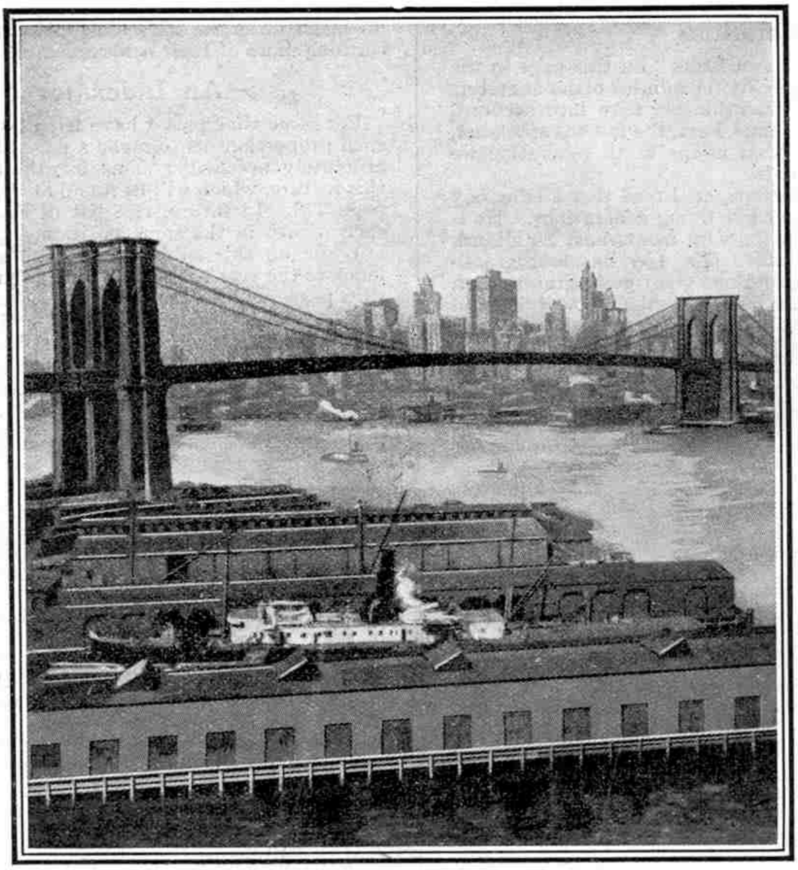
FAMOUS BRIDGES—No. 3

BROOKLYN BRIDGE

The First Large Suspension Bridge

THE East River, separating New York from Brooklyn, is crossed by three of the greatest suspension bridges in existence—the Brooklyn, Manhattan, and the Williamsburgh Bridges, each of which has a fascinating story from an engineering point of view. Of the three, the Brooklyn Bridge, which is the subject of our cover this month, was the first to be built.



Photo] [S.I.B.

The Brooklyn Bridge across the East River

A Pioneer of Wire-rope Making

At the time when the construction of the Brooklyn Bridge was first contemplated, the only means of crossing between New York and the mainland was by ferry boat. In the early eighties, however, the increased traffic between New York and Brooklyn necessitated the introduction of some other means of crossing the river.

Time after time suggestions for various types of bridges had been put forward, but all had been rejected because they were considered impracticable. The East River was both deep and wide and was always so busy with shipping that it was realised that it would be impossible to employ piers on which to rest the girders of any bridge. A single span of so great a width was at that time unheard of, and the construction of a bridge across the East River seemed to be an impossible proposition to put before any engineer.

At last, however, a suspension bridge was suggested by an engineer, who already had considerable experience in this type of structure. The man who launched this daring scheme to bridge the East River was John Augustus Roebling. He was born in 1806 at Mühlhausen in Prussia. He emigrated to the United States in 1831 and ten years later erected a wire-rope works at Pittsburg. He was one of the pioneers of wire-rope making, and to-day the firm he founded is one of the largest wire-rope makers in the world.

He was the first to use the suspension principle in America to support aqueducts for canals. His first suspension bridge, over the River Ohio at Cincinatti, had a length of 1,057 ft. and a height of 103 ft. above the river. It was commenced in 1856 but the American Civil War stopped the work, and the bridge was not opened until 1867. In the meantime Roebling had completed a wire rope bridge across the Niagara Falls, and another at Pittsburg across the Alleghany River.

Roebling's Tragic Death

In his early days Roebling's experience in regard to wire rope bridges was similar to the experience of George Stephenson in regard to railways. Every hand seemed to be against him. His methods and plans were condemned by the leading engineers of the day, who prophesied only failure and disaster for any bridge built on the suspension principle.

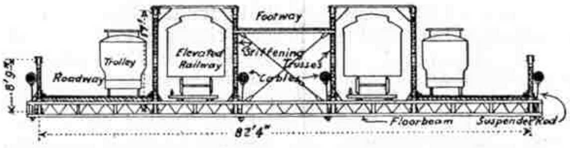


Fig 1. Cross-section of Brooklyn Bridge showing the two roadways, elevated footway, two electric car tracks and two elevated railways

Roebling was a stubborn man, however, and he had full confidence in himself and finally his results themselves proved that his idea of making great bridges with wire was not only possible but also that it was by no means a complicated or difficult matter. Then, and then only, the theory that he had striven so hard to maintain was endorsed by boards of noted engineers and acclaimed by the public. He had had to fight his battles single handed, but in the end his confidence in himself was justified and he came out of the ordeal "on top."

Roebling's death was a terrible tragedy, all the more so for it came just as he had reached the summit of his fame. It occurred in 1869, while the great engineer was inspecting the site for one of the towers. The docking of his boat was bungled by the crew with the result that one of Roebling's feet was crushed between the quayside and the boat, and although the accident was comparatively slight, complications arose that proved fatal.

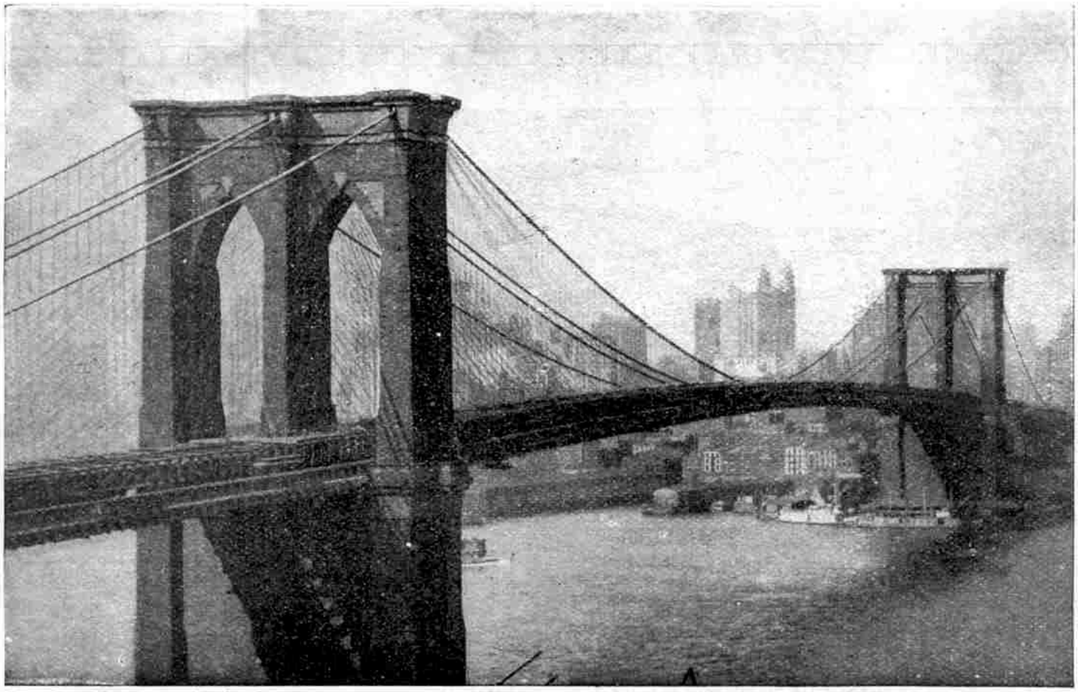
Roebling did not live to see the wonderful structure his imagination had created, but it has been truly said that his name is woven into the very steel of the cables.

His Son Continues the Work

It was a great triumph for Roebling when his plans for the Brooklyn Bridge were accepted in 1867. In May of the same year he was appointed engineer and authorised to proceed with the work. Although he died whilst the bridge was under construction, the work was not allowed to stop, for his son, Washington Augustus, determined to carry out his father's plans.

The actual work did not commence until 1870, but from that time onward until the bridge was completed there was no rest. Washington Roebling lived on the bridge, and under his supervision the massive masonry towers were gradually erected. Old buildings, landmarks of ancient New York, were pulled down and the ground cleared for the approaches. Over six years was required for the construction of the approaches and masonry piers and when at last the towers were completed, there remained the gap across the river to be spanned.

This was accomplished by a boat taking a ¾ in. wire rope from the Brooklyn side to the New York shore, where it was passed over the tower and allowed to drop to the level of the river. Then, at a moment when the channel was free from shipping, the free end was carried across and drawn tight. A second rope was similarly suspended and having been joined to the first, was run over huge pulleys at either end, so that the two together formed an endless belt. To this was fixed a travelling platform, which was moved from one side of the river to the other by steam power.



Reproduced by permission from] [*"Engineering for our Boys"*

The Suspension Bridge, from the Brooklyn Shore, with New York "Sky-Scrapers" in the distance

Contraction and Expansion

These travelling ropes having been fixed, the spinning of the great cables commenced. The wire in each skein of these cables is nearly 200 miles in length and it is not surprising to find that seven years were required to complete the spinning of the cables.

One of the greatest difficulties encountered in this work was the contraction and expansion of the wires, caused by the variation in temperature of the atmosphere. It was very necessary that the wires should all be secured in uniform weather, for every degree of difference in the temperature caused a corresponding deflection in the slack of the cables of ⅓ inch.

At last, however, the great cables were in position and then the roadway itself was built. In 1883, the great day came when the President and the Governor and many other officials attended the opening ceremony, and the work, commenced 13 years before, had its realisation in this, the greatest bridge of its time.

Dimensions of the Bridge

The Bridge has a total length of 5,989 ft. or rather over a mile and a furlong. The central span between the two towers over which the suspension cables hang, is 1,959 ft. in length. The two shore spans from the towers to the anchorages are 930 ft. in length and the approach viaduct on the New York side is 1,562½ ft. in length and on the Brooklyn side 971 ft.

The suspension towers, which are massively built of masonry and stand on two piers built on the solid rock, rise to a height of 272 ft. They extend for 78 ft. below high water level so that they measure 350 ft. from the foundation to the top.

There is a clear headway of 135 ft. between the centre of the bridge and the river, and of 118 ft. near the piers at high water, so that vessels can freely pass beneath.

Details of the Suspension Cables

The four cables each contain 5,296 galvanised steel wires, placed side by side and untwisted. The cables were formed in this manner in preference to the usual method of twisting the wires together, as unbent and untwisted wire has a greater resistance than wire that is twisted. The wires are laid as close together as possible and arranged in nineteen strands, each of which is bound up with thick wire. Each cable has a diameter of 15¾ in. and a breaking strain of 12,000 tons.

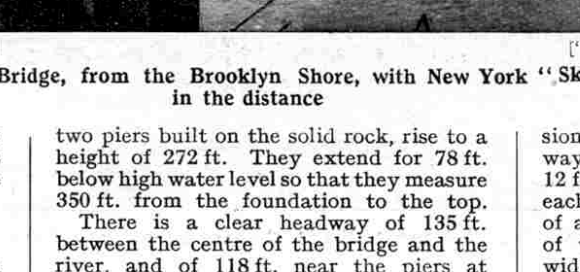


Fig. 2. Section of the top of one of the towers, showing saddle over which the main cable passes*

(*Figs. 1 and 2 are reproduced, by permission of the publishers, from the Editor's book "Engineering for Boys")

The cables have a dip of 128 ft. in the centre of the large span and they rest on moveable saddles at the top of the towers (see Fig. 2). These saddles allow for slight movements of expansion and contraction in the cables, due to changes of temperature and alterations in load.

The cables are anchored at each end by massive masonry built on the shore, and supplementary cables, extending fan-like on each side of the towers, assist in supporting the shore spans and the portion of the long span roadway nearest the towers. They also brace the roadway and reduce its deflection under heavy loads.

The Seven Divisions

The roadway of the Bridge is 82 ft. 4 in. in width and is separated into seven divisions. The centre track forms a footway and is 15½ ft. in width and is raised 12 ft. above the level of the bridge. On each side of the footway are the rails of an elevated railway and on each side of these tracks are roadways 19 ft. in width, each of which has a trolley car track and a road for vehicles.

