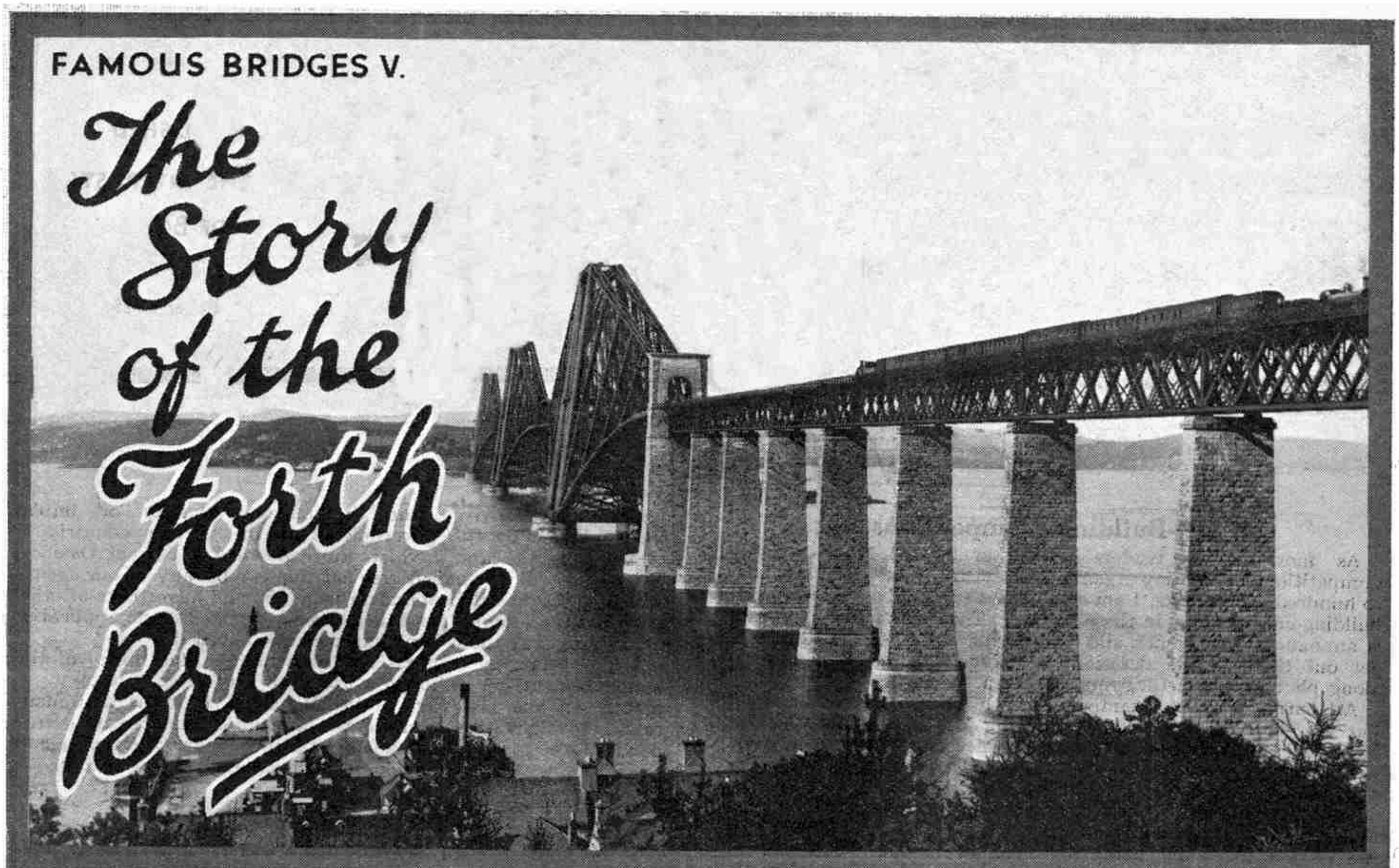
FAMOUS BRIDGES V.

The Story of the Forth Bridge



In this article we commence the story of the great cantilever bridge that spans the Firth of Forth and dominates the landscape for miles around. This bridge, which was opened in March 1890 seven years after the commencement of the works, is one of the most impressive structures in the world and its story is one of great engineering interest.

