SKETCHES OF THE FORTH BRIDGE

OR

THE GIANT'S ANATOMY

FROM VARIOUS POINTS OF VIEW.

By Philip Phillips

R. GRANT & SON
107 PRINCES ST. EDINBURGH.

AUTHORISED DESCRIPTION.

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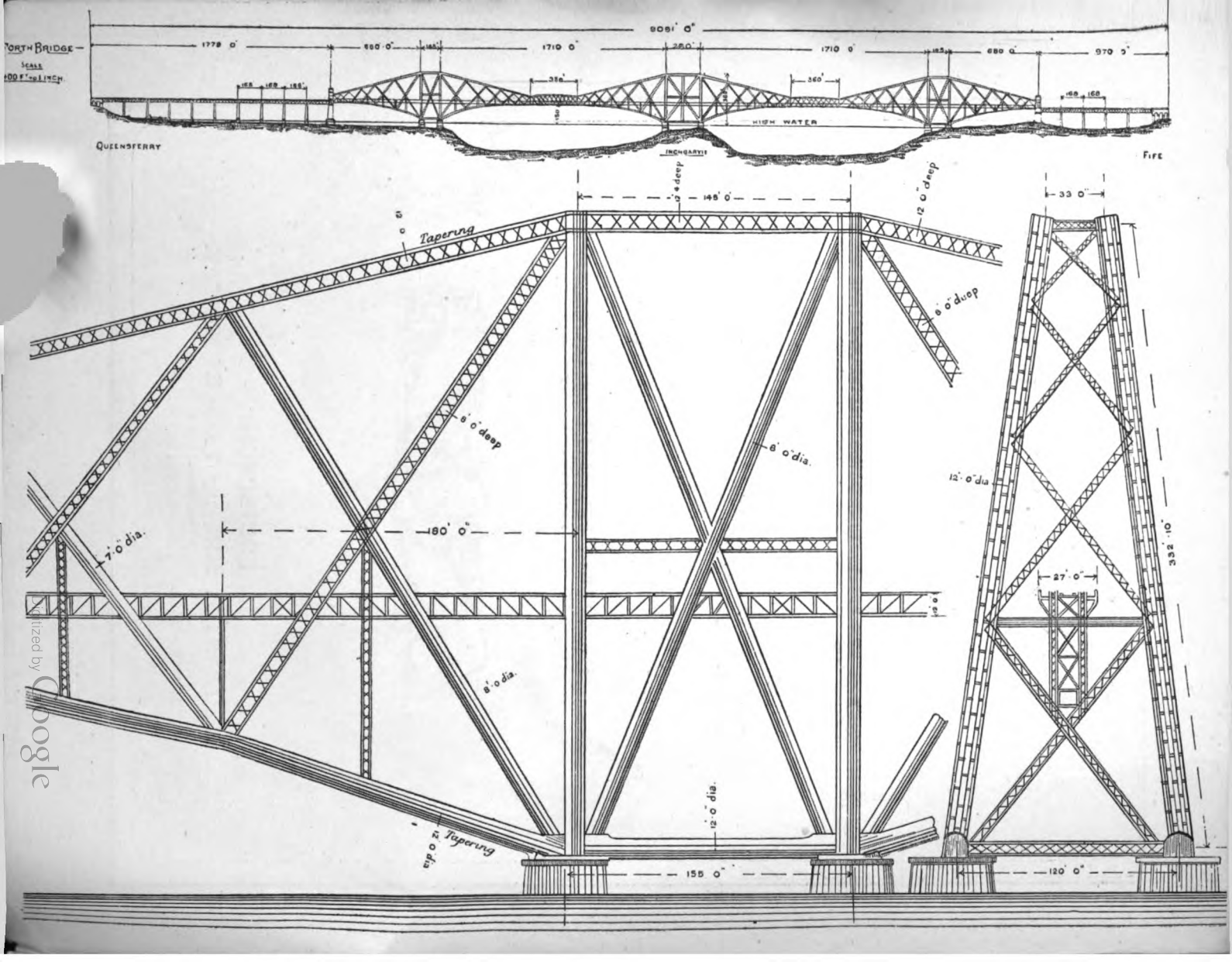
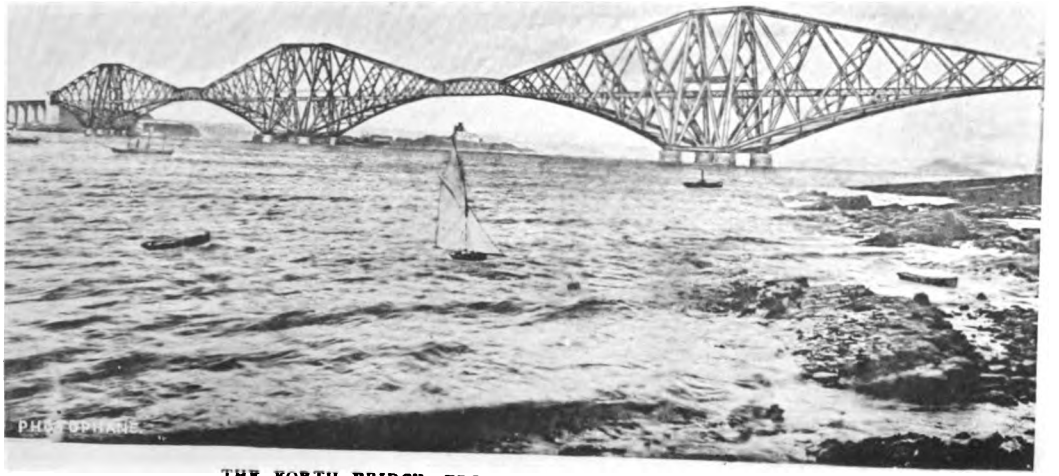
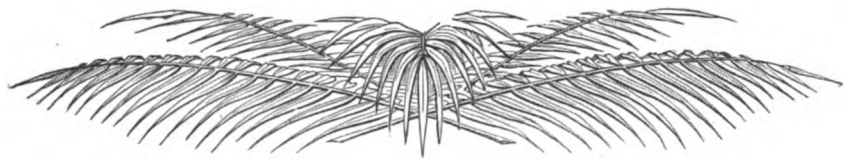




THE FORTH BRIDGE, FROM A SKETCH BY THE AUTHOR, 1885.



Introduction

THE endeavour of the Author in the following pages is to give a short sketch of the progress of the works and workings of the FORTH BRIDGE from its commencement up to date, and in such a way that it shall prove equally useful to the uninformed, as it is hoped it will be to those who from time to time have secured series of his Illustrations, and who on numerous occasions have intimated how greatly enhanced such would be if accompanied by a concise account of the leading features of the work they individually represent.

In this way it is meant not to trespass upon treatises which have been or may be written in a scientific and literary manner on this great work,—a character the Author does not assume for this outline,—but only that, in what follows, the greatest pains have been taken to ensure such clearness of description as may enable anyone having an interest in the undertaking to follow and understand the general design and the mode of its execution.

SOUTH QUEENSFERRY, N.B.

Incidental Reference.

Ref. No.

Sketches of the Forth Bridge.

FOR the sake of easy reference the subject of the ensuing pages has been divided into four parts, as follows:—

(1) APPROACH VIADUCT AND PIERS.

(2) CANTILEVER PIERS.

(3) MAIN PIERS (Including Caissons).

(4) CANTILEVERS AND CENTRAL GIRDERS.

Recurring often as it does hereafter, it is perhaps desirable, before proceeding, to furnish an elementary definition of the technical but inevitable term "Cantilever," which is of very recent application, and even introduction into engineering, and so but little known outside the scientific world, though ignorance on this head is perhaps at the bottom of the erroneous ideas conceived of the structure to which the name is now so widely applied.

A Cantilever, or to be more accurate a Cantilever Girder, is the name applied to a girder having one support only, the parts overhanging this on each side being balanced, and the whole sufficiently strong to carry itself and a load without supports at either end. And this it may do with or without being held down to the pier, depending on its weight, proportions, and general design.