The Bridge thus carries two roadways, two trolley-car tracks, two railway tracks, and an elevated footway.

Opened in 1883, the Bridge remained by far the largest span in the world for seven years. It was deprived of its proud position in 1890 by the Forth Bridge, two spans of which exceed the large span of the Brooklyn bridge by 115ft.

The Brooklyn Bridge, as is the case with most suspension bridges, is a graceful structure. It cost about £3,100,000 or about three times the original estimate.

Effects of Modern Traffic

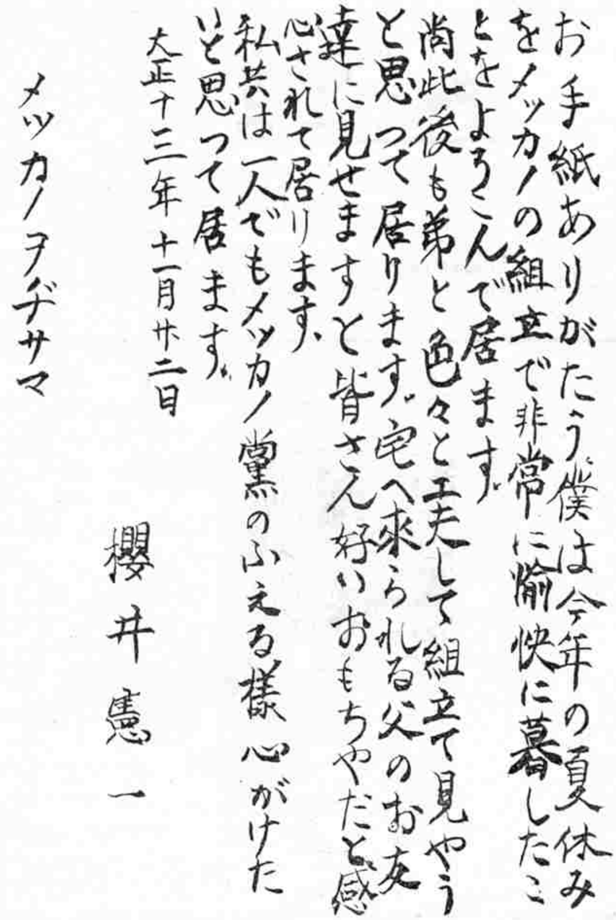
When the bridge was built it was not expected that it would be required to carry the heavy railway rolling stock and electric cars of to-day, and consequently it was not constructed to withstand so great a strain of modern traffic.

Thus it is not surprising that in 1901 several of the short rods suspending the trusses from the cables were found to have snapped. It was then decided that the bridge needed strengthening in all its details.

This work was successfully carried out and the bridge to-day is as strong as ever and likely to remain in use for many years, if no accident occurs to it.

It really was fortunate that his father had expected this, and enclosed a translation, as otherwise there would have been some considerable delay in our discovering the meaning of the letter!

This is what Kenichi wrote to us, reproduced exactly as it appears, each letter and each word a work of art in itself.



お手紙ありがたう僕は今年の夏休みをメッカノの組立で非常に愉快に暮したことをよろこんで居ます、尚此後も弟と色々と工夫して組立て見やうと思つて居ります、宅へ来られる父のお友達に見せますと皆さん好いおもちやだと感心されて居ります、

私共は一人でもメッカノ黨のふえる様心がけたいと思つて居ます、

大正十三年十一月廿二日

櫻井憲一

メッカノヲヂサマ

Kenichi Sakurai's Letter to the Editor of the "M.M."

" Dear Uncle Meccano,

" I thank you for your letter. I am delighted to say that I have had most pleasant times throughout my last summer vacation in working up your Meccano models. And from now on I am going to continue this interesting work, together with my brother, making interesting structures to the best of our ability.

" I always show the models to the friends of my father when they call, and am very pleased to hear their admiration of the excellent toy.

" To increase the number of Meccano engineers is our wish, and we are always keeping it in our mind."

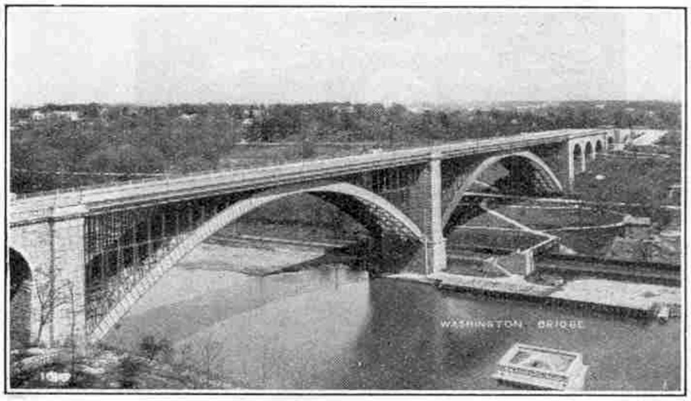
Yours truly,

Kenichi Sakurai.

We know that Meccano boys in all parts of the world will join in extending the hand of good-fellowship to our little friends, thousands of miles away in Sunny Japan. We welcome them to Meccanoland and hope that there are many happy days in store for them.

FAMOUS BRIDGES—No 4

Washington Bridge and High Bridge, New York



Our cover this month shows two famous bridges, Washington Bridge in the foreground and High Bridge in the distance beyond.

Washington Bridge, to which a brief reference was made in our article last month, was constructed at a cost of over £600,000 and required two years to complete. Work was commenced in July 1886 and the Bridge opened for traffic in December 1888.

The Bridge crosses the River Hudson from Manhattan to New York, at a point where the river is 400 ft. in width. It is built in two tremendous steel arches, the span of each being 508 ft. One arch spans the river and the other bridges the land adjoining the water's edge. There is a clearance of 133 ft. under the bridge at high water, the length of the whole structure from end to end—including the masonry approaches—being 2,375 ft. and the width 86 ft. 7 in.

The accompanying photograph, published by the courtesy of the Department of Plant and Structures City of New York, gives an excellent idea of the unusual grace and beauty of this bridge and of the length of the two steel arches. The Bridge is, indeed, an excellent instance showing how nothing of beauty and grace of line need be sacrificed to gain requisite strength.

High Bridge, New York

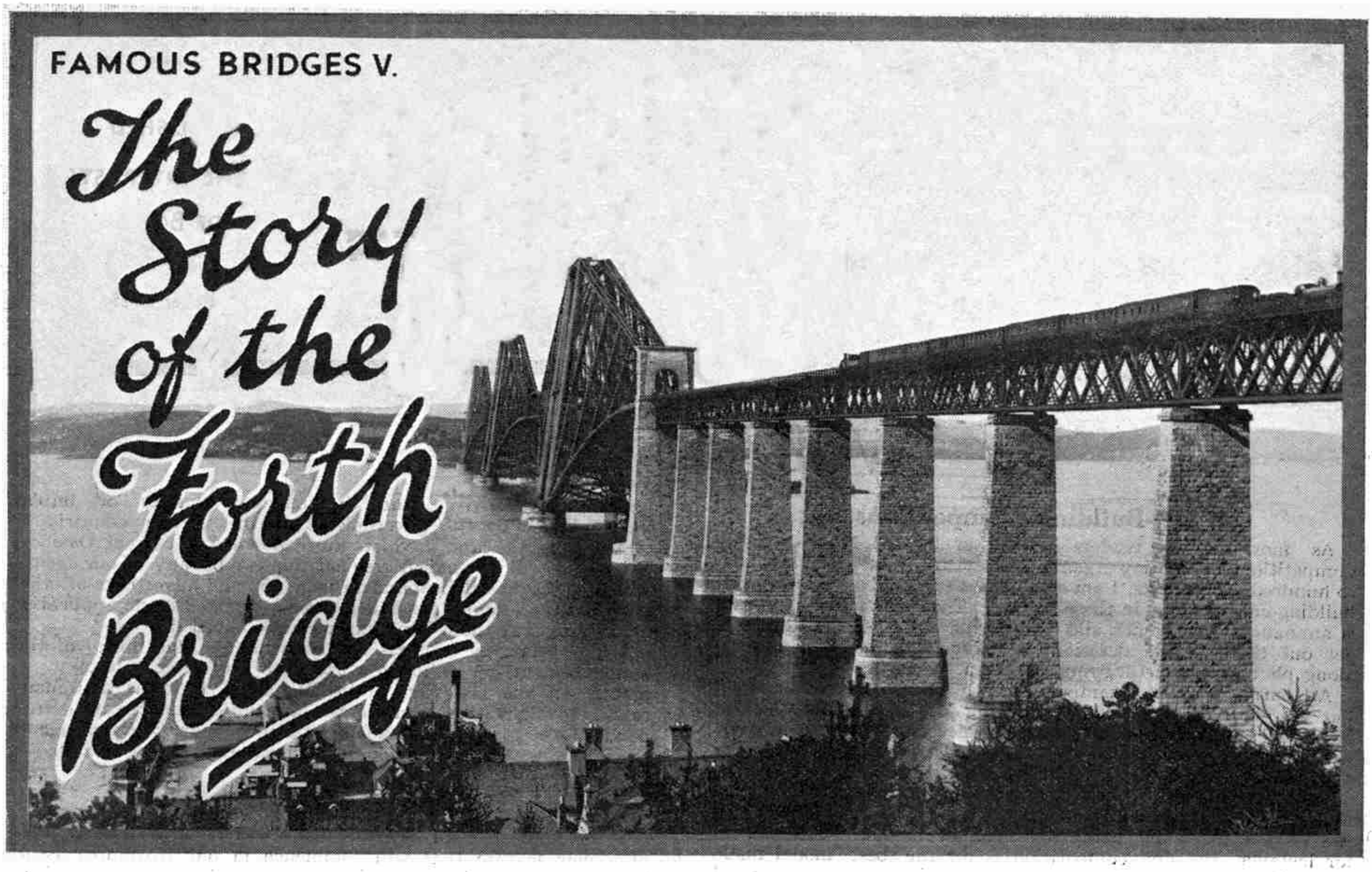
The many-arched bridge in the background on our cover design is the High Bridge. This bridge was built in 1848, as part of the old Croton Aqueduct and carries three water mains with a water-carrying capacity of 90,000,000 gallons of water per day.

The Federal Government consider this bridge a menace to navigation, and plans have now been made for the removal of four of the masonry piers. These will be substituted by a steel cantilever arch of 420 ft. span with a rise of 103 ft., leaving an unobstructed waterway and removing the menace to navigation.

A depth of 15 ft. of water is provided at low water and the estimated cost of remodelling the Bridge is £200,000. The new steel arch, a cantilever, will be sprung from rock to rock, and will eliminate any danger of the future settling of High Bridge.

FAMOUS BRIDGES V.

The Story of the Forth Bridge



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.

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.

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.

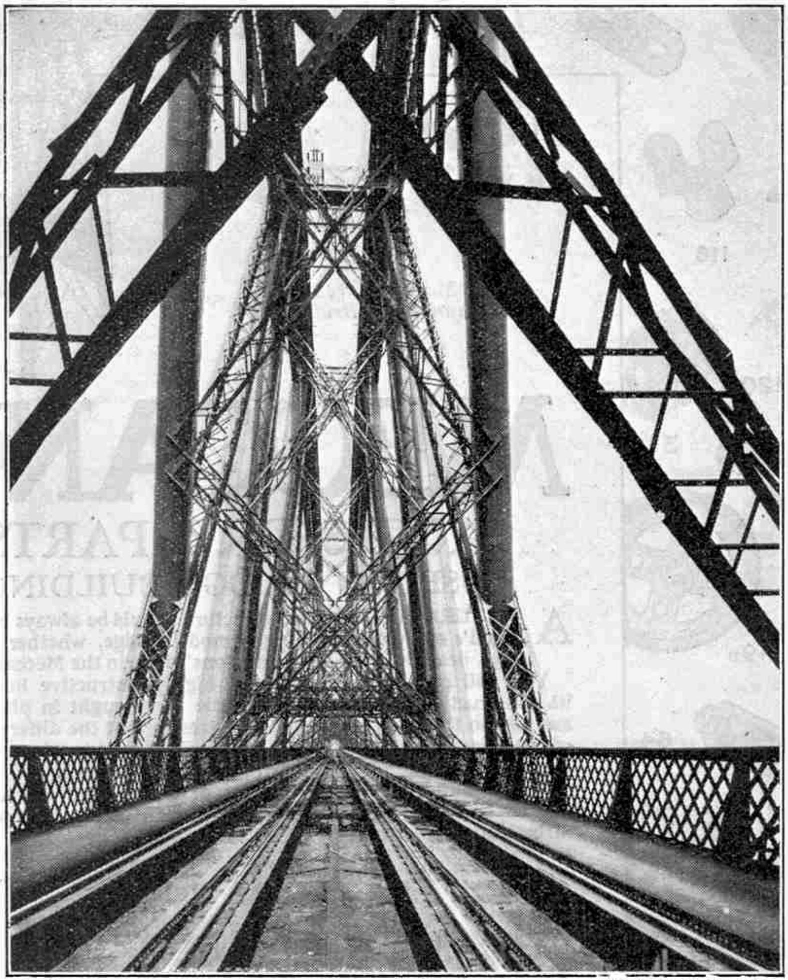
The Tay Bridge Disaster

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.