THE Forth Bridge, which forms the subject of our cover, is one of the engineering wonders of the world. Up to 1917 it held the proud position of possessing the longest span of all the world's bridges, and although in that year it had to yield pride of place in this respect to the Quebec Bridge, it has lost nothing of its fame as a glorious example of British engineering skill.

Previous to the construction of the Forth Bridge travellers wishing to go from Edinburgh to the counties of Fife and Perth were obliged either to make a long detour by way of Stirling or to cross the Firth of Forth by ferry steamer. Either of these courses involved a great loss of time and as traffic increased it became evident that some means of direct communication across the Forth must be found.

First Proposal for a Bridge

As far back as 1805 it was proposed to drive a double tunnel beneath the bed of the Forth, but this scheme came to nothing. The first suggestion for a bridge appears to have been made in 1818, when an engineer named James Anderson proposed the construction of one at Queensferry. This bridge was to be 33 ft. in width with main spans of from 1,500 to 2,000 ft. in length. This scheme also fell through and nothing further was done in the matter until 1860, when the North British Railway planned a bridge of 500 ft. spans some six miles from South Queensferry. This project never took shape, but in 1873 the idea was revived and the Forth Bridge Company was formed with the object of building a suspension bridge to the design of Sir Thomas Bouch, the engineer of the first Tay Bridge.

The proposed bridge was to have two spans of 1,600 ft. each, a clear headway of 150 ft., and towers 550 ft. above high water on the island of Inchgarvie and on the two shores. The necessary Act of Parliament authorising the scheme was passed and work commenced on the foundation of the main pier on Inchgarvie island. Then, on 29th December, 1879, occurred the terrible disaster to the Tay Bridge.

The Tay Bridge Disaster

This bridge was begun in 1871 and opened for traffic in 1878. It crossed the estuary of the Tay at Dundee, forming a connecting link between Fifeshire and Forfarshire. It consisted of 85 spans, its total length being 10,700 ft., and it carried a single line of railway. Eighteen months after the bridge was opened, its thirteen central spans, each 245 ft. long, were blown down while a mail train was crossing. The train was precipitated into the water 90 ft. below and 75 people perished. This appalling calamity destroyed all confidence in Sir Thomas Bouch and work on the new bridge was stopped immediately.

Various other means of crossing the Forth were then considered and finally, in 1881, approval was given to plans for a bridge on the cantilever system submitted by Messrs. Fowler and Baker, afterwards respectively Sir John Fowler and Sir Benjamin Baker. Parliamentary sanction for the bridge was obtained in 1873 and the work was entrusted to Messrs. Tancred, Arrol and Co., now Sir William Arrol and Co., of Glasgow. The contract was signed in December 1882 and work was commenced in the following month.