A Cantilever has all the properties of a girder, of which it is a further scientific development, just as the girder, in its new compound forms, is of the original rectangular beam. It is therefore a structure in what is termed "Stable Equilibrium"—

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all the strains arising from its weight and load being carried within itself, and having to be provided for by an adjustment of proportionate strengths in the different parts.

It follows that such a structure puts no strain on its supports, whether one or more, other than the vertical pressure due to its own weight and the load it carries, and the various sections being braced, it cannot alter its form in parts, being in this respect exactly the reverse of the suspension bridge, which, as it is a development of the principle of the arch, does engender strains outside itself which have to be provided for by abutments or anchorages, and is subject to alter its form from unequal loading, being thence termed in "Unstable Equilibrium."

With this brief consideration of a term which has proved a stumbling-block to many, we pass on to some of the most prominent features of the work.

The structure is founded upon three main piers consisting of three clusters of four each, over which twelve the whole weight of the three cantilevers is distributed. In addition to these there are two supplementary piers, which serve both to receive the arms of cantilevers and also to connect same with approach viaduct, which is comprised in all of eleven spans, 168 feet centres, two of 179, and two of 173 feet, together with arches forming abutments. The three cantilevers make two spans of 1710 feet each, which cross the respective channels, and two half spans stretching inland to the piers referred to.

The Central Girders serve to connect the arms of the cantilevers about mid-channel, where for a distance of upwards of 160 yards there is a clear headway of 150 feet at high-water, and as each of these girders weigh about 800 tons, it will be observed that the cantilever piers, so far from—as is commonly supposed—giving any support to the superstructure, are designed to hold it down, to aid which purpose the inner arms are ballasted.

Having briefly considered the structure as a whole, some further detail may now be entered into, during which frequent

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reference will be made to the various illustrations obtained from time to time in order to assist those who have not had an opportunity of inspecting the work in person, and who nevertheless watch its progress with more than ordinary interest.

But, first, it is perhaps necessary to remind the reader that it is the immensity of the main spans—each a third of a mile in length—with their subsidiary side spans, and the consequent magnitude of the constructive work required to meet the necessities of the case, which form the very special and distinct feature of this bridge as compared with all others, making it a matter of considerable interest, not only to the engineering profession, but to the public and outside world at home and abroad.

For not only in the respect of spans is the Forth Bridge without a parallel, but so largely is it in excess of all hitherto attempted upon the same principle of "Stable Equilibrium"—and therefore without taking suspension bridges into account—that it has been not inaptly named "The Giant Bridge," a designation it is likely to hold unchallenged for many years to come. The necessity for such spans, if the Forth was to be crossed at this, the narrowest point for some miles up or down, was imposed upon the engineers by the depth of water, and by the importance of maintaining the freedom of the navigation both during the building and afterwards, and it was the latter condition that involved the placing of the rail level at such an unusual height. The problem was, therefore, How best to construct a bridge in accordance with such requirements, and at the same time in compliance with the Board of Trade conditions, stipulating for a rigid structure capable of carrying the heaviest mineral traffic and the fastest trains of a first class line without oscillation and with ample marginal safety in every other respect.

To Sir John Fowler and Mr Benjamin Baker, two of our leading engineers, fell the solution of this problem, which they have dealt with by the design and execution of a structure which, more perhaps than any other, reduces the difficulties,

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and indeed largely renders what were considered such, as well as many of the imposed conditions, subservient to the purpose of the accomplishment, and at once sources of increased stability and economy.

Photograph No. 1 may here conveniently be referred to, illustrating the Firth of Forth at the site of the bridge and the structure itself, as it will appear when in its completed state. At this point the estuary narrows to some mile and a half in width, and prominent in it appears the rocky islet of Inch Garvie, cropping up—not in the centre of the water-way—but in that of the deep channel, which it practically bisects, thereby forming two navigable channels, one on either side, having a depth of some 200 feet.

It is due to this fact that Inch Garvie becomes the centre of the main structure. On the north side of the island the rock is almost perpendicular, a similar condition of things maintaining on the Fife shore. A strong tide sweeps up and down on each side of the island, the stronger being that of the north channel, which, as it so happens, is that mostly used for purposes of navigation. On the south side of the island the rock is less precipitous, and though at a short distance out a depth of water similar to that in the north channel is found, it shoals again rapidly towards the south shore, the bed of the river hereabouts being composed of boulder clay with a stratum of mud many feet thick.

It will thus be seen that the founding of piers, other than on or near the island was impracticable, even if the interests of the navigation before referred to had not been antagonistic to obstructions, permanent or temporary, in the water-ways.

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Approach Viaducts

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160
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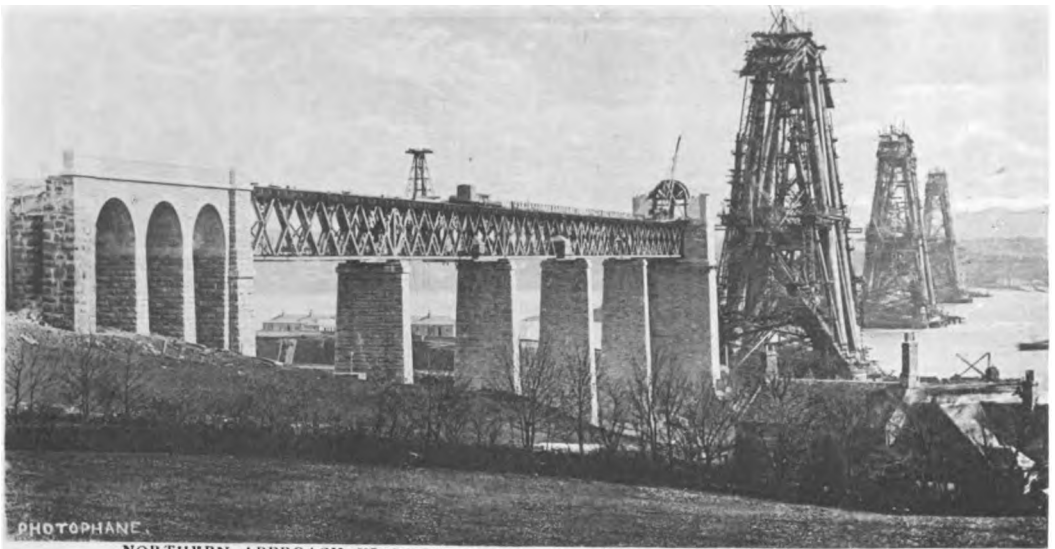
THE piers comprised in the above having been built up to a given level, the girders were put together upon a temporary stage some 3 feet higher than the masonry and erected between each pier. The means adopted for raising these girders to their full height, as it excited considerable curiosity among numerous visitors, it may be well to explain was the application of the same principle, "hydraulic power," which has been so largely developed throughout the undertaking. 73 0.37 56

Raising Girders.

In this case it was applied in such a way as to act at once on the greatest number of girder spans that could be put together at the level found most convenient for a commencement, taking in the other spans built at higher levels as they and the piers beneath them were carried up. Thus on the Queensferry side seven spans were first put together, extending from the public road to the cantilever pier. The girders are designed continuous over two openings, but for the time being were all temporarily connected. Beneath, and bolted to them transversely over each pier, were strong cross girders extending beyond same, between which and firmly attached to them were two hydraulic jacks capable of lifting some two hundred tons if required, though in point of fact such a pressure was never necessary. Each jack was connected with pumping engines placed for the purpose at the inner end of girder, and in such a manner that the whole worked simultaneously. All being ready, pressure was applied to the jacks, and a lift of about a foot, the limit of the stroke, was made. Packings composed of hard wood from 3 to 12 inches thick, and from 4 to 5 feet long, were here placed under the girder, 34

Spans.



NORTHERN APPROACH VIADUCT, AFTER RAISING TO FULL HEIGHT. MAY 7, 1888.