The Cantilever Principle

In order to appreciate fully the magnificence of the Forth Bridge it is necessary to know something of the principle of the cantilever. The name is derived from the French "*cant*" meaning angle and "*lever*" to raise. The principle is a very old one, having been used hundreds of years ago in China, Japan and India. These early structures were, of course, very primitive, and the type developed little until comparatively recent years.



Photo] [Photochrom Co. Ltd.

On the Forth Bridge, showing the Massive Tubular Girders and the cross-bracings of lattice-braced girders

An excellent description of the cantilever principle was given by Sir Benjamin Baker at the Royal Institution in the course of a lecture on the Forth Bridge. On this occasion the lecturer exhibited what he called a living model of the Forth Bridge arranged as follows:—

"Two men sitting on chairs extended their arms and supported the same by grasping sticks butting against the chairs. This represented the two double cantilevers. The central beam was represented by a short stick slung from the near hands of the two men, and the anchorages of the cantilevers by ropes extending from the other hands of the men to a couple of piles of bricks. When stresses were brought to bear on this system by a load on the central beam, the men's arms and the anchorage ropes came into tension, and the sticks and chair legs into compression.

"In the Forth Bridge it is to be imagined that the chairs are placed one-third of a mile apart; that the men's heads are 340 feet above the ground; that the pull on each arm is about 4,000 tons; the thrust on each stick over 6,000 tons, and the weight on the legs of the chair over 25,000 tons."

The diagram on page 497 illustrates well the foregoing description and if carefully examined will make the principle quite clear. The great advantage of the cantilever system is that it permits the cantilever arms to be built out in pairs on each side of their towers in such a manner as to balance one another during construction, thus rendering external support unnecessary.

The Forth Bridge as erected consists of two approach viaducts; three double cantilevers resting on two piers near the shore and on a central pier on the island; and two pairs of girders spanning the intervals between the ends of the central and side cantilevers over the channels. The South Approach viaduct has ten spans of 168 ft. each and four arches of 66 ft. each, and the North Approach viaduct has five spans of 168 ft. and three arches of various sizes.

Constructional Details

The cantilever portion of the bridge includes three huge double cantilevers and two intervening suspended spans. This portion of the bridge measures about 5,349 ft. 6 in. The cantilevers are symmetrical steel structures rising 361 ft. above high water level, that is nearly as high as St. Paul's Cathedral. They are composed of a central portion over the piers from which two cantilever arms extend out on each side for a distance of 680 ft., tapering at their extremities, both horizontally and vertically.

The central portions of the cantilevers consist of four columns each resting upon a circular granite pier. These piers are 120 ft. apart at the base and 33 ft. apart at the summit. Longitudinally, the columns of the central pier on the rock island of Inchgarvie are 260 ft. apart from bottom to top, while those of the two side piers are 145 ft. apart. The vertical columns are connected at the top and the bottom and braced together horizontally and vertically. The cantilever arms are composed of two curved steel tubes at the bottom in compression and two flanged lattice steel ties at the top, in tension, braced together vertically and horizontally.

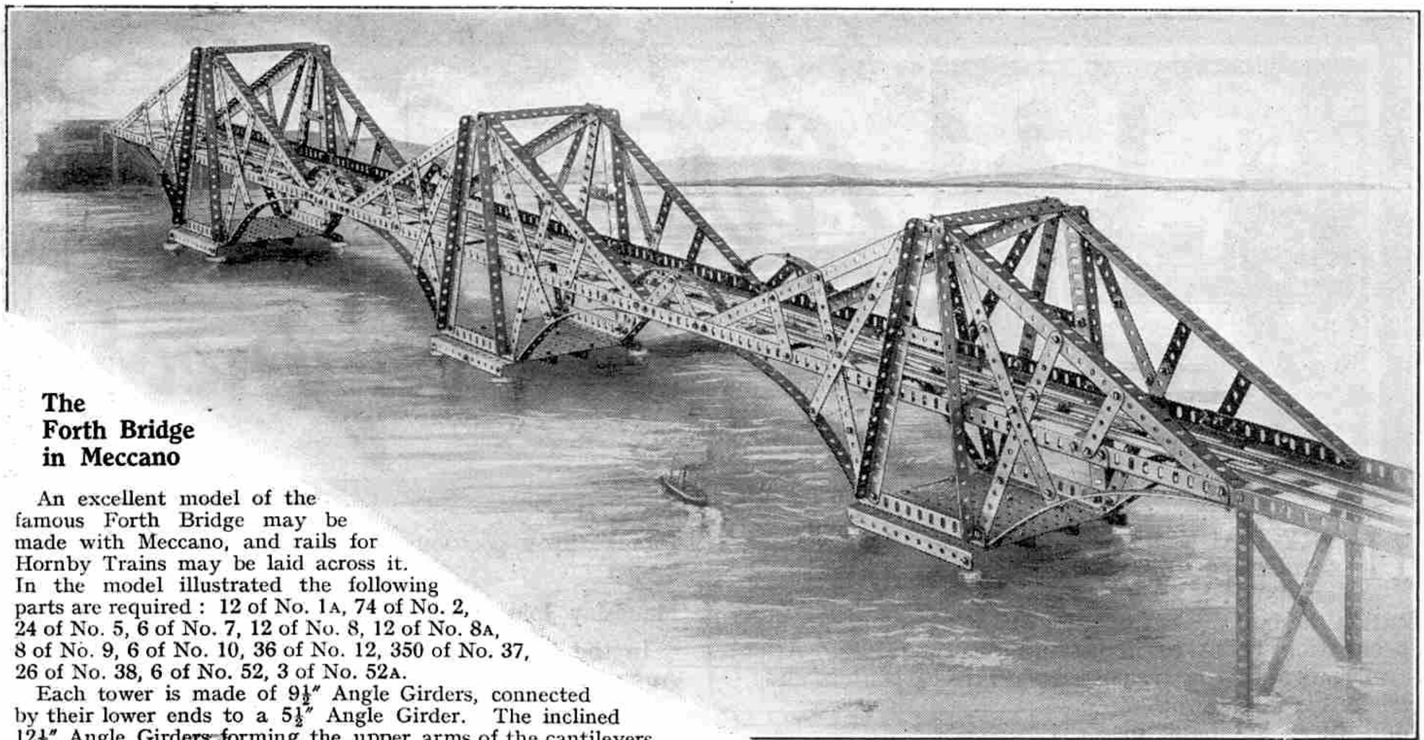
The ends of the cantilevers reaching out over the channels serve to support girders of 350 ft. span which complete the communication between the cantilevers over the channels, cantilevers and girders together forming a bridge with two clear openings of 1,710 ft. between the piers.

Two lines of railway with a footpath on each side run through the cantilever arms.

Millions of Rivets

The total length of the bridge, together with the approach viaducts, is about 8,296 ft., and the piers carry a total weight of 50,958 tons of steel. Sir Benjamin Baker stated that six battleships could be safely suspended from the cantilever ends. The superstructure contains about 6½ million rivets; 65,000 cubic

(*Continued on page* 497)



The Forth Bridge in Meccano

An excellent model of the famous Forth Bridge may be made with Meccano, and rails for Hornby Trains may be laid across it. In the model illustrated the following parts are required : 12 of No. 1A, 74 of No. 2, 24 of No. 5, 6 of No. 7, 12 of No. 8, 12 of No. 8A, 8 of No. 9, 6 of No. 10, 36 of No. 12, 350 of No. 37, 26 of No. 38, 6 of No. 52, 3 of No. 52A.

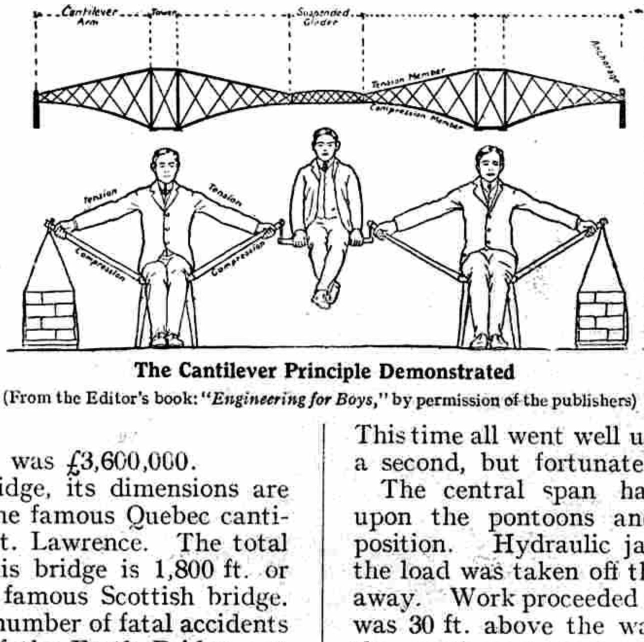
Each tower is made of 9½" Angle Girders, connected by their lower ends to a 5½" Angle Girder. The inclined 12½" Angle Girders forming the upper arms of the cantilevers are connected to the top holes of the tower girders, which are coupled by Flat Brackets, and at their lower outer ends to horizontal Angle Girders. The horizontal girders are connected across by 5½" Strips disposed at intervals of about 11 holes apart. On these are secured gauge 0 track rails, held to the cross strips by bolts, beneath the heads of which are Washers engaging the lower flange of the track rails and binding them on to the cross strips.

The bases of the towers are formed by two 5½" Flanged Plates coupled at the centre by a 5½" Flat Plate.

The Story of the Forth Bridge—*(continued from page 495)*

yards of concrete ; 49,000 cubic yards of rubble and 750,000 cubic feet of granite. The Inchgarvie tower contains about 7,036 tons of steel and the other towers each about 4,815 tons.

The bridge is painted once every three years and the extent of this task may be realised from the fact that the total area to be painted inside and outside is 145 acres. The whole of the outer surface of the bridge was covered five times during construction—once with boiled linseed oil, twice with red lead and twice with oxide of iron paint. The total building period was about seven years and at the busiest times no less than 4,600 workmen were employed. As might be expected, the building of such a huge structure involved many dangerous operations. During the whole period of construction 57 fatal accidents occurred and 106 serious but not fatal accidents.



The Cantilever Principle Demonstrated

(From the Editor's book: "*Engineering for Boys*," by permission of the publishers)

The total cost of the bridge was £3,600,000.

Gigantic as is the Forth Bridge, its dimensions are exceeded in some respects by the famous Quebec cantilever bridge across the River St. Lawrence. The total length of the main span of this bridge is 1,800 ft. or 90 ft. greater than that of the famous Scottish bridge.

Although, as we have seen, a number of fatal accidents occurred during the building of the Forth Bridge, yet from first to last the work proceeded without any great disaster. In this respect the Quebec Bridge presents a great contrast.

The first bridge was commenced in 1900 and the sub-structure was completed two years later. From that time the erection of the steelwork proceeded rapidly and without interruption until 29th August, 1907, when a terrible disaster occurred. On the afternoon of that day, while work was in full progress, the lower chords in the anchor arms buckled up without any warning and 17,000 tons of steel collapsed with a report that was heard many miles away. The 86 men working on the arm at the time went down with it and of these only 11 were saved. This terrible accident came as a great shock to the engineering world, and it made a profound impression on the general public.