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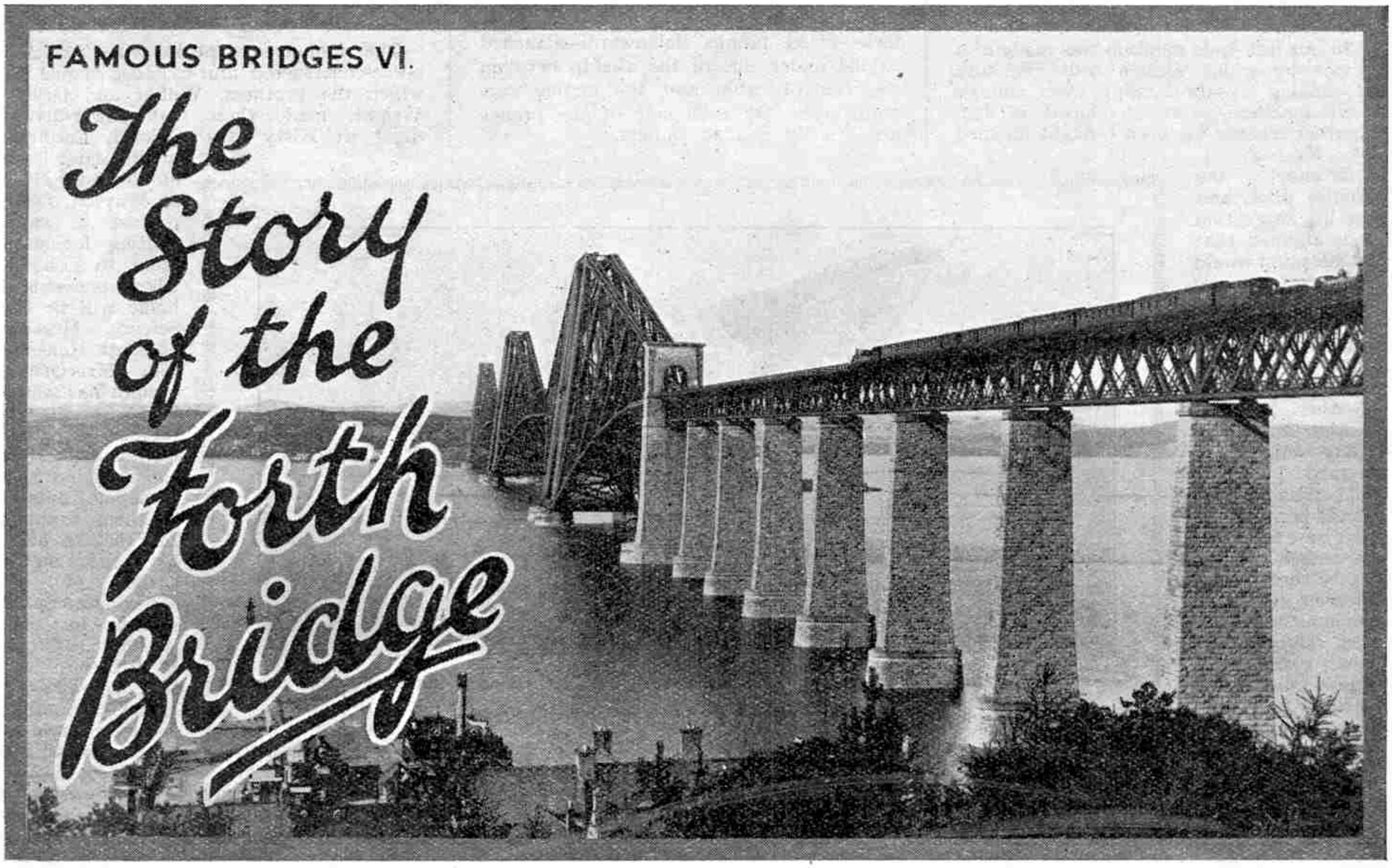


PART II.

LAST month we outlined the history of the great cantilever bridge across the Forth and gave a description of the completed bridge. In the following article we deal with an even more interesting topic—the actual building of the bridge.

Preliminary Operations

Work was commenced in January 1883, and on the rising ground at the south side several acres of land were secured and here offices, workshops and stores were erected. Lines were laid down throughout the various yards and workshops and by means of a siding the whole was brought into direct communication with the North British Railway.

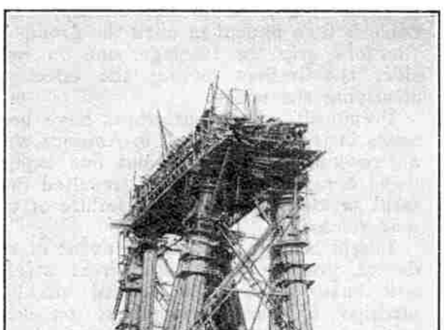
In addition to all this, steamers, barges and boats of all kinds ; cranes, steam and hydraulic, and a bewildering amount of machinery for drilling, lighting, pumping, riveting, etc., had to be provided. Many of these machines were specially designed for the work by the contractors. Temporary cottages had to be built for the workmen, as the accommodation afforded by the local villages of Dalmeny and Kirkliston was insufficient.

Foundation of the Piers

The first task was to secure the foundation of the piers, which were fixed into bed-rock and boulder clay. The masonry work necessarily had to be very substantial and was carried out in cofferdams.

The engineers drove into the ground a circle of heavy piles, filled up the space between the piles with clay, and inside the palisade thus formed erected a framework of timber to strengthen it and to resist the pressure of the water. The water inside was then pumped out and the workmen were able to dig the foundations.

Many difficulties were encountered in this work owing to the sloping nature of some of the foundations on which the piers had to rest, and also because the tides had to be waited for, as much of the work in the centre of the river could only be carried out at low-water of big tides.



The Platforms, after building out the first strut

The cofferdams were about 70 ft. in length and 40 ft. in width, and averaged in depth between 30 ft. and 40 ft. below high water. The whole area of the bottom of the cofferdams was covered with concrete a few feet thick, upon which the masonry was constructed.