Incidental Reference. | Ref. No.

which was then allowed to rest on same. A new bearing having been provided for the jack already in position, a second lift was now made. This process was repeated as many times as it was desired to raise the girder in feet, or in other words, until space to admit two courses of masonry amounting to about 3 feet 6 inches had been provided. Taking the depth of the cross girders into account, and room to work under them, the girders always stood when blocked up about 6 feet above the masonry. In continuing building, two sets of packing only were removed at any one time. Lifting the girder originally occupied one day or more, but subsequently a much shorter period, though more spans were added as greater height was gained; and eventually, even with the maximum number, ten spans, the lifting was frequently done in half a day, and in some cases, three and a half hours. A scaffold encircling the top of each pier was suspended from the girders to rise with them, and protected by a railing so as to form a suitable platform for the packings, building, and attending to the general operations; whilst along the whole length of the girders

Bottom Bracing. a flooring was laid on the bottom bracing, which carried lines 29
of rails to convey the materials to each pier in the same trucks into which they had been loaded below, the lifting being effected by a steam hoist. The girders themselves thus acted as an overhead traveller and workshop during the progress of the viaduct.

The building of the masonry between each lift, including the time necessary for the "setting" of the work on the one half of the pier before the other was commenced, was executed at the rate of about 9 feet vertical on each pier for the month. To facilitate the setting of the stone, rope-worked friction winches driven by the same steam power employed for the hydraulic work were employed, and ponies were provided to draw the trucks from the hoists to the piers as required.

The height to which the girders were ultimately raised was about 150 feet above high water, and as only 3 feet 6 inches or thereabout constituted one lift, the time occupied in reaching the

Incidental Reference.

First Lift.
Last Lift.

Ref. No.

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36

final altitude was considerable, the first lift being made April 1886, and the last July 1887, thus including many winter months, when for a number of weeks together the work was entirely suspended.

Although, however, the process seemed slow, it will readily be seen that the labour involved was far less than must have been the case had the piers been carried to their full height in the first instance, and the girder lifted piece by piece, to say nothing of a staging between each pier something like 130 feet high. The girders themselves call for no remarks, being of the ordinary lattice girder type built of steel. They have a depth of 22 feet 6 inches.

Incidental Reference. | Ref. No.

Cantilever Piers

Cantilever Pier.

THESE two Piers, one on the Fife side of the Firth some distance inland, and the other about 450 yards from Queensferry shore, are in construction similar in every respect. The process of securing a good foundation for these mammoth piers was of necessity widely different. 150 5 & 6

In the case of the Fife pier, standing as it does upon the mainland, straightforward excavation and levelling of rock only was required, whereas in that of Queensferry a hydrostatic process of some kind was necessary.

Internally these two piers differ from the smaller ones in that they are constructed with cross walls and arches instead of being solid masonry.

Respecting the foundation of the South Side pier, the method adopted, so far as principle is concerned, was only one that can usually be seen in operation in connection with work of a similar class, but the exceptional dimensions of this coffer-dam gave rise to much comment, and it was a source of considerable interest to strangers and the profession at large. 38

Cofferdam.

The maximum head of water to be contended with, and the depth of mud overlying the boulder clay at this point, were considerable, but it was the position of the pier, which is entirely exposed to the heaviest gales, that rendered the most elaborate precautions necessary.

The internal dimensions of the dam were, roughly, 120 feet by 70 feet.

The piling consisted of two double rows of pitch pine, sawn on the sides of contact, and driven by steam in the usual manner; the outer rows being securely tied to the inner by chains and bolts, and the space between filled with puddle subsequently removed by dredging.

Incidental Reference. —

Ref. No. —

The whole was combined internally by horizontal and diagonal struts, and externally by connection with piles and dolphins expressly driven in such a manner that immense strength was ensured and all rocking motion reduced to a minimum.

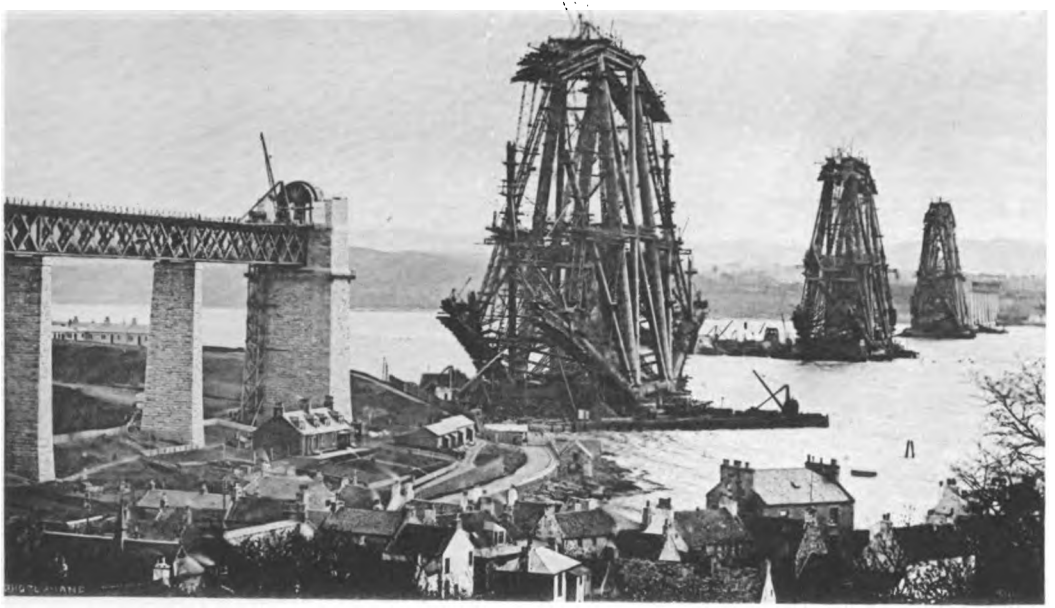
Though, as already stated, steam pile drivers were brought into operation, as a matter of fact modified forms of the same supplimented by steam crabs were found to be equally efficient.

Piles, removing of

The difficulty subsequently experienced in the extraction of these piles, owing to their excessive length and the tenacity of the materials through which they passed, was greater than anticipated, various appliances designed for the purpose proving inadequate. Eventually, however, they all disappeared. Those which resisted ordinary efforts were removed either by hand at low water, or by means of dynamite. Excavation was carried on down to depth of 35 feet below high water, at which level a first-rate foundation of boulder clay was reached. The whole area of the bottom of cofferdam was covered to a depth of about 11 feet with concrete, upon which the masonry was built. The dimensions of the pier at cutwater are about 96 feet by 45 feet, above which it has a considerable batter, rising to a total height of 209 feet above high water, forming a tower of proportions and architectural character suitable to connect the main structure and the viaduct approach.

End of Cantilever.

Provision is made in these piers for attaching the end of cantilevers by a series of holding down bolts anchored in the masonry itself, and contrived in such a way as to admit of the horizontal movement due to expansion and contraction. 127



GENERAL VIEW OF THE STRUCTURE, AS SEEN FROM N. QUEENSFERRY HILLS. MAY 8, 1888.

Incidental Reference. | Ref. No.

Main Piers

Inchgarvie Pier.

THE most interesting and novel feature in connection with the earlier stages of the work was probably the construction of Inchgarvie and Queensferry piers by the pneumatic process. 0·48

The depth of water to be dealt with, the enormous quantities of material to be handled, and the various unfavourable conditions under which the foundation of these piers had to be carried out, combined to render the apparent progress from day to day almost imperceptible.

Foundation

To the foundation of the several piers at Inchgarvie and the Fife shore, which offered no exceptional difficulties, further reference is unnecessary, and our attention will therefore be confined to the remainder. 12

Coping.

