FORTH BRIDGE

The Forth Bridge is a cantilever railway bridge across the Firth of Forth in the east of Scotland, 9 miles (14 kilometres) west of central Edinburgh. Completed in 1890, it is considered as a symbol of Scotland (having been voted Scotland's greatest man-made wonder in 2016), and is a UNESCO World Heritage Site. It was designed by English engineers Sir John Fowler and Sir Benjamin Baker. It is sometimes referred to as the Forth Rail Bridge (to distinguish it from the adjacent Forth Road Bridge), although this has never been its official name. Construction of the bridge began in 1882 and it was opened on 4 March 1890 by the Duke of Rothesay, the future Edward VII. The bridge carries the Edinburgh–Aberdeen line across the Forth between the villages of South Queensferry and North Queensferry and has a total length of 8,094 feet (2,467 m). When it opened it had the longest single cantilever bridge span in the world, until 1919 when the Quebec Bridge in Canada was completed. It continues to be the world's secondlongest single cantilever span, with a span of 1,709 feet (521 m).

HISTORY

Before the construction of the bridge, ferries were used to cross the Firth. In 1806, a pair of tunnels, one for each direction, was proposed, and in 1818 James Anderson produced a design for a three-span suspension bridge close to the site of the present one. Calling for approximately 2,500 tonnes (2,500 long tons; 2,800 short tons) of iron, Wilhelm Westhofen said of it "and this quantity distributed over the length would have given it a very light and slender appearance, so light indeed that on a dull day it would hardly have been visible, and after a heavy gale probably no longer to be seen on a clear day either".

For the railway age, Thomas Bouch designed for the Edinburgh and Northern Railway a roll-on/roll-off ferry between Granton and Burntisland that opened in 1850, which proved so successful that another was ordered for the Tay.[9] In late 1863, a joint project between the North British Railway and Edinburgh and Glasgow Railway, which would merge in 1865, appointed Stephenson and Toner to design a bridge for the Forth, but the commission was given to Bouch around six months later.

It had proven difficult to engineer a suspension bridge that was able to carry railway traffic, and Thomas Bouch, engineer to the North British Railway (NBR) and Edinburgh and Glasgow Railway, was in 1863–1864 working on a single-track girder bridge crossing the Forth near Charlestown, where the river is around 2 miles (3.2 km) wide, but mostly relatively shallow. The promoters, however, were concerned about the ability to set foundations in the silty river bottom, as borings had gone as deep as 231 feet (70 m) into the mud without finding any rock, but Bouch conducted experiments to demonstrate that it was possible for the silt to support considerable weight.

CONSTRUCTION

The Bill for the construction of the bridge was passed on 19 May 1882 after an eight-day enquiry, the only objections being from rival railway companies. On 21 December, the contract was let to Sir Thomas Tancred, Mr. T. H. Falkiner and Mr. Joseph Philips, civil engineers and contractor, and Sir William Arrol & Co.. Arrol was a self-made man, who had been apprenticed to a blacksmith at the age of thirteen before going on to have a highly successful business. Tancred was a

professional engineer who had worked with Arrol before, but he would leave the partnership during the course of construction.

The new works took possession of offices and stores erected by Arrol in connection with Bouch's bridge; these were expanded considerably over time.[45] Reginald Middleton took an accurate survey to establish the exact position of the bridge and allow the permanent construction work to commence.

The preparations at South Queensferry were much more substantial, and required the steep hillside to be terraced. Wooden huts and shops for the workmen were put up, as well as more substantial brick houses for the foremen and tenements for leading hands and gangers. Drill roads and workshops were built, as well as a drawing loft 200 by 60 feet (61 by 18 m) to allow full size drawings and templates to be laid out. A cable was also laid across the Forth to allow telephone communication between the centres at South Queensferry, Inchgarvie, and North Queensferry, and girders from the collapsed Tay Bridge were laid across the railway to the west in order to allow access to the ground there. Near the shore a sawmill and cement store were erected, and a substantial jetty around 2,100 feet (640 m) long was started early in 1883, and extended as necessary, and sidings were built to bring railway vehicles among the shops, and cranes set up to allow the loading and movement of material delivered by rail. In April 1883, construction of a landing stage at Inchgarvie commenced. Extant buildings, including fortifications built in the 15th century, were roofed over to increase the available space, and the rock at the west of the island was cut down to a level 7 feet (2.1 m) above high water, and a seawall was built to protect against large waves. In 1884 a compulsory purchase order was obtained for the island, as it was found that previously available area enclosed by the four piers of the bridge was insufficient for the storage of materials. Iron staging reinforced wood in heavily used areas was put up over the island, eventually covering around 10,000 square yards (8,400 m2) and using over 1,000 tonnes (980 long tons; 1,100 short tons) of iron.