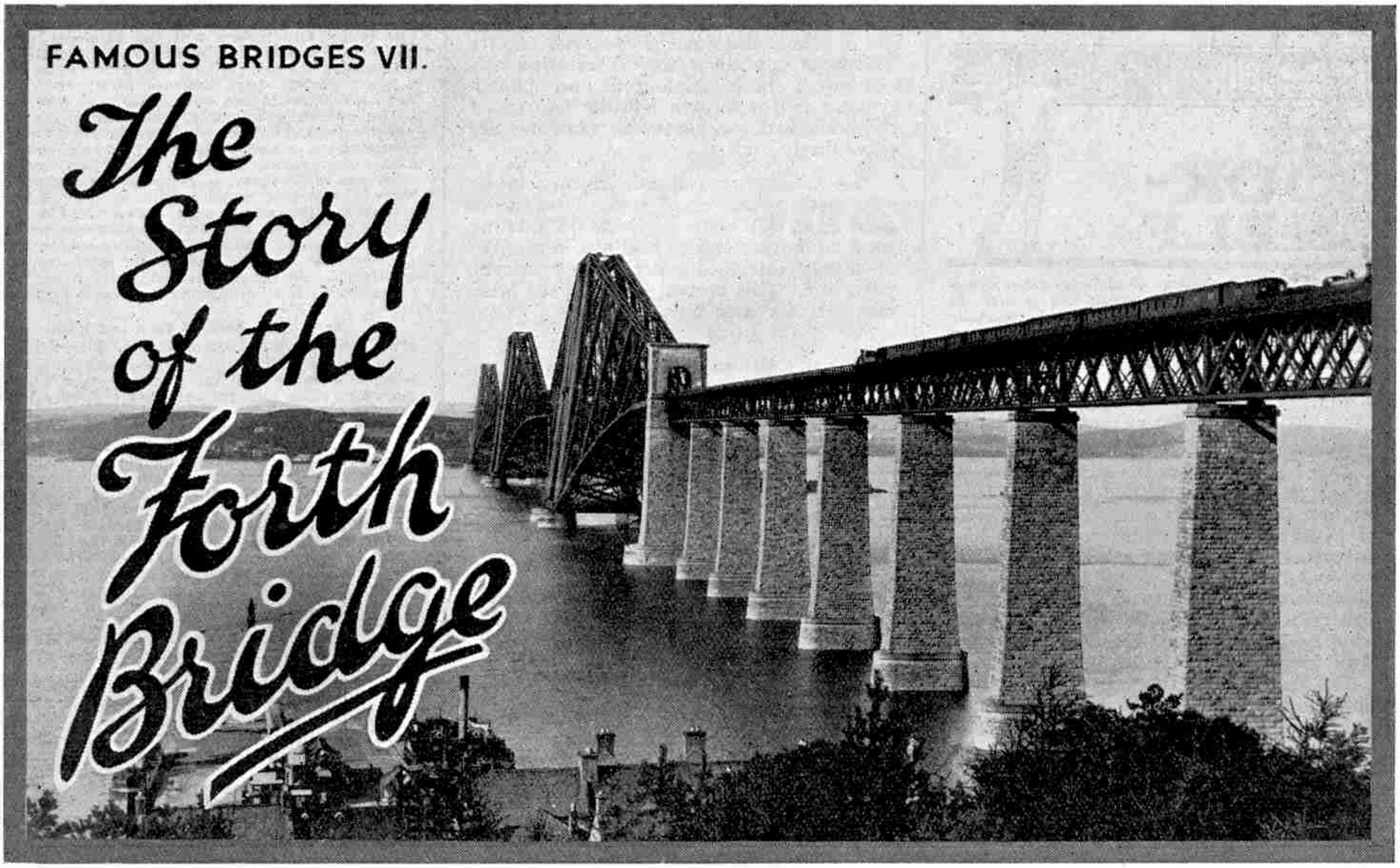
The foundations of the Fife piers, which stood on the mainland, demanded nothing further than straightforward excavation and rock levelling.

Constructing the Caissons

The two southern piers on the island and the four southern or Queensferry piers were constructed by the aid of caissons, huge cylindrical structures closely resembling an ordinary gasometer. They were built in a small bay to the east of the bridge. The structural material was mainly wrought iron, with the exception of the lower or cutting edge which was made of steel.