Each pier has at its base a diameter of 70 feet, and is built with a batter sufficient to reduce it to 49 feet at the level of the coping. From low water each pier is faced with granite averaging 2 feet in thickness. 0·22 Below this point is a solid mass of concrete covering the 70 feet area already mentioned. The interior of these piers is composed of Arbroath stone set in cement. At the level of coping a course of granite forms the surface of each pier,

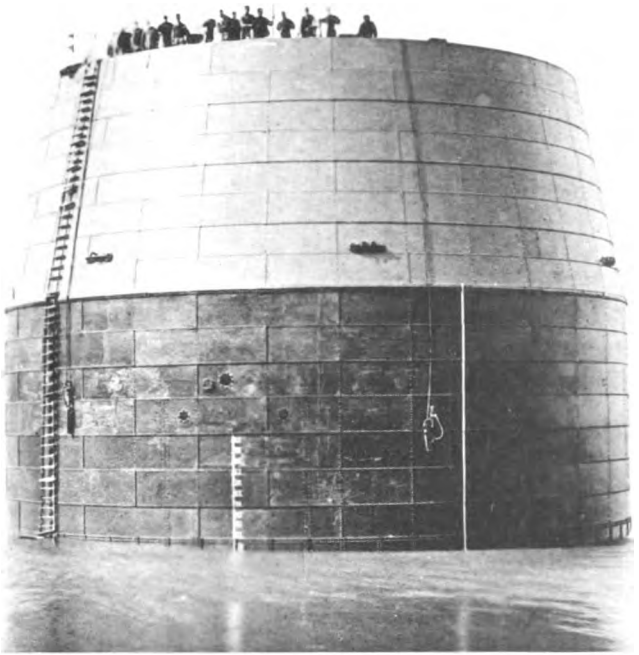
Steel Bolts.

through which project 48 steel bolts 2½ inches in diameter, extending downwards to a depth of 24 feet, where they are secured by washer plates designed for the purpose. 0·42 0·20

It has been calculated that the load on the base of these piers will never at any one time exceed 24,000 tons, from which it is evident that no square foot can be subjected to a greater weight than some half-dozen tons.

Queensferry and Fife piers form rectangles with 120 feet centres transversely, and 155 feet on the bridge line; that on Inchgarvie, otherwise the same, being 270 feet on the bridge line. 3 & 4

Incidental Reference.		Ref. No.
Fife S.E.	Before dwelling upon the foundations of the deep water piers, a word should be said upon that of the Fife south-east, which, being situated between wind and water, entailed more work than was anticipated.	
	An ordinary half-tide dam was originally employed in this case, but owing to the irregularity of the rock, the exposed position, and the strength of the tide, it soon became evident that additional measures would have to be adopted to ensure the execution of the foundation in a thoroughly workmanlike manner.	
Segment of Caisson.	To this end, what might be termed the segment of a caisson 60 feet in diameter, with the lower edge cut to the contour of the rock, was constructed above the dam, rising only to the height of low water, at which point other temporary work was bolted on, and the whole then made tight by means of clay and concrete.	0·18
	The time occupied over this pier was considerable, as there was much rock to be removed, for which purpose diamond and rock drills were brought into operation prior to blasting, a course usually necessary.	
Q'nsferry Caissons, S.E. and S.W.	**Caissons.**—This brings us to the Caissons themselves, of which there were six in number, four in connection with the Queensferry and two with the Inchgarvie foundations.	41
Inchgarvie do.		34
Temporary Work.	As, however, they were all similar in construction, differing only in the amount of temporary work on the upper part, features governed by the depth of water in which each was intended to be sunk, a general description of one will suffice.	0·40
Plan.	In plan they were round, and—to the eye of the general public—perhaps more resembled an ordinary gasometer minus its weight and chains than anything else. A small bay to the east of the line of the bridge, moderately free from rock, was selected as the most suitable birth-place of these monsters. In the first place a cradle was constructed some few feet above the ground, of such a nature that it could be set in	0·67
Launching Ways.	motion in much the same manner as the launching ways of a	0·60 22



INCHGARVIE S.W. CAISSON, JUST LAUNCHED. MAY 29, 1885.

Incidental Reference.		Ref. No.
	shipbuilding yard. Upon this the Caisson was built, principally composed of wrought iron, an exception being, however, the	
Cutting Edge.	lower or cutting edge, which was of steel, at which point the diameter was 70 feet, with a slight taper upward to facilitate sinking.	19
1st Caisson Built.	The height to which they were built before being launched varied, that of the first, for example, being inconsiderable, and obviously with a view to rendering it as manageable as possible while being towed into position. Experience, however, warranted a further development prior to that event in the case	10 0·51
Towing.	of others. All the towing necessary was accomplished by a couple of steam tugs, supplemented by a flotilla of smaller craft engaged upon the work.	38
Launch.	The first launch took place on the 26th of May 1884, under the auspices of the Lord High Commissioner and the Countess of Aberdeen, amidst a brilliant concourse of spectators, which the fine weather and somewhat unprecedented nature of the experiment had brought together.	25
	An hydraulic ram, adjusted for the purpose, having been brought to bear upon the structure, the mass was set in motion, gliding into the water without a hitch. A steel hawser was then attached to lugs provided for the purpose on the sides of the Caisson, and towing commenced. At this point, the Caisson suddenly took a considerable list, alarming as it must have done, the onlookers, though not so much perhaps as those aboard—an effect produced by the confinement of a large volume of air in the lower chamber. This air subsequently, becoming liberated by discharging itself under the lower edge, thereby producing the effect of an exploded torpedo, the Caisson righted itself.	
	In some instances the Caisson was towed direct to its destination; in all cases the operations prior to sinking were	
Internal Arrangement.	similar, but before detailing these, it will be as well to take a glance at their internal arrangements.	0·61
	To compare the inside of the Caisson, as we have already done the outside, to a gasometer would scarcely be correct, in-	

Incidental Reference.		Ref. No.
	asmuch as the former has a bottom and no top, whereas the essential features of the gasometer are a top and no bottom.	
	Though, however, the Caisson has a bottom or floor, it cannot satisfactorily be so described, for seeing that there is a space of seven feet between it and the cutting edge, it may under certain conditions be referred to as a ceiling or roof.	
Girders.	This floor was supported from above by a series of girders resembling joists, which were in their turn secured by four open girders with a depth of eighteen feet each.	26
	Upon the floor, and some seven feet from the outer skin, was an internal one, giving the appearance of two Caissons one inside the other—the two skins being braced together in such a manner that the space between was converted into a series of independent chambers, which, filled with concrete, served for weighting the Caisson at any given point, a device resorted to in the case of the cutting edge coming into contact with any exceptionally hard substance.	
Temporary Caisson.	The height of the permanent Caisson not being sufficient to exclude the water at flood tide, temporary iron segments of the same radius were bolted on to the top, amply high enough to answer their purpose under all conditions.	37 0·53
	At the level of the top of these segments a platform of substantial character was constructed, from which most of the ensuing operations were carried on, the concrete however,	
Working Platform.	being mixed upon a special platform at a somewhat lower level. From the floor already described—which it will be remembered divides the Caisson into two distinct chambers—	14
Shafts.	to this platform three shafts were conducted, two for the purpose of raising materials, and the third for the access and egress of men to and from the air chamber, an iron ladder being adjusted inside the latter for this purpose.	0·61
Lock for Material.	The material shafts (diameter 3 ft. 6 in.), were supplied with sliding doors actuated by hydraulic power, which were specially designed for the occasion; but it is to the third shaft and the use thereof that attention will now be called.	0·17
	The lower chamber having no bottom, and the shafts by	