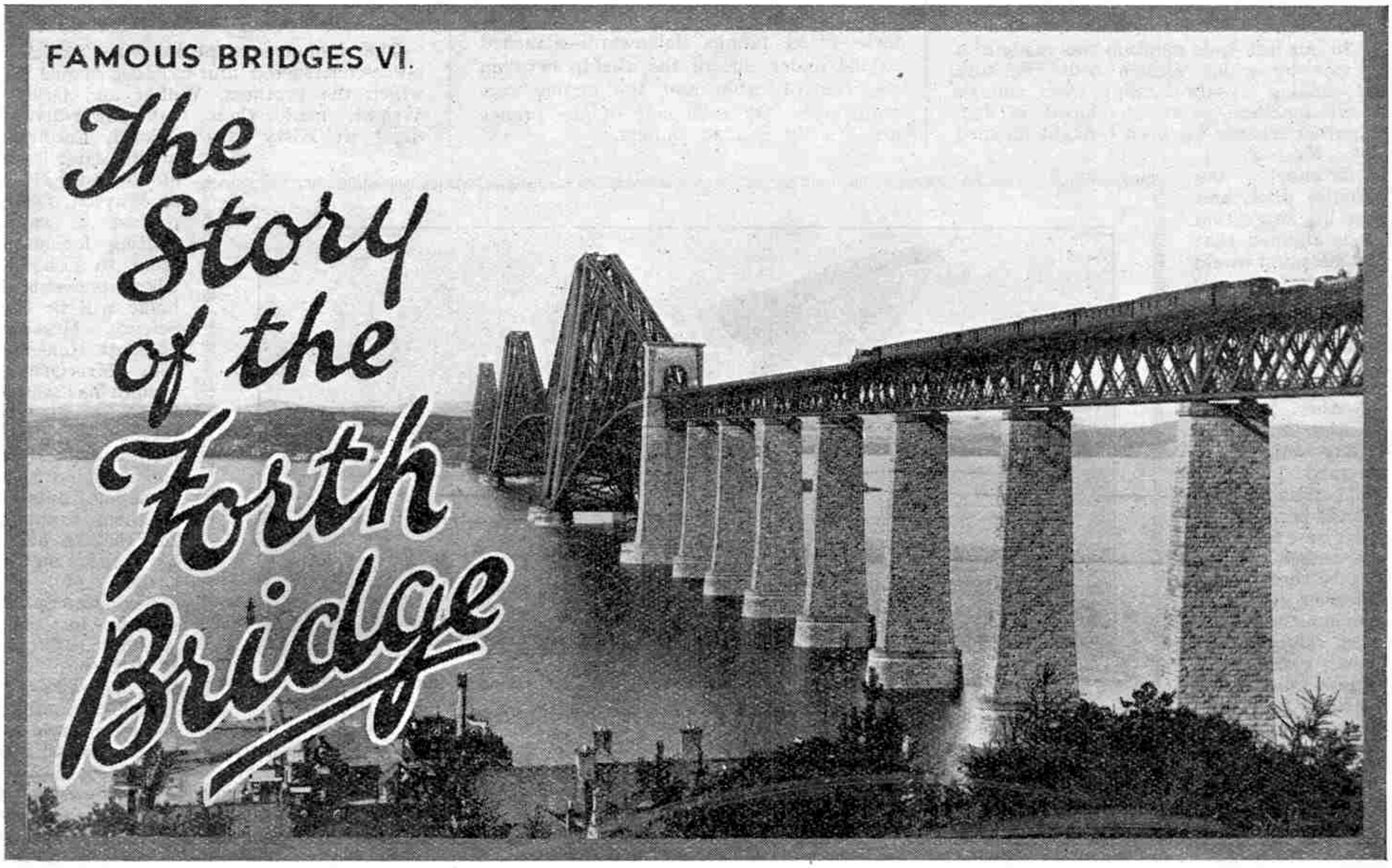
Matters were not allowed to remain there, however, and after the causes of the disaster had been carefully investigated, preparations were made for building a new bridge and two years later work was commenced. This time all went well until 11th September, 1916, when a second, but fortunately less serious disaster occurred.

The central span had been floated into position upon the pontoons and the hoisting chains were in position. Hydraulic jacks then raised the span until the load was taken off the pontoons, which then floated away. Work proceeded according to plan until the span was 30 ft. above the water, when something failed at the south-west corner. With a terrible crash that corner dropped into the water, and desperate efforts made to prevent its further progress were without avail.

(To be continued)

FAMOUS BRIDGES VI.

The Story of the Forth Bridge



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.

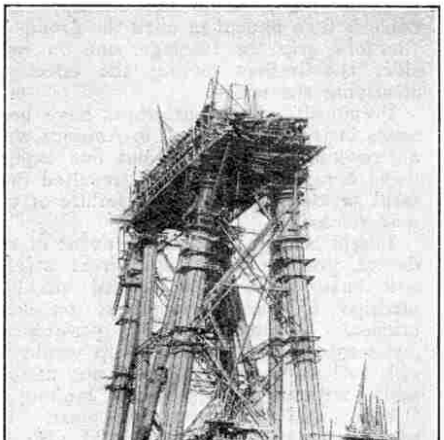
In addition to all this, steamers, barges and boats of all kinds ; cranes, steam and hydraulic, and a bewildering amount of machinery for drilling, lighting, pumping, riveting, etc., had to be provided. Many of these machines were specially designed for the work by the contractors. Temporary cottages 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

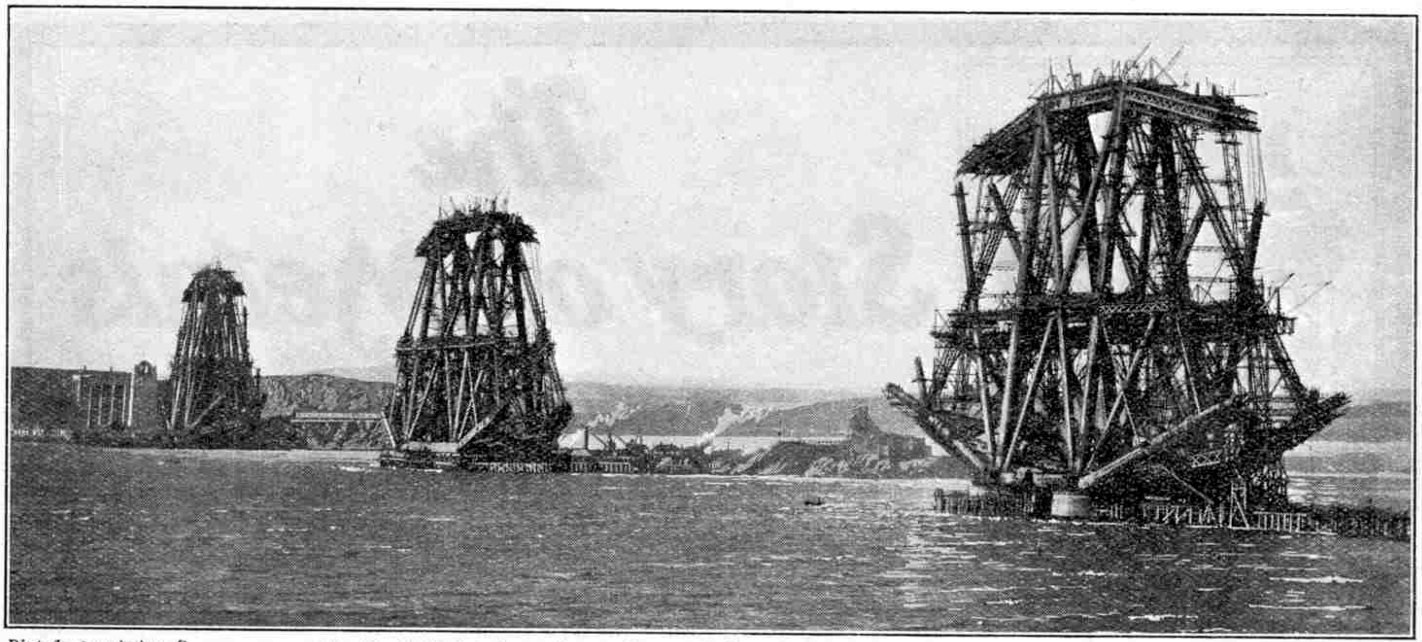


Photo by permission of] **The Forth Bridge from the south-west before the cantilevers were built out** *[Messrs. Baker and Hurtzig, Westminster*

when loaded with concrete this weight was increased to about 15,000 tons.

Working by Compressed Air

The height of the permanent caissons was not sufficient to keep out the water at high tide and to serve this purpose temporary iron segments were bolted on. On a level with the top of these segments a platform was erected from which most of the operations were carried out. From the floor of the caisson to this platform three shafts were constructed. Two of these were for the purpose of handling materials and the third provided the means by which the men entered and left the air chamber.

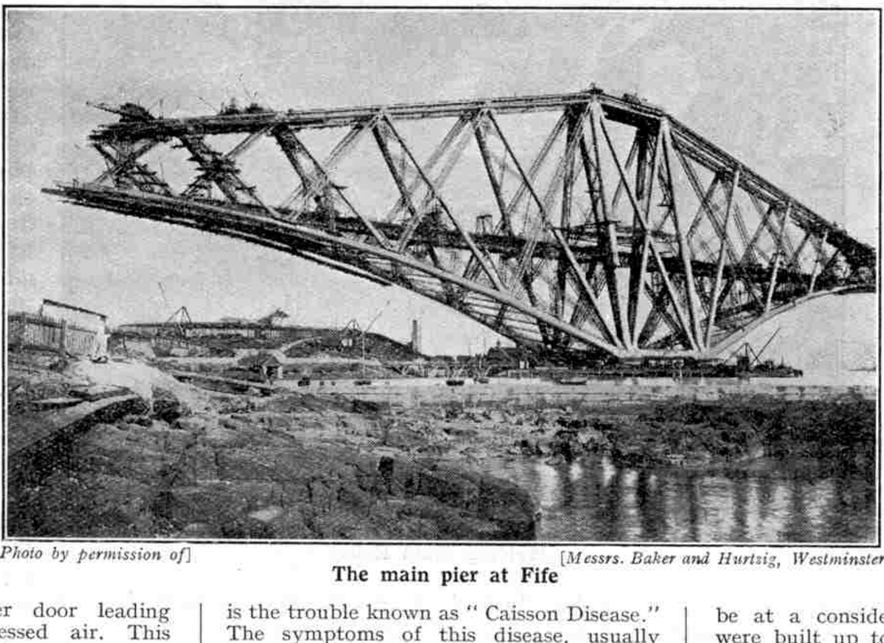


Photo by permission of] *[Messrs. Baker and Hurtzig, Westminster*

The main pier at Fife

The lower chamber had no bottom, and therefore as the shafts by which it was connected with the air were open, it is obvious that, until steps were taken to prevent it, water would rise in them to the level at which it stood outside. Before the men could descend to work, this water had to be expelled, and this was carried out by compressed air.

When the compressors had provided the pressure necessary to drive out and keep out the water from the air chamber, the men descended into an air lock and found themselves in a chamber containing an inner door leading directly to the compressed air. This inner door was held fast by a pressure of many tons from within, and before it could be opened the pressure in the two chambers had to be equalised. This was effected by closing the outer door and admitting compressed air through a valve until the outer door was held fast by the increased pressure. At this stage the pressure in the two chambers was the same, the inner door swung open and the workmen were able to continue their descent by means of iron ladders.

Caisson Disease

Working in compressed air has certain decided disadvantages. The large supply of oxygen enables the men to work with unusual energy, but the strain is severe and only men of thoroughly strong physique are able to withstand it for long. The density of the air produces many curious effects, such as exaggerating noises to an almost alarming extent. Voices too, sound harsh and quite different from their normal tones. The worst feature of all, however, is the trouble known as " Caisson Disease." The symptoms of this disease, usually intensely severe pains in the joints, are felt when the air pressure is reduced to normal, and the mischief is caused by an excessive amount of nitrogen being absorbed by the blood. If the transition from high pressure to normal pressure is performed very slowly and gradually there is little inconvenience, but if the process is hurried the results are extremely unpleasant.

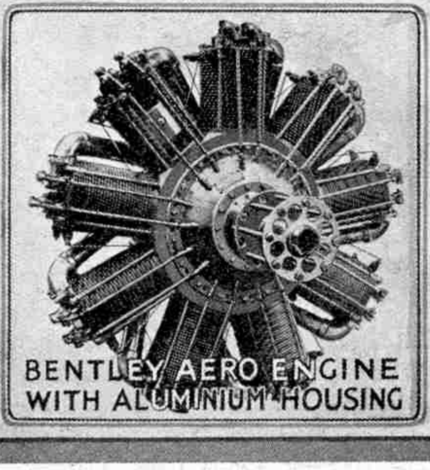
The main difficulty experienced was to make the men stay in the air locks while the pressure was gradually reduced and the unwanted nitrogen expelled by means of the lungs. When a man had neglected the necessary precautions and on reaching the open air was attacked by caisson disease, the only method of affording him relief was to carry him back into one of the air locks and increase the pressure again, subsequently reducing it very slowly and gradually. It is stated, whether truly or not, that some of the men employed in the Forth Bridge caissons suffered so much from caisson disease that they were only too glad to spend their Sundays in the air locks in order to obtain relief !

The one exception to the successful sinking of the caissons was due mainly to the slope of the river bed at that particular point. This particular caisson was watched with anxiety from the first, and although every possible care was taken it heeled over so far as to permit the rising tide to create an amount of damage that took some months to repair.

