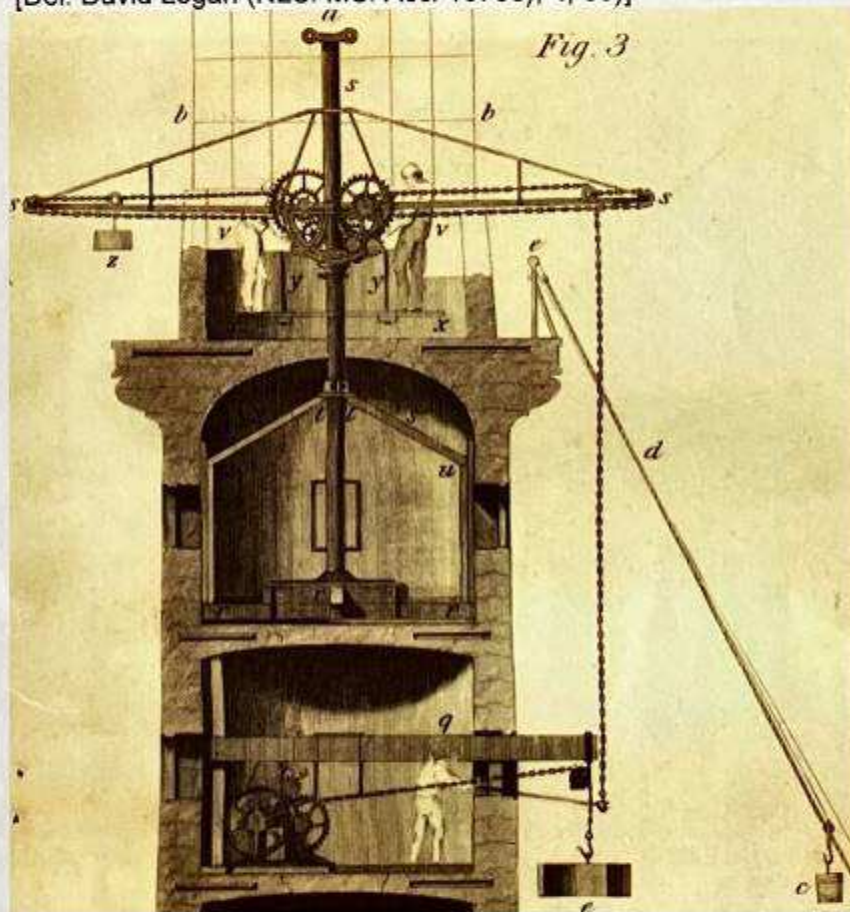


Fig. 7 (lower) View in July 1810 [Stevenson 1824, 1, IX] showing an improved counterpoise crane of c.1817 in operation. Stone 'e' about to be lifted would have been balanced by weight 'z'. Fig. 7 (upper) shows the actual crane used in 1810

Findings

- The creation of the lighthouse was an heroic example of empirically based civil engineering before the age of 'strength of materials' design and steam-powered equipment. The innovative temporary works enabled completion in four working seasons.
- the project influenced the *modus operandi* for sea-washed lighthouse building, and maritime construction generally, for several decades. Watt's ingenious cranes had a

much wider application following leading articles in the *Mechanics Magazine* and other publications by 1825.

- contrary to nearly two centuries of public misunderstanding of Rennie's role as Chief Engineer, stemming from its being played down by Stevenson (who omitted Rennie's key 1809 report (3) from his definitive account of the project (1)), recent research by the author has confirmed that, whilst recognising Stevenson's invaluable role in the lighthouse's creation, its basic design as implemented was determined by Rennie. He exercised an overall superintendence of the project by giving advice and directions in reports, sketches, many letters, and on visits, particularly that of 1809 (3).
- the lighthouse, modelled largely on Smeaton's practice, was designed and executed jointly and competently in the capacities of their Northern Lighthouse Board appointments by Rennie and Stevenson and their dedicated workforce headed by the talented Logans, the inventive Francis Watt and five sea captains and their crews (3). Its success enabled Stevenson to establish the Scottish lighthouse service, and also, to found the private family firm which, with changes of partners from time to time, lasted 141 years.



Watercolour by R.M. Ballantyne 1865

© NLS. Acc.1196

Fig. 8 'The Strangers' Room or Library' below the light room, fitted out in fine style by Stevenson. As occupied by author R.M. Ballantyne when writing 'The Lighthouse'

References and abbreviations

- [1] Stevenson, R. *An account of the Bell Rock Light-House ...* Edinburgh, 1824.
- [2] Smeaton, J. *A narrative of ... the Edystone Lighthouse ...* London, 1791.
- [3] Paxton, R. *Dynasty of engineers – the Stevensons and the Bell Rock*. Edinburgh, 2011.
- [4] Leslie J. & Paxton R. *Bright Lights ...* Edinburgh, 1999.

(NAS) National Archives of Scotland; and (NLS) National Library of Scotland – to whom the author acknowledges his thanks for access to manuscripts and permission to include two figures.