Incidental Reference.		Ref. No.
	which it is connected with the air above being open, it is obvious that the water will rise in them to the level at which it stands outside, so that until means have been adopted for expelling the same no descent can be made.	
	The mean pressure of the atmosphere at sea level being sufficient to support a column of mercury 30 inches, or its equivalent a column of water 32 feet high, it is obvious that for every 32 feet of water outside, a pressure equal to one atmosphere, *i.e.*, 15 lbs. to square inch, will be necessary to expel the water from the air chamber.	
	Before, however, any pressure can be brought to bear upon the water in the working chamber, it is evident that all pipes conducting to and from it must be hermetically sealed. This done, and a means of access having been provided by an air	
Air Lock.	lock—a chamber within a chamber—fitted with iron doors opening inwards, and fitted with rubber washers to ensure an air-tight joint, the pumps may be set to work, and the necessary pressure brought to bear upon the water in the chamber below.	0·29
	Assuming the cutting edge of Caisson to have over it a head of water 50 feet in height, it is clear that a pressure equivalent to the weight of that column of water must be provided.	
	As a head of water 32 feet necessitates a pressure of one atmosphere (15 lbs.) obviously a head of 50 feet will require half as much again, hence the total pressure requisite to counteract the weight of 50 feet of water will be about an atmosphere and a half, or 23 or 24 lbs. per square inch.	
	Supposing the compressors to have been set at work, and the pressure necessary to expel the water from the air chamber provided, we may now enter the lock with a view to descent.	
	Having done so, we find ourselves in a confined chamber containing an inner door, which conducts directly into the compressed air.	
	Before, however, we can open this door, which is sealed by a pressure of many tons from within, we must equalise the pressure in the two chambers. To effect this we close the outer door, and by means of a valve provided for the	

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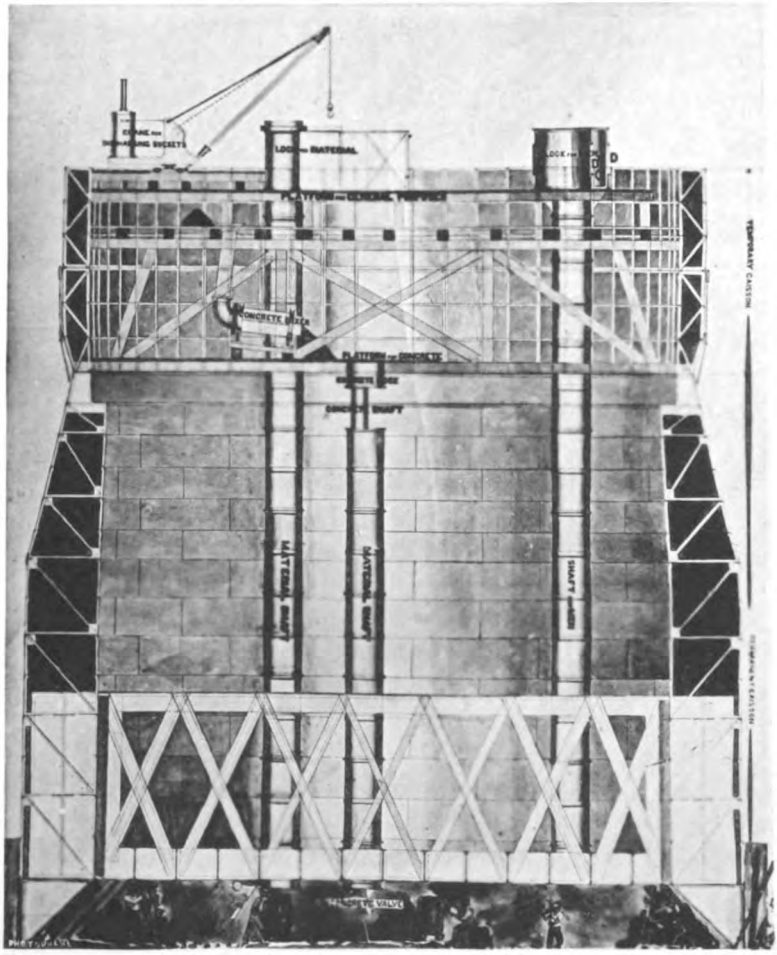
purpose admit the compressed air to where we are standing until the outer door is sealed by the newly admitted pressure, at which point, the atmosphere in the two chambers being now the same, the inner door swings open, and we are able to continue our descent. This we accomplish by means of iron ladders adjusted within the shaft, the hydraulic lift supplied for this purpose never having been brought into service, and in due course reach the air chamber, some ninety feet below the level at which we have entered the lock. Hitherto we have been assuming that we are making a descent at Queensferry pier soon after the Caisson has been placed in position, but for our present purpose we shall suppose the work of sinking to have been in operation for, say a fortnight or more. At this period we find the air chamber—which may be not inaptly described as an immense submarine vault, 7 feet in height and 70 feet in diameter—illuminated by the electric light, occupied by gangs of men busily engaged in excavating the boulder-clay in the bed of the river, and tumbling it into little skips placed on trollies, running on miniature tramways, which radiate from the bottom of the shafts, up which the material has ultimately to pass, to all parts of the chamber. Here and there is a spade specially designed for the purpose, and actuated by hydraulic power, and which, perhaps, might be more accurately described as a "mechanical cutter," as its office is confined to slicing off square slabs of clay—some sort of heading having been first prepared—which were finally picked up and loaded into the skips by hand. That the roof of the chamber afforded the necessary resistance to receive the thrust of an hydraulic ram, coupled with the fact that much of the material to be excavated was of a nature that lent itself to such manipulation, has to answer for the success with which these mechanical contrivances were adopted.

Electric Light.

Hydraulic Spade.

So far as the four Caissons employed in the foundation of the Queensferry Pier are concerned, operations varied only according to the different proportions of mud and boulder-clay to be dealt with, but in that of the two deep water piers



QUEENSFERRY S.W. CAISSON, (SECTION OF).

Incidental Reference.		Ref. No.
	at Inchgarvie new elements had to be contended with in the shape of the exceptional contour of the ground and the presence of formidable rock, owing to the shelving character of which it was necessary to take elaborate precautions with a view to keeping the caissons in an upright position. In the	73
Shelving Rock.	diameter of the Caisson itself the rock shelved no less than 20 feet, and as it was necessary that it should bed on the rock all over, excavations had to be effected to this depth at least, the caisson in the meanwhile being continually kept in a condition of equipoise.	
	To accomplish this, as the caisson, being circular, could only touch the rock at one point, it was necessary to provide temporary supports elsewhere. A rampart of sandbags, many thousands in number, was provided for this purpose, the bags being thrown in from a circular raft moored over the site, forming a bank extending round to the highest level of the rock.	
Sandbags.		0·53
	These bags were adjusted by divers, and in addition two piers of concrete in bags were built up at the most favourable points, so that the caisson should have always three solid points of support.	
	Generally speaking, and in spite of the seemingly overwhelming difficulties of the situation, the work of sinking these caissons was conducted with as much expediency and freedom from unlooked for obstacles as could have been desired. A few amusing incidents are associated with this interesting feature of the work, one of the most novel, perhaps, being the	
Diver.	*entrée* of a diver, who had been engaged round about the rampart of sandbags, into the Caisson itself, attracted thereto by the rays of light projected beneath the cutting edge of the caisson—at this period many feet above the bed of the river—by a brilliant arc lamp suspended in the air chamber; though beyond scaring the man and startling the spectators, this little diversion was unattended by any untoward result.	
Greatest Depth.	The greatest depth to which any of the Caissons were sunk was about 90 feet below high water. With one exception they	

Incidental Reference. —

Ref. No. —

were all built, launched, and sunk, without any serious mishap; of this exception more hereafter.

Compressed Air.

The effect of compressed air on the human system is too well known to call for any remark; like many other unnatural conditions, though it may in moderation be indulged in with impunity by anyone free from grievous physical defects, if undue liberty be taken with it the consequences are apt to be disastrous.