Viaduct Piers

The rail level of the bridge having been fixed at 150 ft. above high water, it was necessary that the viaducts connecting the cantilevers with the two shores should also be at a considerable height. The piers were built up to a certain level and the girders were put together on a sort of stage a few feet above each pier. The steelwork was then raised by hydraulic jacks, each capable of lifting some 200 tons if necessary. Each jack was connected with pumping engines in such a manner that all worked together. When pressure was applied to the jacks the girders were raised, and packings of

(Continued on page 584)



The Story of Metals

V. ALUMINIUM.

LAST month we gave a brief outline of the history of the metal Aluminium and of the method employed for its production from Bauxite. In the following article we shall deal with a few of the many applications of this interesting metal and its alloys.

Pure aluminium is naturally a soft and weak metal. Its most remarkable feature is that of lightness, and during recent years a great deal of research has been carried out with the object of discovering alloys of the metal which, while preserving to a great extent its quality of lightness, have in addition the valuable quality of high tensile strength.

Copper and Zinc Alloys

Copper and zinc are the metals mostly used along with aluminium. Alloys of zinc are cheaper to produce than copper alloys, but they are inferior in many important respects. The well-known alloy Duralumin, which was discovered in 1910 by a German named Wilm, possesses lightness together with great tensile strength. This alloy consists of a little over 94 per cent. aluminium and about 4 per cent. copper, with small quantities of iron, manganese, magnesium and silicon. Duralumin is an alloy of very great value, but alloys of copper, magnesium and aluminium have been prepared in England which possess even greater tensile strength.

Photo courtesy] [*Messrs. Thermit Ltd.*

Welding Tram Rails

Aircraft and Automobiles

Aluminium alloys to-day occupy a very important place in the construction of aircraft and automobiles. During the war the application of such alloys to aeroplanes was pushed forward with great rapidity, mainly in order to obtain strength with lightness, but also to make it possible to produce an all-metal machine and thus fire-proof. The successful development of airships has been made possible largely by the use of aluminium alloys, notably Duralumin. These are used for the construction of almost the whole of the framework and the cars to carry the crew, and they also enter largely into construction of the power units.

The use of aluminium alloys in the engines of aircraft and automobiles has developed in a very remarkable manner. There are few parts of the modern car engine for which aluminium cannot be used and in most cases with distinct advantage. To-day we find aluminium cylinder blocks, crank cases, pistons and connecting rods. One result has been the attainment of an extraordinarily low weight-power ratio, and also the high thermal conductivity of aluminium has proved of great advantage. A steel piston may be made even lighter than an aluminium piston, but the heat generated in the combustion chamber is not so rapidly conducted to the walls of the cylinder as is the case with aluminium. This advantage becomes even more marked at very high temperatures because the thermal conductivity of aluminium alloys increases with temperature, whereas that of cast iron and steel decreases.

The saving in weight resulting from the introduction of aluminium is well-illustrated by the fact that a rear axle made of this metal will weigh something like 33 per cent. less than a similar axle made in steel, and this including the parts that of necessity are made in steel. The remarkable results obtainable by the

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Obtain a copy of the Christmas number of the *Meccano Magazine*, which will be ready on 9th December, look at *all* the articles advertised and then decide which you would like the postman to hand to you on Christmas morning. Write the name of it on the top of your postcard, marking it No. 1. Then write the name of the article that you would like second best and mark it No. 2. Do this with six articles altogether, write your name and address at the bottom in very plain letters, and send the postcard to "Christmas Presents, *Meccano Magazine*, Binns Road, Liverpool."

To the boy whose list corresponds most nearly in order of merit with the total voting we will post the article that heads his list, to reach him on Christmas morning.

"Christmas Presents" postcards must reach us not later than 18th December.

Lives of Famous Engineers—

(*Continued from page* 559)

degree upset there was always the danger of a splash of hot metal, which frequently set the men's clothes on fire or caused terrible scalds and burns.

Nasmyth's safety ladle was designed to prevent these accidents. He applied a screw wheel keyed to the trunnions of the ladle, which was acted upon by an endless screw attached to the sling of the ladle. By this arrangement one man could move on its axis the largest ladle and pour out its contents with perfect safety, at the same time securing better castings by means of the increased steadiness of the flow of metal into the mould.

Another improvement brought about by Nasmyth was the fixing of a skimmer to the edge of the ladle to keep back the dross or slag floating on the surface of the molten metal. This process also was previously done by hand and many accidents occurred in consequence. Nasmyth did not patent these inventions, but preferred to make them over to the public.

The Story of the Forth Bridge—

(*Continued from page* 581)

hard wood were placed beneath them to hold them in position while the jacks were moved to a new bearing, when a second lift was made. By repeating this process the lifting of the girders and the building of the masonry proceeded until the required height was attained. The building of the masonry between each lift, including the time required for setting of the work on one half of the pier before the other was commenced, was carried upward at the rate of about 9 ft. on each pier per month. As the girders were ultimately raised to 150 ft. above high water, and as each lift was only about 3 ft. 6 in., the time occupied in the process was considerable. The first lift was made in April 1886 and the last in April 1887. The steel girders used were of the ordinary lattice type having a depth of 22 ft. 6 in.

The Conquest of the Air—(*cont. from p.* 585)

The petrol tank is fitted in rather a novel position, it being incorporated in the upper wing of the machine. It will be clearly seen from our illustration that part of the upper wing above the fuselage is a metal tank, and it is here that the petrol is stored, being fed to the engine by gravity.

An improvement has been made in the tail skid, so that better control on the ground is obtained, and any sudden stress on the rudder bar prevented.

The machine is fitted with a seaplane undercarriage for use with either normal or large wings. The undercarriage is interchangeable and special provision is made in the fuselage for hoisting so that the machine may be lifted by crane or derrick from the sea without damage.

Dimensions of the
Fokker C.V Aeroplane

	Normal	*Small*	*Large Wings*
Wing Area ...	48.68 sq. yds.	43.65 sq. yds.	55 sq. yds.
Span ...	42.04 ft.	40.55 ft.	48.25 ft.
Length ...	30.35 ,,	30.35 ,,	30.64 ,,
Height ...	10.86 ,,	10.77 ,,	11.09 ,,
Weight empty	3,160 lbs.	3.050 lbs.	3.271 lbs.
,, laden	4,928 ,,	4,376 ,,	5,481 ,,
,, per h.p.	10.0 ,,	9.72 ,,	12.16 ,,
Speed (max.)	137.4 m.p.h.	143.7 m.p.h.	131.2 m.p.h.

Meccano Platform Scales—

(*Continued from page* 565)

suspended by means of Flat Brackets 20 and Hook 21, connects with the levers 23 in the base of the model (Fig. C, page 565). These levers are pivoted on Hooks 24 and carry a central 3" Rod 25 from which hangs a link 26 consisting of a Double Bracket and ¾" Bolt. This link supports a further Rod 27 carried in the ends of another pair of levers 28 pivoted to the Hooks 28A. The 6½" Rods 29 and 30, on which the Hooks are mounted, are journalled in the framework of the base.

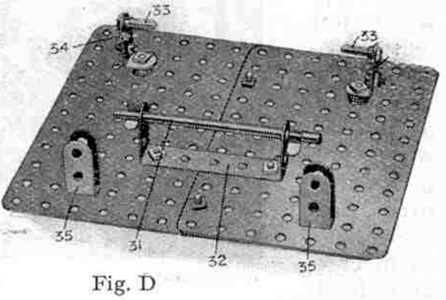


Fig. D

The platform, shown inverted in Fig. D, is composed of two large Flat Plates overlapped one hole and secured together; the Axle Rod 31 carried in a Double Angle Strip 32 rests upon the levers 23, while the Threaded Pins 33 bolted in 1" by ½" Angle Brackets 34 rest upon the levers 28. Two Washers are placed on the bolts underneath each end of the Double Angle Strip 32 and four Washers are placed beneath each of the brackets 34. Single Bent Strips 35 form guides for the platform and fit over the Rod 30 in the base.

A weight 36 consisting of a Strip Coupling, short Rod, and ¾" Pinion slides along the steelyard 1 and carries a small pointer, cut from cardboard, which indicates the load being weighed by means of the graduated rule 37. A piece of cardboard 38 cut in the form of an arrow may be bolted to a 1" Reversed Angle Bracket 39 and arranged to rest against the cardboard indicator 40 when the scales are exactly balanced.

When the model is complete, and before commencing to weigh, care should be taken in balancing the steelyard by means of the weight 11 and adjustment 15, so that the arrow 38 rests on the line at 40 when the sliding weight 36 is at the "O" mark in the rule 37.

The graduated scale may be prepared by placing known weights on the platform, and accurately marking the position at which the sliding weight 36 must point in order to maintain the arrow 38 dead on the line at 40.

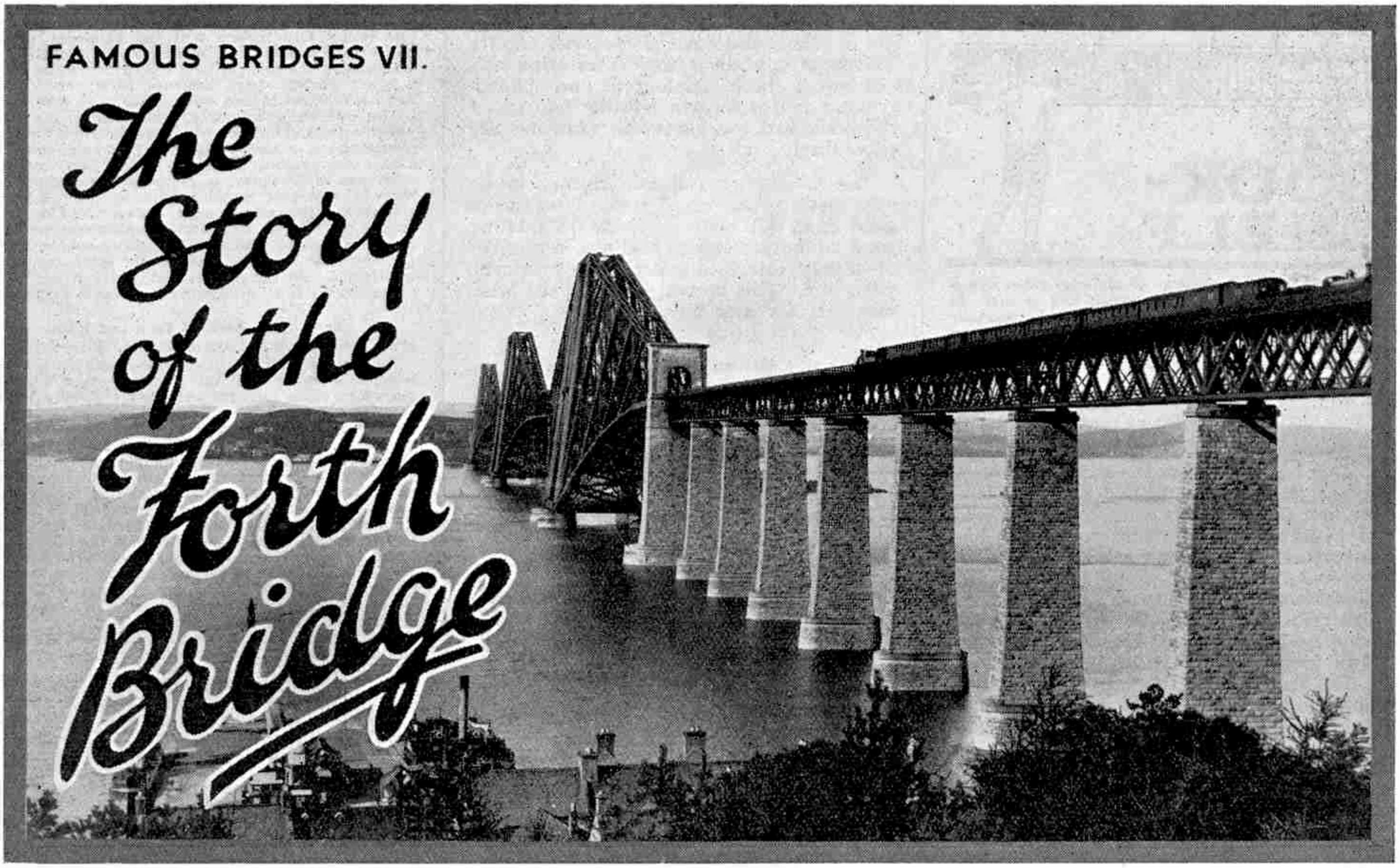
The model should be oiled at frequent intervals, and all working parts must be perfectly free to move. The fulcrum 7, especially, should not be allowed to make contact with the suspended 3½" Strips.