Each caisson had a floor which formed the roof of the air chamber and was supported from above by a series of girders. Upon this floor and about 7 ft. from the outer skin was an internal skin, the two being braced together in such a manner that the space between them was converted into a series of chambers which, when filled with concrete, were utilised for weighting the caisson at any given point. The caissons were built to a certain height and were then towed into position, where they sank into the boulder clay by pressure.

With one exception all the caissons were built, launched and sunk without any serious mishap, which was a great tribute to the skill and care of all concerned in the operations. This will be realised when it is learned that the average weight of each caisson was about 400 tons, and



PART III.

THE two cantilever piers, one on the Fife shore and the other between 400 and 500 yards from the Queensferry side, are similar in appearance, rising to a total height of 209 ft. above high water. Provision was made in these piers for attaching the end of the cantilever by means of a series of holding-down bolts, anchored securely in the masonry itself, but yet arranged in such a manner as to allow of the horizontal movement produced by expansion and contraction.

Erecting the Cantilevers

Perhaps the most interesting task of all was that of erecting the cantilevers. Commencing with the vertical columns, we first come to the bed-plates. These were composed of several thicknesses of steel and were placed on the piers, supported by blocks, and riveted by hydraulic machinery working simultaneously from both the upper and lower sides. All the rivet heads were countersunk in order to provide a perfectly smooth surface. The bed-plates were then lowered on to the masonry in which holes had been cut previously for the holding-down bolts. In a similar manner the upper bed-plates were put together and placed upon the lower.

These plates provided the base for the "skewbacks," each of which formed the point of the junction of the five different compression members, which were connected with the skewbacks in such a manner as to transfer to them all strains. In any movements of the cantilevers produced by contraction or expansion the skewbacks slid with the upper bed-plates.

When the skewbacks were in position the junctions of the compression members were fitted and the vertical columns and struts were built up to as great a height as the cranes permitted. The height that could be attained in this manner was very limited, and it soon became necessary to adopt some method by which cranes, platforms, etc., could be raised together. Finally an ingenious scheme was put into operation. In the vertical columns, at a height of about 30 ft. above the surface of the pier, one plate was omitted on each side and in the gaps thus formed were built two box girders about 5 ft. by 2 ft. Upon these girders were erected what were known as the lifting platforms, composed of material that was ultimately to be worked into the permanent structure and through which the upper ends of the vertical tubes and struts projected. The actual lifting was done by means of powerful hydraulic jacks.

Last month we dealt with the preparation of the foundations of the Forth Bridge and with the building of the piers. In this article we describe the construction of the giant cantilevers and the final completion of this engineering masterpiece, which stands to-day a fine monument to the imagination of its designers and to the engineering skill of its builders.

An Error of Two Inches

In this manner the work progressed, the structure grew steadily in height and the great arms reached out towards one another.

The building of the giant cantilevers is well described by Mr. W. Westhofen, who was in special charge of the operations on Inchgarvie. In this account he draws attention to the tremendous effects of sun and wind on such a huge structure. He writes :—" By this means was achieved the successful building out of these arms, nearly 700 ft. in length and weighing some 5,400 tons, with an error of only 2 in. For an error there is and, curiously, it exists in nearly all the six cantilevers and in the same direction, namely, to east. Whether this is due to the prevailing westerly winds, and the fact that the total west pressure upon the structure in the course of a twelvemonth must be probably 50 times as great as the total from the east, or whether the fact that the lateral deflections due to the sun's rays are always so much greater from the west than from the east has something to do with it, the writer will not take upon himself to say, but appearances decidedly point in that direction."

The Central Girders

The central girders which connected the cantilever arms resembled in appearance those forming the main spans of the new Tay Viaduct. Each was 350 ft. long and over 30 ft. broad at the rail level, the depth varying from 40 ft. at the point of connection with the cantilever arms of 51 ft. in the centre.

It was a matter of great speculation among the general public as to how these girders were to be erected, and the prevailing idea appears to have been that they would be built on shore, floated out into the river to their positions beneath the ends of the cantilevers and raised to their proper level by hydraulic power. This method had been adopted in the case of Robert Stephenson's Britannia Bridge across the Menai Straits and also in the building of the new Tay Bridge, but it was impossible to adopt it in this case. the amount of traffic passing up and down the river was so great as to make it impossible to close the waterways even temporarily, and it was a condition imposed by the Board of Trade that no such interference with navigation should occur.