Of the various scenes associated with the earlier stages of the work, those in connection with the sinking of these immense cylinders were undoubtedly the most attractive, and of this interesting department the chambers themselves were naturally the most interesting feature. The extraordinary dimensions of these submarine vaults—their difficulty of access—the efficiency of the incandescent lamps depending from the roof, and the consequent absence of the smoke and dimness inseparable from candle illuminations—the busy air of activity imparted to the operations by the presence of the mechanical diggers, trollies, tramways, and in some cases rock drills—the noise of the in-rushing air—the sense of danger entailed by the knowledge that one was for the time being excommunicated from the upper world—the novelty of one's surroundings generally, all combined to impart to the visitor some of the weird sensations described by Lytton's celebrated hero in "The Coming Race," when, deep down in the bowels of the earth, he found himself for the first time in the land devoid of sun.

Casting of Caisson.

Before closing the subject, a few words may now be added respecting the accident to Caisson above referred to, viz., the north-west of the Queensferry group.

Indirectly, the capsizing of this Caisson was due to the slope of the bed of the river at this point, and perhaps it is not too much to say that if it had been level the accident could never have happened. From the moment of being launched it seemed destined to give trouble, and a great amount of anxiety was experienced for its safety while it was being towed into position, for a strong westerly wind having sprung up, it was

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only by the greatest exertions of those in command of the tug-boats, supplemented by those on shore, that the Caisson was kept in hand. This was finally effected by means of connecting it with a steel hawser led to steam winches on the stage, alongside the east end of which it was eventually moored, being warped round to its destination on the following day.

To understand what subsequently took place it is necessary to explain that for some days after these Caissons were in position they were permitted to rise and fall with the tide, resting or not upon the bed of the river, according to the amount of material within.

The week previous to the catastrophe some 3000 tons of concrete was deposited in this caisson, but in order that it might have perfect liberty to rise and fall with the tide during the ensuing New Year Holiday, loading was stopped at mid-day on Friday the 30th of December, and on the night of the 31st December 1884 it rose in the usual manner with the flood-tide. A steel hawser had been placed round the body of the caisson and led back to the staging, where it was carefully secured. This precaution and others were necessary—the Caisson having already an inclination outward, and a tendency, on account of the slope above explained, to leave the wailling against which it rested when in position.

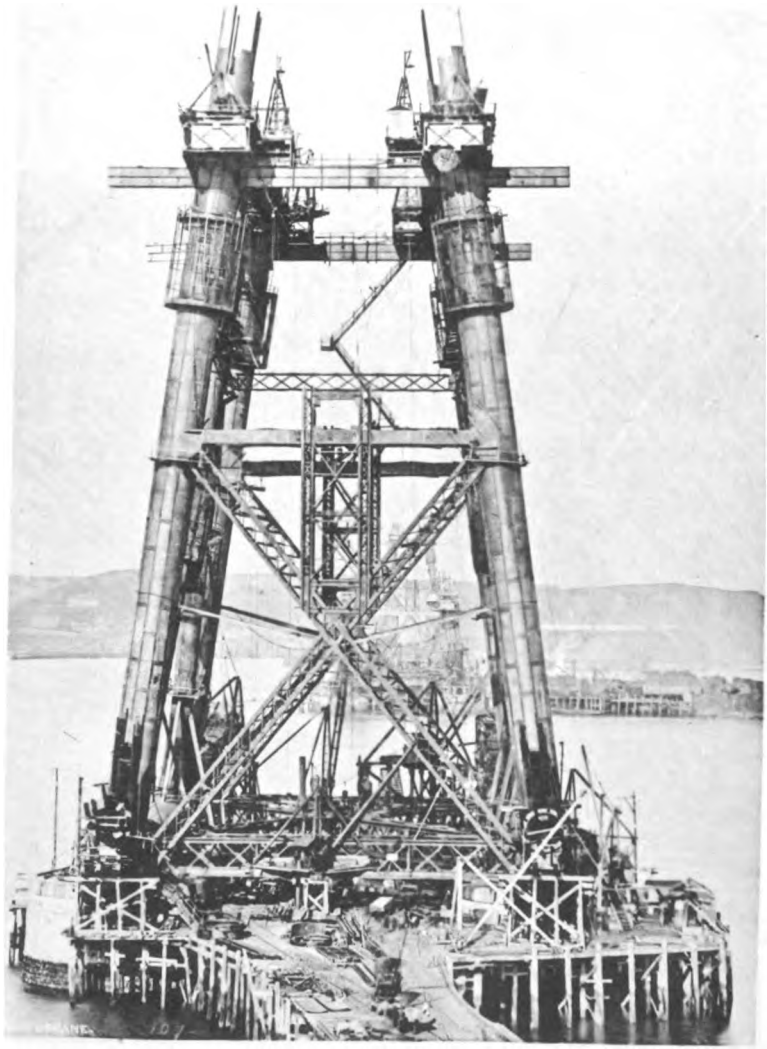
Precautions.

On Sunday, January 1st, 1885, an exceptionally calm day, it was observed that for some inexplicable reason the Caisson did not show the usual signs of floating with the incoming tide.

The period that elapsed before any movement took place was considerable. That the mass was under the influence of an enormous aquatic force was evident, as was also the fact that, if suddenly released, it would come up like a cork, snapping everything that had been provided to hold it.

For the space of an hour or two the water lapped into the Caisson with the natural rise and fall of the swell always perceptible at the approach of the flood, and later on flowed freely through the upper plates, the joints of which, no such emergency having been anticipated, had only been temporarily

Incidental Reference.		Ref. No.
	made. Though gradually loosing its equipoise, the caisson still maintained a fairly upright position, but as the tide rose and the water flowed freely through the unplugged rivet holes it canted considerably, and before the ebb, had heeled over so far as to permit the inflowing water to create, in a few seconds, an amount of damage, to repair which occupied many months.	
Angle.	The angle which the caisson ultimately assumed was very considerable, so great in fact, that at high water more than a third of it was submerged, though fortunately, its new position once assumed, it remained stationary. Many schemes suggested themselves by which it might be righted, and that ultimately adopted—a previous experiment having proved unsatisfactory—was the conversion of the submerged cylinder into a giant cask.	36
Wooden Ring.	With this end in view a massive wooden ring was constructed, made in segments and bolted through the iron-work in a corresponding position to the head of a cask, and firmly	0·46
Struts.	strutted and braced in every direction.	42
Piles.	The sides or staves were composed of whole timbers, the edges of which were bird-mouthed, each joint being lined with felt. These piles which, in many cases, owing to the depth of water, had to be scarfed, were bolted together in pairs. When thus prepared they were placed in position and secured to the caisson, which, by degrees assumed the nature of a perfect cask, steel hoops to correspond with chime, quarter, and bilge, being afterwards added and duly tightened up.	36
	The space due to taper and distortion existing between the timber-sheeting and iron-skin was filled with Portland cement. All that timber, bolts, and chains could do, was done to stiffen the caisson inside, and the whole structure both within and without presented a unique appearance and afforded a spectacle of exceptional novelty. Some eight months after the accident pumps were set at work, the effect being to slightly lift the caisson, but it was not until some time after, that the success of the scheme became evident, the consummation of which	
Caisson Floated.	took place on 19th October 1885 when the caisson was once more afloat and moored in its original position.	0·47



QUEENSFERRY CANTILEVER, AS SEEN FROM N. END OF APPROACH VIADUCT, MAY 4, 1887.

Incidental Reference.

Ref. No.

Cantilevers

THE Cantilevers upon the Queensferry and Fife shores coincide in every respect, but whereas the piers upon which they are reared form a rectangle of 120 feet by 155 feet, those carrying the Inchgarvie superstructure, though a corresponding distance apart east and west, if measured on the centre line, give, it will be remembered, an additional 115 feet. 7 & 8

In consequence of this fact the work and material at that point is heavier than at any other part of the bridge.