Parts required:
(Revised List)

3 of No. 1	1 of No. 15	6 of No. 57
2 ,, ,, 2	3 ,, ,, 16	20 ,, ,, 59
2 ,, ,, 3	2 ,, ,, 16B	2 ,, ,, 62
2 ,, ,, 4	1 ,, ,, 17	8 ,, ,, 63
3 ,, ,, 5	2 ,, ,, 18A	1 ,, ,, 63B
2 ,, ,, 6	1 ,, ,, 18B	1 ,, ,, 64
6 ,, ,, 6A	8 ,, ,, 20	2 ,, ,, 65
4 ,, ,, 8	1 ,, ,, 25	1 ,, ,, 81
2 ,, ,, 9	2 ,, ,, 26	4 ,, ,, 90
4 ,, ,, 10	8 ,, ,, 35	3 ,, ,, 100
1 ,, ,, 11	78 ,, ,, 37	2 ,, ,, 102
2 ,, ,, 12	14 ,, ,, 38	2 ,, ,, 108
1 ,, ,, 12A	1 ,, ,, 46	1 ,, ,, 111
3 ,, ,, 12B	3 ,, ,, 48	1 ,, ,, 111A
2 ,, ,, 13	4 ,, ,, 48D	2 ,, ,, 115
2 ,, ,, 14	2 ,, ,, 52A	2 ,, ,, 126A

FAMOUS BRIDGES VII.

The Story of the Forth Bridge



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.

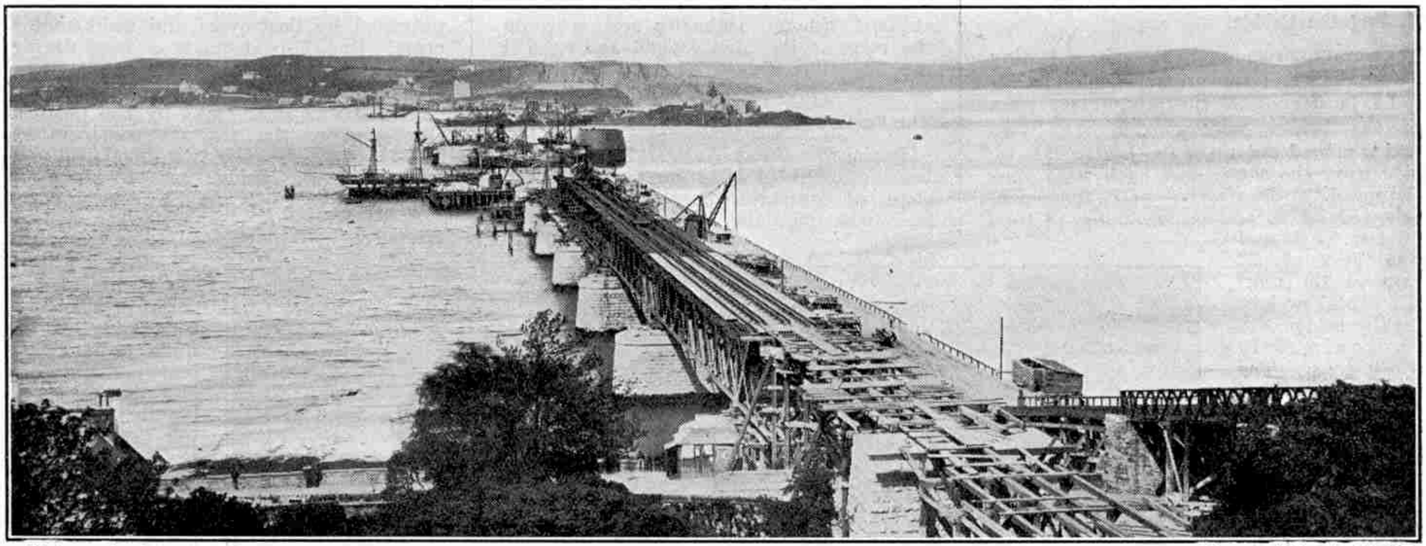


Photo courtesy] [*Messrs. Baker & Hurtzig*

The Foundations of the Forth Bridge as seen from the South Shore on 9th June 1885

An entirely different method had to be found, and the difficulty was finally solved by the adoption of an overhang system similar to that on which the cantilever arms themselves were carried out. The girders were temporarily connected with the cantilevers, thus becoming for the time being a continuation of the arms. When the ends of the girders were in position, the top and bottom members with struts and ties were carried out from each cantilever arm until they almost met in the centre, when a connection was made by permanent central plates. Afterwards the temporary connections at the ends were removed so that the girders rested on the ends of the cantilever arms.

Electric Light Adopted

The lighting of such an enormous working area was, as may be imagined, a great problem. In addition to lighting the actual points where work was proceeding, which of course changed day by day, there was the necessity for lighting all the approaches to these points and all stores, engine houses, workshops, landing places, etc. Electric lighting was decided upon, employing arc lamps for the shops and outdoor work and incandescent lamps for interiors. Incandescent lamps proved of great value in lighting the interior of the air shafts and air chambers of the caissons, and were used also with great success by divers under water. The arc lamps had the disadvantage of glare combined with the throwing of dense black shadows, and Lucigen oil lamps were introduced to overcome these defects.

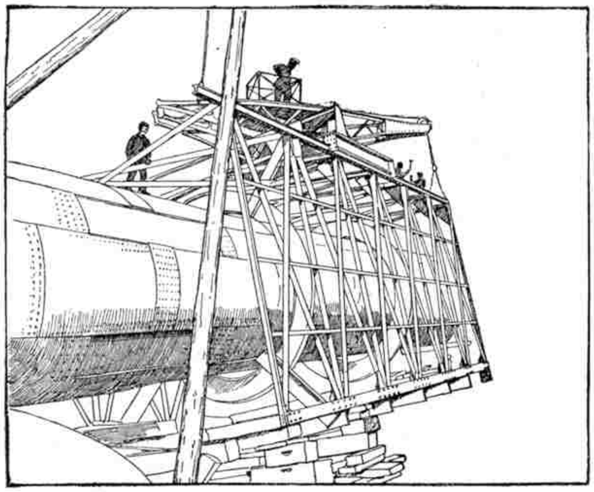
A Disaster Narrowly Averted

During the whole time that the bridge was under construction navigation proceeded as usual, and after a while it was found that the constantly changing positions of the lights on the piers, etc., as work proceeded, introduced a serious problem for navigators. On a very dark night it was extremely difficult to ascertain the exact position of all the piers. One night, when there was a slight mist, the captain of a tug coming down river towing a barque mistook the lights on the Fife erection for those of Inchgarvie and steered his ship straight for the hamlet of North Queensferry, which at the time was entirely hidden in mist. He found out his mistake in time to back out his tug and slip the tow rope, but the barque went on and damaged itself and the jetty very considerably.

It was apparent that an accident of this kind might occur again at any time, and therefore it was decided to build a lighthouse at the north-west corner of the island of Inchgarvie, with a revolving light giving five-second flashes and visible for twelve miles up and down stream.

Heating the Rivets

About half the riveting of the bridge was carried out by means of hydraulic riveting machines. At first ordinary coal-fired furnaces were used for heating the rivets and these proved satisfactory for a time. Later, as the work progressed, however, it became clear that these furnaces could not be moved with safety to outlying platforms. In addition to the tremendous weight of the furnace itself, there was also the weight of the fuel, and a further objection lay in the danger of timber-staging being set on fire by hot ashes from the furnace.



Building out one of the Lower Booms

(*From the Editor's book "Engineering for Boys," by permission of the publishers, Messrs. T. C. & E. C. Jack Ltd.*)

In the end small oil-fired furnaces were used with great success. These little furnaces, constructed of iron lined with brick, weighed rather more than half-a-ton. They could be placed in any position required by means of a crane and all that was required for their working was a small pipe to supply compressed air and a small tank of oil. One of these furnaces could heat 200 rivets per hour easily.

A great advantage of these oil furnaces was that when a furnace had finished a spell of work, and the air and oil were turned off, everything was cold in about five minutes and there was no possibility of fire breaking out after the workman had left.

For hand rivetting in the struts and lattice-girders small hand or treadle-operated forges were used. If an oil furnace was within reach it was used for pre-heating the rivets for the hand workers.

How the Bridge was Painted

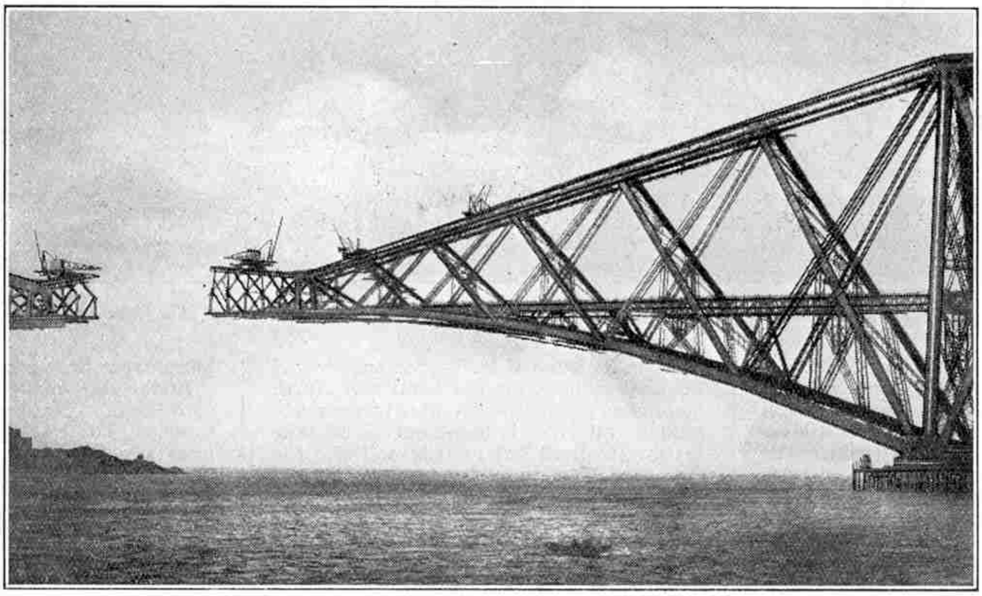
As soon as they had passed through the shops or yards, all the plates, bars, angles and other parts of the super-structure were thoroughly scraped with steel scrapers and steel wire brushes. They were then given a coat of boiled linseed oil, which was applied as hot as possible. The next step was to give them a coat of red lead paint, and this was done as soon as possible after the parts were erected, and in some cases before erection. Subsequently a second coat of red lead was given followed by two coats of an oxide of iron paint, the first a priming coat of dark chocolate and the second a finishing coat of bright Indian red. The inside of the tubular members of the bridge was given one coat of red and two coats of white lead paint.

In order to prevent rain water from finding places where it could lie and cause rust, all places in which water could not of its own accord drain away were filled with asphalt-concrete. In certain cases, where it was not possible to adopt this course, holes were drilled and the asphalt was so laid that the water was drained to the holes and away through them.

Testing the Bridge

There now remained the task of testing the stability of the mighty structure.

In January 1890 the preliminary tests of the bridge were carried out. Two trains moved out upon the bridge side by side from the south end, each train consisting of two locomotives of 72 tons each, followed by 50 wagons weighing 13 tons 10 cwt. each and one loco of 72 tons at the rear. The total weight on the bridge was approximately 1,800 tons. The trains were moved forward very slowly and minute observations were made as to the effects upon the bridge when the huge weight reached the most unfavourable positions of loading for the cantilevers. The various deflections were carefully noted and it was satisfactory to find that in every case these were well within the calculated limits.



Building out the Central Girder to connect with Cantilever

Another very severe test, this time not by officials, occurred about this time during a severe storm in which wind gauges on Inchgarvie recorded a pressure of 37 lb. per sq. ft.—7 lb. per sq. ft. more than the estimated force of the wind during the storm that wrecked the first Tay Bridge. The Forth Bridge stood this severe weather test without sustaining damage of any kind, and the greatest lateral movement of the central cantilever was under 1 in. As a matter of fact the bridge was constructed to withstand a wind pressure of 56 lb. per sq. ft.

Further exhaustive trials were carried out later by Board of Trade officials, who reported after their final inspection that: "This great undertaking, every part of which we have seen at different stages of its construction, is a wonderful example of thoroughly good workmanship with excellent materials, and both in its conception and in its execution it is a credit to all who have been connected with it."