The old coastguard station at the Fife end had to be removed to make way for the north-east pier.[48] The rocky shore was levelled to a height of 7 feet (2.1 m) above high water to make way for plant and materials, and huts and other facilities for workmen were set up further inland.

DESIGN

The bridge spans the Forth between the villages of South Queensferry and North Queensferry and has a total length of 8,094 feet (2,467 m)[1] with the double track elevated 150 feet (45.72 m) above the water level at high tide. It consists of two main spans of 1,700 feet (518.16 m), two side spans of 680 ft (207.3 m), and 15 approach spans of 168 ft (51.2 m). Each main span consists of two 680 ft (207.3 m) cantilever arms

supporting a central 350 feet (106.7 m) span truss. The weight of the bridge superstructure was 50,513 long tons (51,324 t), including the 6.5 million rivets used.[23] The bridge also used 640,000 cubic feet (18,122 m3) of granite.
The three great four-tower cantilever structures are 361 feet (110.03 m) tall,[1] each tower resting on a separate granite pier. These were constructed using 70 ft (21 m) diameter caissons; those for the north cantilever and two on the small uninhabited island of Inchgarvie acted as cofferdams, while the remaining two on Inchgarvie and those for the south cantilever, where the river bed was 91 ft (28 m) below high-water level, used compressed air to keep water out of the working chamber at the base. Senior engineer Charles Alton Ellis, collaborating remotely with Moisseiff, was the principal engineer of the project. Moisseiff produced the basic structural design, introducing his "deflection theory" by which a thin, flexible roadway would flex in the wind, greatly reducing stress by transmitting forces via suspension cables to the bridge towers. Although the Golden Gate Bridge design has proved sound, a later Moisseiff design, the original Tacoma Narrows Bridge, collapsed in a strong windstorm soon after it was completed, because of an unexpected aeroelastic flutter. Ellis was also tasked with designing a "bridge within a bridge" in the southern abutment, to avoid the need to demolish Fort Point, a pre–Civil War masonry fortification viewed, even then, as worthy of historic preservation. He penned a graceful steel arch spanning the fort and carrying the roadway to the bridge's southern anchorage.
Ellis was a Greek scholar and mathematician who at one time was a University of Illinois professor of engineering despite having no engineering degree. He eventually earned a degree in civil engineering from the University of Illinois prior to designing the Golden Gate Bridge and spent the last twelve years of his career as a professor at Purdue University. He became an expert in structural design, writing the standard textbook of the time. Ellis did much of the technical and theoretical work that built the bridge, but he received none of the credit in his lifetime. In November 1931, Strauss fired Ellis and replaced him with a former subordinate, Clifford Paine, ostensibly for wasting too much money sending telegrams back and forth to Moisseiff. Ellis, obsessed with the project and unable to find work elsewhere during the Depression, continued working 70 hours per week on an unpaid basis, eventually turning in ten volumes of hand calculations. With an eye toward self-promotion and posterity, Strauss downplayed the contributions of his collaborators who, despite receiving little recognition or compensation,[23] are largely responsible for the final form of the bridge. He succeeded in having himself credited as the person most responsible for the design and vision of the bridge. Only much later were the contributions of the others on the design team properly appreciated. In May 2007, the Golden Gate Bridge District issued a formal report on 70 years of stewardship of the famous bridge and decided to give Ellis major credit for the design of the bridge.