This being the case, Inch Garvie Cantilever, which varies from the other two only in this respect of dimensions, may suitably be selected for consideration, as generally speaking remarks applicable to it are equally so to the remaining two. In brief outline this cantilever is composed of 4 vertical columns, 2 upper and 2 bottom members, 28 struts, 24 ties, and the indispensable quantity of wind and additional bracing. 9 & 11

Though described as vertical, the columns referred to are accurately speaking very far from being perpendicular, and regarded from the centre line of the bridge assume an appearance not unlike a pair of gigantic sheer legs, though the resemblance is somewhat qualified by the fact that their centres are upwards of 30 feet apart at the top, whilst considered as a whole the 4 columns with the several members completing the heart, so to speak, of the cantilever, suggest the outline of a wedge, thin end upwards, having for its base a rectangle of the dimensions already given. 76 97 21

Sheer Legs 0·59

Wedge Outline. 140 21

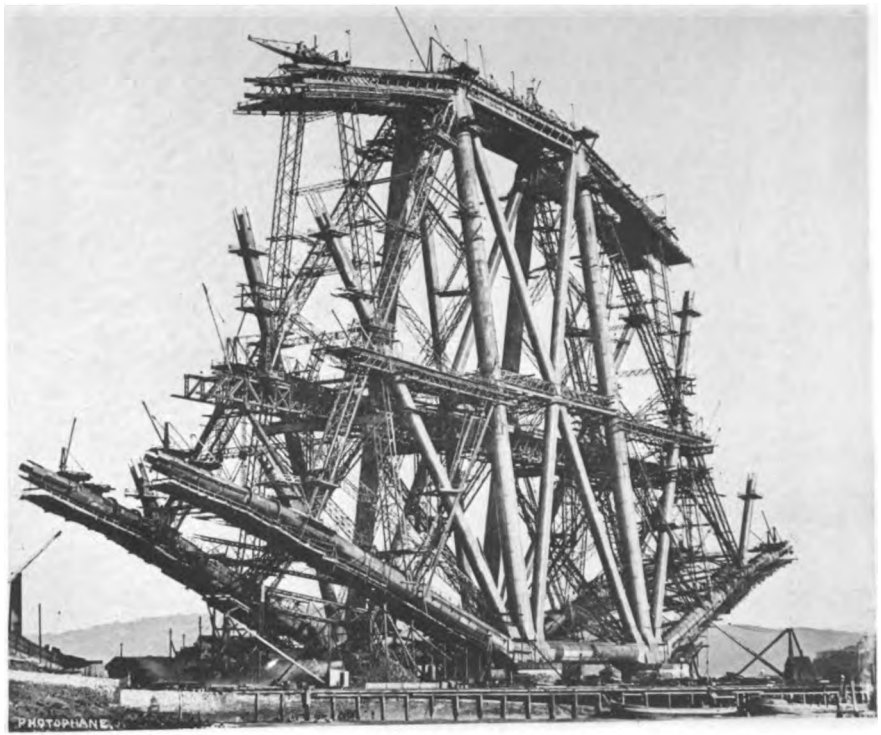
Vertical Column.

These columns spring, not from the actual centre of the piers, but from a point inside, in order that the weight of structure shall be concentrated around centre of same. 130 153

Upon each pier is placed an upper and lower bed plate, the latter being composed of several thicknesses of steel plates rivetted together and weighing something like 40 tons.

These plates are furnished with holes to admit the heads

Incidental Reference.		Ref. No.
	of the holding down bolts previously described. Upon this lower one the upper bed plate rests constructed so as—though connected with the superstructure—to be free to slide on the rigid plate beneath.	
Skewback.	This plate forms the base of what is known as the "Skewback," that being a term employed to indicate the junctions formed by the various compression members upon each pier. In its modified form the "Skewback" might be likened in shape to an ordinary cigar box with a curved lid, and it is	0·27 2
Junctions.	about these junctions that the principal strains of the various parts of the cantilever are concentrated. As might therefore be expected, the "Skewbacks" are of immense strength and considerably complicated in detail.	0·23 59
	But to return to the vertical columns; these are 12 feet in diameter throughout, in common with the bulk of the work being composed of Siemens Martin steel plates, and diminish in thickness towards the top.	
	As some miles of tubing similar in construction, though of varying dimensions, were necessary for the erection of the bridge, it was most desirable, not to say indispensable, that a really expeditious method of dealing with the same should be adopted at the outset.	
	The plates supplied for the purpose were just as they left the rolling mills of the manufacturers, and the first process to which they were subjected was heating to red heat in a gas furnace, from which they were duly extracted and placed in a bending press fitted with a die of the desired curve, and actu-	
Hydraulic Press.	ated by hydraulic rams capable of exerting a pressure of some 1500 tons.	0·44
	To counteract any twisting taking place after this operation it was found necessary to give them an extra squeeze when nearly cold, whereupon they were transferred to that	
Drill Roads.	part of the works known as the "drill roads."	55 58 15 39
	As punching these plates was not admissible, each hole required to be drilled, and as the number of these holes was estimated at over 5,000,000, special machinery was requisite	



FIFE CANTILEVER FROM W. SIDE. MAY 7, 1888.

Incidental Reference. — | Ref. No.

and duly designed for the purpose. The novel character of this design will repay the few moments of attention that it invites. Upon a carriage are mounted two cast iron rings having an internal diameter of upwards of 12 feet. These rings, which are vertical, and some distance apart, are connected by four other castings, upon which the drills—to the number of eight—are adjusted. To the same carriage are attached an engine and boiler for giving motion to the drills, a result effected in an ingenious manner by an endless rope. The same engine and boiler give locomotive power to the whole machine.

Core. Round about a core, consisting of an iron tube, flush on the outside, which is supported by tressels upon the framework between the two lines along which the machine travels, the great tubes of the permanent structure were built up horizontally.

12/t. Tube. The rings of the machine now encircle the tube, and as the drills are radiating and capable of circular as well as horizontal motion, they command every inch of the surface to be operated upon. The tubes, which were temporarily bolted together in lengths, were taken to pieces again as soon as the drills had passed over them, and transferred by various means to the most convenient situation till required for use. These drilling machines, in spite of their somewhat formidable dimensions, are remarkably compact, and are protected from the weather by corrugated iron casing. 18

Tubes, interior of. 28 54

The total height of the vertical columns from the surface of the piers to the upper side of top member is rather more than 340 feet; and while preserving a rectilineal form in a longitudinal elevation they incline toward each other in a transverse section, as previously explained. 24

Bottom Member. **Bottom Members.**—This is a term applied to the tubes forming the underside of the arms of the cantilevers, and which, owing to their proximity to the ordinary spectator convey better perhaps than other features of the design the gigantic proportions of the structure; for notwithstanding their enormous dimensions they are strangely insignificant when con- 117*a*

Incidental Reference. | Ref. No.

sidered in conjunction with the span to be bridged. At the point where these tubes leave the "skewback" they are of the same diameter as the verticals, which however decreases towards the junction with first main tie, where it is reduced by 1 foot 6 inches, which dimension in its turn is again reduced toward the next junction, and so on with reductions throughout each length to the cantilever end. The bottom members are in point of fact continuations of the horizontal tubes running from pier to pier, but decrease their diameter as above explained after

Junctions. leaving the vertical columns. The junctions of these bottom 154
members may be fairly described as resembling on a smaller scale, the "skewbacks" on the piers.

There are six lengths of this tapering tube in each bottom 30
member, the whole, though each section is straight in itself, forming the two curves which the central girder ultimately connects, having a total projection of 680 feet from centres of column.

60
Top Members.—These are the great tension members con- 69
necting the vertical columns at the top, and running down on 141
either side toward the extremities of the bottom members. 10
Each of these members consists of a pair of box lattice & 13

Spaced. girders. They are spaced at top of columns 33 feet centres, gradually closing on each other towards their extremities, where they are a little more than 22 feet apart.

Each girder has a depth of 12 feet, which is reduced in the same manner as the member below. So that not only do these girders make an angle with the vertical plane of the centre line, but each being built throughout on a taper their sides are not parallel with each other, hence it will be readily imagined what ingenuity and calculation the design of so complicated a structure demanded.

As in the case of the bottom, these members are practically continuous throughout the whole length of the cantilever, though between the columns the material of which they are 37
composed is somewhat heavier than at any other part.