Opening by Prince of Wales

On 8th March, 1890, the Forth Bridge was opened by King Edward VII., then Prince of Wales. The ceremony took place during a fierce gale, the sound of which, roaring through the steel framework, made a great impression on the spectators and provided an object lesson in the enormous strength and stability of the giant structure.

The Forth Bridge is of never-failing interest to the thousands who cross it by rail. The north-bound expresses run due west for some distance after leaving Waverley station, Edinburgh. They then part company with the Glasgow line and turn away towards the Forth, running along an easily graded line. At Dalmeny there is a junction with the Glasgow-North direct line and numerous single lines and sidings serve the naval base at Port Edgar. Dalmeny station is on the verge of the high ground and from it the line runs almost directly on to the viaduct approach of the bridge.

The Forth Bridge in War Time

During the Great War the Forth Bridge became a link of vital importance in the chain of communications, and when we look back upon the conditions existing it appears remarkable that more attacks were not made upon it by aircraft or submarines. When the Grand Fleet established its bases in the far north at Cromarty and Scapa Flow, vast supplies of coal and general stores and large numbers of men had to be constantly passing over the bridge, and in the event of an invasion by the enemy it would have been a matter of the utmost importance to maintain the crossing of the Firth of Forth. If any further test of the strength of the great bridge were needed it was supplied during this period by the heavy coal trains from South Wales and Yorkshire.

The great height of the bridge above the level of high water enabled the largest warships to pass beneath it, and the important Naval base at Rosyth, with its great dry-dock and repair basin, was in great demand. Rosyth lies quite near the northern extremity of the Forth Bridge and its great hammerhead cranes and forests of masts and funnels are to be seen on the landward side from trains crossing in a northerly direction.

A large fleet of destroyers and various auxiliary craft had a base at Port Edgar, which adjoins South Queensferry at the south end of the bridge. As both Port Edgar and Rosyth are higher up the Forth than the bridge, it will be seen readily that the destruction of the bridge would have been a great disaster.

Elaborate steps were taken to protect the bridge from submarine attacks and the defences were not complete until the middle of 1917. Powerfully-armed forts were established on the north and south shores, and also upon Inchgarvie and other islands in the estuary. An extensive layout of steel-meshed nets prevented any raiding submarines from entering the Forth except by one or two narrow channels, which were constantly patrolled by destroyers and swift motor craft. One U-boat made a very daring attempt to reach the bridge, but when almost at her goal she fell a victim to the nets and was dealt with by the patrols. Danger from the air was considerable, but only one extensive raid developed and fortunately the bridge escaped damage.

The Bridge seen from the Railway

When actually crossing the bridge it is difficult to form an adequate impression of its huge proportions, and perhaps this is done most readily by looking upward from the carriage window to the giant super-structure towering above. If a great warship happens to be passing up the Forth at the time it also serves to help one's sense of proportion.

Leaving the bridge at the northern end the train plunges through a series of tunnels in the solid rock and descends steeply towards the junction for Dunfermline. During this run along the Fife coast the train remains for many miles in view of the bridge it has recently crossed, and some extremely picturesque glimpses are obtained of its massive and yet graceful proportions as seen from varying angles.

The Story of Railway Signalling—

(*Continued from page* 669)

catch by the side of the line striking a trigger on the train and actuating the brake apparatus.

On some lines a three-aspect colour-light is installed, the third aspect showing whether the next signal ahead is at "clear" or "danger." An even later development is four-aspect signalling, which is now being installed on the electrified sections of the Southern Railway. The indications are as follows:—Red, "Danger, stop"; Yellow, "Caution, next signal shows 'Danger'"; Double Yellow, "Caution, next signal shows 'Caution'"; and Green indicating that the track is clear for at least two sections ahead.

Another development of automatic signalling is the automatic operation of points. This method was first used at a terminal station on the Mersey Railway. When a train arrives at the platform it operates the apparatus, but the actual movement of the points does not take place until 30 seconds have elapsed. Thus, if the train should happen to over-run the platform it would enter a siding, and not cross over to the departure line where another train might be standing.

With these and other improvements in automatic train control it is possible to secure the most intensive train service not only without any increase in danger to the travelling public, but actually with a great decrease, owing to the elimination of the human factor in the various operations.

The Story of Railway Signalling

Courtesy] *[London Underground Railways*

Power Interlocking Frame, Camden Town Signal Cabin

RAILWAY SIGNALS to-day are such a common sight that it is difficult to realise that railways were conducted without them during the first nine years of their existence, 1825 to 1834, the traffic being regulated by policemen. During these nine years trains apparently left the stations when they were ready to do so, quite irrespective of whether the line ahead was clear or not. This naturally led to complications on single track, and it was by no means an uncommon event for two trains to come to a standstill and remain there with the locos facing one another while the drivers had a fight to settle the argument as to which train must go back to the loop line!

The First Signal

In 1834 the Liverpool and Manchester Railway introduced the first form of fixed signal. This consisted of a red flag stretched on a wooden frame fixed on a vertical rod that was pivoted on bearings on the signal post. At the bottom of the post there was a handle by means of which the flag could be turned either to face the driver, indicating "danger," or to be parallel with the track, indicating "line clear." It is obvious that when the flag was parallel with the track it would be practically invisible to the driver of an approaching train, so that the system really amounted to a permit to keep on going until the flag was seen across the track.

Soon afterward Edward Woods invented an improved type, employing a wooden board painted red in place of the red flag. The fixed portion of the signal post in this case was a hollow tube something like a lamp post, through which passed the revolving spindle carrying the board. A slot was cut in the tube to the bottom to allow a handle to be attached to the spindle in order to rotate the board, and lamps were added to show the state of the road at night. Later a fixed projecting board was fitted to one side of the post so that the signal would be noticeable when in the "off" position.

The early forms of signal evidently did not give satisfaction, for we find that many new types were introduced within a very short period. A unique signal was designed by the Great Western Railway in 1837. This consisted of a fixed upright post provided at the top with carrying pulleys. A cord passed round these pulleys and by this means a ball was hoisted to the top of the post to indicate "line clear" and lowered to indicate "danger."

A Semicircular Signal

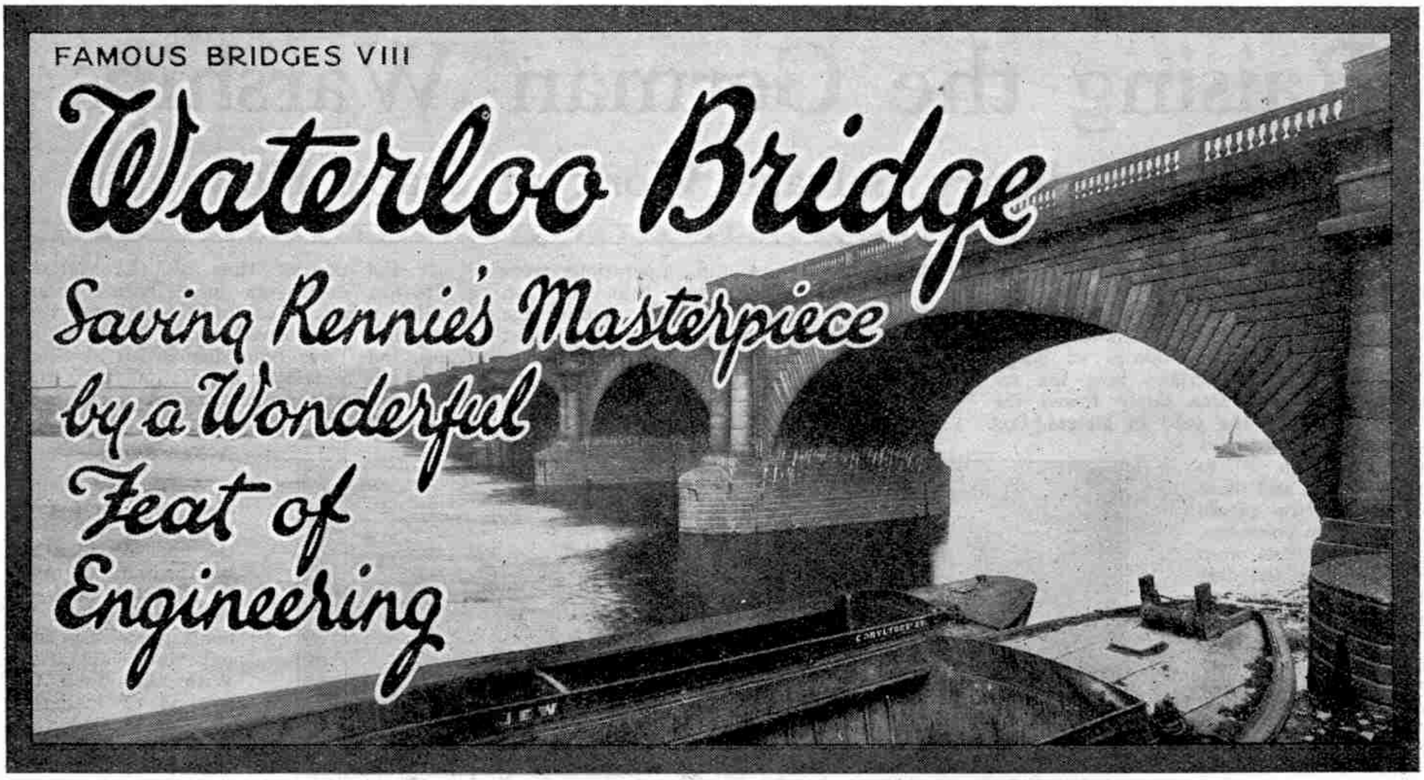
The Grand Junction Railway, opened in 1838, was the first line to be properly equipped with signals from its commencement. The type of signal adopted was similar to the revolving board type already described, except that in this case the board took the form of a semicircle, a type that was used also on the Liverpool and Manchester Railway.

This semicircular signal appears to have met with considerable popularity for we find that the London and South Western Railway adopted a modification of it two years later. The alterations from the old type were designed to promote economy, for one instrument signalled both running tracks at the same time. It consisted of a ring of iron, half of which was filled in with tin or canvas and the other half left hollow. Thus there was a semicircle of tin and a semicircle of "space." The whole was pivoted on the centre of the circle and normally fixed facing along the line. The closed part was turned to the left when the left-hand line only was blocked, to the right when the right-hand line was blocked, and to the top when both lines were blocked. To indicate that both lines were clear the whole disc was turned through a right-angle so that its edge was presented to trains approaching from both directions.

The disc type of signal evidently proved too complicated for everyday use and in the next year a new pattern was introduced on the same railway. This model consisted of a disc fixed on the upper end of an upright rotatable rod, which also carried a cross-bar below the disc and at right angles to it. When the disc was facing an on-coming train, only the edge of the cross-bar was visible and "line-clear" was indicated. When the rod was turned through an angle of 90 degrees only the edge of the disc could be seen and the cross-bar was visible, a position that indicated "danger." This form of signal was used on the G.W.R. for many years but was eventually superseded by the semaphore type.

The Semaphore Signal

The first semaphore signal was erected by Sir C. H. Gregory in 1841 at New Cross on the London and Croydon Railway. It consisted of a wooden post with a slot at the upper end in which were pivoted two arms, one to control each line of track. Each arm was attached to a pulley operated by a lever attached to its axle. When an arm was horizontal it indicated "danger"; when inclined downward at an angle of



FAMOUS BRIDGES VIII

Waterloo Bridge

Saving Rennie's Masterpiece by a Wonderful Feat of Engineering

DURING the past few months we have made several references in these columns to Waterloo Bridge which, as our readers know, has had to be closed temporarily for repairs made necessary by the subsidence of one of the stone pillars.

The repairs have been described as a wonderful piece of engineering work and the end of the first stage was reached when a 280 ft. span weighing 500 tons, to be used for a temporary bridge, was moved 93 ft. sideways from the old bridge to the four concrete caissons provided for its support.

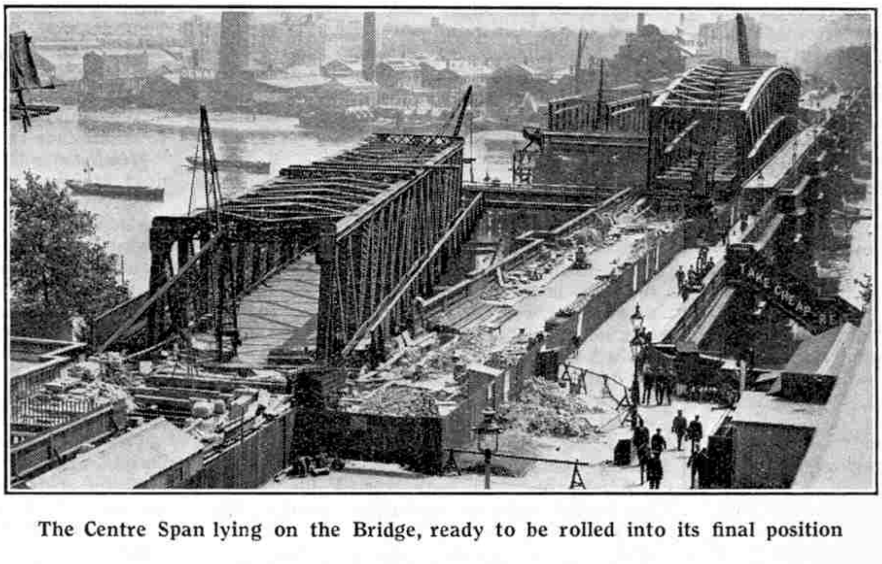
Moving the 500-ton Span

This huge span was put together on the old stone bridge where it lay on bogies placed on rails. These rails were laid along girders that stretched 93 feet over the water. The work of moving the span was commenced by an army of 150 men at 4 o'clock in the morning. Steel hawsers working on winches pulled the span inch by inch across the gap.

Special means were provided for preventing the span from moving too quickly, and the proceedings were controlled by engineers at whose direction signals were given by means of whistles, the men up aloft responding by waving white or red flags. Steadily the enormous mass proceeded on its journey, and shortly after noon the task was accomplished, when the Union Jack was run up amid ringing cheers. It is interesting to know that the engineers found that the span had expanded $\frac{5}{8}$ of an inch between the coolness of the early morning and the heat of mid-day.

The span was not placed immediately on to the caissons but rested on rails about 10 ft. above. The task of lowering the span inch by inch into position was one of extreme difficulty, but it was accomplished on the following day without a hitch.

Thousands of Londoners gathered on the banks of the Thames to watch the operations, and Meccano boys were evidently well represented, for we have received several accounts from eye witnesses. One enthusiastic reader took a number of photographs as he thought they would be of interest to readers of the *"M.M."* who had heard of the repairs to the bridge but were unable to see the operations for themselves. "Being a Meccano boy myself," he wrote, "I can quite appreciate their wanting to know all about it." Incidentally our young photographer tells us that the film was developed at 9 o'clock the same evening, and the prints were made at 6.30 next morning so that they could be sent to us in good time.



The Centre Span lying on the Bridge, ready to be rolled into its final position

The Centre Span ready for lowering. It was raised and lowered by Hydraulic Jacks

Engineers Disagree

There has been considerable discussion in regard to the future of Waterloo Bridge. The experts of the London County Council reported that the structure was worn out and dangerous, and recommended that it be demolished. Members of various London societies, however, are anxious to preserve the bridge on account of its architectural beauty and because it is one of the masterpieces of Rennie, the great engineer. These members pleaded for reconsideration of the sentence passed by the engineers, and the L.C.C. agreed to re-open the matter if sufficiently good grounds could be advanced to justify this course.

On hearing this decision the societies went to work and they have now presented reports of other engineers, and these seriously challenge the reports of the L.C.C. experts. One of these engineers, whose report should carry weight, is Mr. C. F. Bengough, formerly Chief Engineer of the North Eastern Railway. This engineer describes, as conclusive evidence of how the bridge can be saved, the work he himself carried out in under-pinning the south pier of the High Level Bridge over the Tyne at Newcastle four years ago. The conditions there were almost identical with those at Waterloo Bridge.

Under-pinning the High Level Bridge

" The method adopted at Newcastle," says Mr. Bengough, " was first of all to construct a dam of steel sheet piling round the pier. This dam was practically watertight, a six inch pump, working intermittently, being all that was required to deal with the water. The underpinning of the pier with concrete was carried out in sections without any difficulty, the dimensions being determined by the spacing of the piles, and the original piles, which were perfectly sound, being left in."

Mr. Nicholas Geyde, another engineer who was consulted about the Newcastle Bridge, strongly supports Mr. Bengough in his view that the methods employed on the Tyne are admirably adapted to the case of Waterloo Bridge.

Will the Bridge be Saved ?

These reports are of considerable interest, but it is difficult to reconcile them with the report of the L.C.C. experts, which stated most definitely that both the timber and the stonework of the bridge piers had decayed.

It will be interesting to learn what is to be the next step. Certainly the L.C.C. must give careful consideration to the new reports before finally deciding to demolish Rennie's masterpiece.

One of the most important points that will, no doubt, receive their attention, is the fact that the present bridge can be repaired for half the sum that a new bridge would cost.

History of the Bridge

The project of a bridge to connect the Strand near Somerset House with the Surrey side of the Thames at Lambeth, dates back to 1809, when a bridge company took up the matter. A plan was submitted by George Dodds, a well-known engineer of the time, but was not approved. Later, when the Act authorising the construction of the bridge had been passed, the company applied to Rennie for advice as to a suitable structure.

Rennie's first step was to make an entirely fresh chart of the river and its shores after a careful survey had been made by Francis Giles, an expert land surveyor, whom Rennie had frequently employed to carry out the hydraulic surveys for the canals and harbours under his construction. Two designs were prepared, one with seven equal arches and the other with nine, and after due consideration the nine-arch scheme was ordered to be carried out.

The Waterloo Bridge as executed consists of nine equal semi-eliptical arches each of 120 ft. span with a rise of 34 ft. 6 in. The piers are 20 ft. wide, each having projecting buttresses supported by two three-quarter Doric column pilasters after the design of the temple of Segesta in Sicily. The roadway above the piers is

(*Continued on page 52*)

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Waterloo Bridge—*(cont. from page 27)*

supported by six brick walls 2 ft. 3 in. thick, covered with corbel stones. It was formed by a layer of puddled clay 15 in. thick, then a layer of lime and fine gravel 3 in. thick followed by a layer of granite, broken in pieces 2 in. in diameter, 1 ft. thick. The roadway for carriages is 28 ft. wide and the footpaths on each side 7 ft. wide.

Through the centre of the masonry of each pier a hole 18 in. in diameter was cut, entering the river at one side of the pier at low water, and from the top of this hole inside the pier pipes were carried to drains on each side of the roadway, thus effectually carrying away all rain and surface water into the river.

An Ingenious Expedient

The engineer Dodds had proposed to found the piers of his bridge by means of caissons, but Rennie decided upon the use of cofferdams. A cofferdam may be described as consisting of two concentric rings of piles driven in contact with one another around the area on which the foundation is to be built. The space between the two rings of piles is tightly packed with clay so as to make the enclosure watertight, and the water inside is pumped out. Excavation to the proper depth is then made, the foundation is laid, and building operations proceed until the pier has reached a height above the level of the outside water. At this stage the cofferdam has served its purpose and is then removed.

The method employed by Rennie for constructing, floating and fixing the centres for the arches was very ingenious. Each centre consisted of eight ribs on the truss principle, resting upon wedges supported upon struts placed upon the offsets of the piers and abutments. All the ribs were connected together by transverse and diagonal ties as well as planking upon which the arch-stones rested.

The centres were constructed on a platform by the riverside, floated between the piers on barges specially built for the purpose, and raised into their proper places by means of four powerful screws fixed in cast iron boxes firmly bedded in the solid floor of the barge. The scheme proved so successful that the fixing of one centre was usually completed within a week. This method was new at the time and it is interesting to note that it was the same as that afterwards followed by Robert Stephenson in fixing the great tubes of the Conway and Britannia Bridges.

A Knighthood Declined

The bridge and its approaches were completed and opened with great ceremony in June 1817 by George IV., then Prince Regent, who was accompanied by the Duke of Wellington. It was originally named the Strand Bridge, but the name was subsequently altered to Waterloo in commemoration of the Battle of Waterloo and in honour of the Duke.

At the opening ceremony the Prince Regent offered to confer the honour of knighthood upon Rennie, who respectfully declined it. Writing afterwards to a friend he said : " I had a hard business to escape knighthood at the ceremony." He preferred to remain simply John Rennie, engineer of the noble structure he had successfully brought to completion.

The Conquest of the Air—

(Continued from page 55)

aeroplane's wings. When in the air, the machine is controlled by the elevator and steered by the rudder in the ordinary manner.

The chief advantages of the Auto-giro are that in addition to being able to fly at a comparatively high speed, climbing and gliding in the usual manner, it is also able to fly at very low speeds and to descend almost vertically under complete control. The fact that it can fly at such low speeds makes the type valuable for observation purposes, for with the ordinary aeroplane, which must be kept on the move, it is often very difficult for a detailed observation of any particular feature to be made, unless the aeroplane circles over the spot or travels backwards and forwards over it a number of times.

The Auto-giro has a span of 36 ft. and a total weight, including pilot, of 2,000 lbs. Its maximum air speed is 68 miles per hour, and its minimum speed 30 miles per hour. It is claimed that in its earlier tests the machine climbed to a height of 1,150 ft. This is indeed a creditable performance for a machine of such unusual design and one that is obviously only in the experimental stages.

The designer of the Auto-giro claims that he could build a machine that would attain a higher speed than any existing aeroplane and yet retain a low landing speed. He suggests that fitted with 450 h.p. engines, his future machines will certainly attain a speed of over 300 miles per hour, and that such machines would have a landing speed of under 40 miles an hour. On the other hand, at a sacrifice of speed, Auto-giros can be built to carry big loads.

Whether these anticipations can be realised or not remains to be seen, but it is a fact that the Auto-giro has caused considerable interest among experts and has proved that there is a decided possibility in machines of the helicopter type, a point that has long been denied by some experts.

Motor-Cycle and Sidecar—

(Continued from page 13)

pillion (constructed from two short Flat Girders " sprung " by a method similar to that employed in the saddle) and a rear stand, for attachment if the model is used as a solo outfit. Still further refinements, such as number-plates, etc., would give the finishing touch to the compact and realistic appearance of the model.

PARTS REQUIRED :—

Motor Cycle

2 of No. 2
2 „ „ 3
1 „ „ 4
10 „ „ 5
1 „ „ 6A
2 „ „ 10
6 „ „ 11
4 „ „ 12
1 „ „ 15
1 „ „ 15A
1 „ „ 16
5 „ „ 17
4 „ „ 18A

1 of No. 18B
2 „ „ 19B
1 „ „ 22
1 „ „ 23A
2 „ „ 32
28 „ „ 37
10 „ „ 37A
16 „ „ 38
11 „ „ 59
8 „ „ 63
3 „ „ 77
2 „ „ 90
6½" „ „ 94

1 of No. 96
1 „ „ 96A
1 „ „ 101
2 „ „ 103G
3 „ „ 111
3 „ „ 111A
2 „ „ 115
1 „ „ 116
3 „ „ 120A
2 „ „ 126A
2 „ „ 142
Small elastic band

Sidecar

2 of No. 2
2 „ „ 2A
5 „ „ 3
5 „ „ 5
2 „ „ 6A
1 „ „ 9F
1 „ „ 10
2 „ „ 11
3 „ „ 12
2 „ „ 16
1 „ „ 16A

1 of No. 17
1 „ „ 18A
1 „ „ 19
1 „ „ 19B
55 „ „ 37
1 „ „ 37A
3 „ „ 38
2 „ „ 43
7 „ „ 48A
4 „ „ 59
5 „ „ 63

1 of No. 64
6 „ „ 89
8 „ „ 90
2 „ „ 103F
2 „ „ 103H
1 „ „ 111A
1 „ „ 125
2 „ „ 133
1 „ „ 142

My Clockwork Train

Sometimes on rainy Saturdays,
I can't go out to play,
And so I take my clockwork train,
And travel miles away.
I start at Bookcase Corner,
And go to Plymouth Sound ;
And via Table Tunnel,
I travel round and round.
Sometimes I have an accident,
My train falls off the rail ;
I have to send the breakdown gang,
I know it cannot fail.
I sometimes have excursion trains
To Wembley once I went ;
And I have football specials too,
And mails with me are sent.
I take my sister's little dolls,
And ride them round the track,
And when they've had their money's worth,
I bring them safely back.
Although I've lots of other toys,
I still come back again,
And many happy hours I spend
With my " Hornby Clockwork train."

(By Master Wilfred Ashworth, of Parton, Cumberland).

Meccano Assists Inventor—*(cont. from page 50)*

An escalator based upon Mr. Cannon's patent is to be installed in the White City Exhibition for 1927, and a similar transport system is already employed in three or four factories in this country, where it forms an economical method of conveying goods. It is claimed to be the cheapest form of transport known.

At the White City it will be possible to maintain in continuous motion any number of cars up to 30 ; this would give the machine a maximum capacity of 2,000 passengers per hour. It is also claimed that this method of transport is quite safe, for the cars keep the same distance apart over the whole of the track, and there is no fear of some sticking and others racing.