Incidental Reference.

Ref. No.

Struts.—By reference to photograph No. 1 the total number of struts in each arm of cantilever will be seen to be 12, and between the vertical columns 4. Their internal arrangement is the same throughout, and the means adopted for their construction precisely the same as that employed in connection with vertical columns, from which however they differ not only in dimensions but also in section. Like the verticals, they are cylindrical in form but are flattened on two sides. This modification offers considerable advantage, as each in its course from the bottom member to the top has to pass through a corresponding tie, and these flat sides must necessarily admit of a more substantial joint than would be possible in the case of perfect cylinders. 129

Section of 17

The two intersecting between the vertical columns are of the same diameter (viz. 8 feet) as the corresponding ones rising from the same base on the outside of the former. 113 27

No. 2 strut is less in diameter by 1 foot, and proportionately lighter in material; it is not parallel with No. 1, increasing its distance from same as it nears top member, which it strikes at a point about 333 feet from column.

And so on with the remainder, each one having a little more rake than the former, and the smallest being about 75 feet long, and like the last lengths of bottom member somewhat modified in its construction.

Ties.—As in the case of the struts, the ties are all similar in construction, varying only in their several dimensions. The first tie is connected with the main vertical column directly under the joint formed by the top member. 162 148 145 39

Form. In shape the ties are rectangular, and in detail a series of lattice girders interwoven with angle iron bracing.

The first tie strikes the bottom member at a distance of 190 feet from base of column, so forming a cross with first strut, and constituting part of the joint from which the second strut springs. In the same manner, the second tie again forms part of the joint of third strut, and so on throughout, every tie

Incidental Reference. —

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being met by a strut, and every strut by a tie, so that a side elevation of the bridge presents a series of diamond-shaped figures, becoming rapidly smaller as the centre of span is approached.

Vertical Ties.—In addition to the main ties the, bottom member, owing to the length of each section, requires further support. To this end, at certain points between each joint, a secondary tie is provided. These are carried up to, and form junctions with, the main strut and tie directly above them, and whilst serving to stiffen the lower tubes, at the same time form a vertical support for the internal viaduct. 149 18

Auxiliary Tie.

Like the main ties they are in shape rectangular, decreasing in dimensions towards upper joint.

Central Girders.—The extremities of the Cantilever arms, projecting over the deep water channels, are respectively connected by two large girders, one end of which is rigidly attached, whilst the other is left free to allow for expansion, &c., and in such a manner that the total amount of same cannot represent more than is due to about one-sixth of the whole length of Bridge between Cantilever piers. 40

The extreme length of each girder is 350 feet, with a depth of 50 feet at centre, and 41 feet at the ends, while their weight, as previously stated, is something like 800 tons each.

The above form the essential features of a brief outline of the works of the Forth Bridge. To obtain fuller and more minute particulars of this remarkable undertaking is left to our readers themselves, the remainder of the space at our disposal being devoted to the various details of interest comprised in some of the most important pictures of the several series.

NOTE.—Large figures in margin refer to detail Photographs (18 in. by 24 in.), small figures to the more ordinary sizes.

DIMENSIONS are in some instances approximate.

VIEW FROM DALMENY PARK. SEPTEMBER 26, 1888.

Incidental Reference.

Ref. No.

Description of Large Illustrations

(SIZE 18 by 24—PUBLISHED SEPARATELY).

THE following brief remarks taken in conjunction with the foregoing sketch, necessary by way of explanation to the detailed work of the large Photographs, will it is hoped answer all the purpose for which these few pages are intended.

In a number of cases artistic effect has been sacrificed to clearness of detail, against which, however, bright sky backgrounds, deep shadows, and volumes of smoke persistently militate. As a guide to the selection of pictures, it should here be explained that for end elevations South Queensferry pier only should be chosen; for side elevations, taken from points nearly at right angles to centre line, those of Inchgarvie; while for general views, those of the superstructure on the Fife shore, as offering facilities foreign to either of the other two, are to be preferred.

Incidental Reference. | Ref. No.

No. 1.—The Bridge Complete.—*From a Drawing by the Author.*

No. 2.—A "Skewback."—Relative proportions of the men and their work in this view afford an admirable illustration of the remarkable dimensions of the Bridge. The five tubes shown represent the bottom members, the vertical column, and two struts 8 feet in diameter. The bottom member on the right hand side is part of the first length of the span, and is continued at this angle until it meets first tie.

Cage. Surrounding one or more of these tubes will be noticed a cylindrical cage composed of angle iron, hoops, and bars, and protected by a fine mesh wire netting. 63

To the upper part of these cages were bolted iron straps passing up and connected to the lower side of lifting girder, so that when the latter ascended it carried up the cage along with it. These cages, within which all the rivetting of the vertical columns was effected, were designed to ensure the safety of the workmen, for which purpose they proved invaluable.

The depth of each cage was sufficient to admit of a 16 feet plate being rivetted up without a hoist, the working space allowed between tube and netting being 4 feet. The difference of shades upon the horizontal tube in the foreground of picture is only due to the fact that it was being used at that date as a suitable surface for testing various samples of light coloured paint.

Nos. 3 and 4.—Fife Superstructure (Lifting Girders and Platforms).—Owing to the fact that the Fife cantilever occurs on the foreshore and is overlooked by rising ground to the north, it afforded an opportunity of obtaining certain views not practicable in the case of the other two. Not only did its situation admit of perspective effect being duly emphasised, but also

Rectangular Form. that of the rectangular form of the structure, only apparent when 64

70
94

Incidental Reference.		Ref. No.
	each vertical column is separately defined. The cages referred to in No. 2 are all seen here in position prior to the first lift. Up to this level the superstructure was erected by means of ordinary cranes and staging.	91
	In the vertical columns, and at a height of about 30 feet above the surface of the pier, a plate was omitted on either side	74
Gap.	of the same. In the gap thus formed were built two box girders, having a dimension of about 5 feet by 2 feet. Superimposed upon these girders were what were subsequently	96
Lifting Platforms.	known as the lifting platforms—comprised of material destined to be ultimately worked into the permanent structure—and through which the upper ends of the vertical tubes and struts projected.	65*d* 96
Girders, &c.	The total weight of these four girders and their accessories amounted to about 400 tons, the whole being supported by and lifted from the vertical columns in the following manner:— Inside each of these columns were constructed two frames, the upper side of the one being connected to the lower side of the other by means of hydraulic jacks contrived in such a way as to oscillate in a plane at right angles to the centre line of bridge. Through the ribs of the columns holes were drilled at equal	67
Steel Pins.	distances apart, and into these holes steel pins were inserted supporting either frame. Everything being ready for a lift the jacks were set in motion, the thrust being taken by the lower frames and duly transmitted to the pins. At the end of the stroke pins were inserted below the under side of upper frame and the jacks eased, whereupon the whole weight of the platform came upon the upper frame, the lower one, simultaneously drawn up by the closing of the jacks and secured by pins, being at once in readiness for another lift.	
Progress.	The rate of progress was to a large extent governed by the weather, but under favourable circumstances it was extremely rapid, as many as three lifts having been effected in eight days and the necessary rivetting accomplished in the cages attached.	
	The tension girder connecting the vertical columns from east to west is noticeable in the foreground of the picture, as is	

Incidental Reference.		Ref. No.
Gallows.	also a part of the diagonal bracing, which is designed to afford the principal support for the internal viaduct. The gallows so conspicuous above the vertical columns on the lifting-platforms answer the purpose of cranes, and were employed in lifting and holding the plates in position until temporarily bolted. The means of access to the upper part of the structure, independently of lifts, is shown in the staircase running up the diagonal bracing and subsequently continued in a similar fashion to the full height of the superstructure.	100
	Nos. 5 and 6.—General View from High Ground back of South Queensferry.—These views make an angle of about 35 degrees with the centre line, and were taken when Queensferry cantilever was ready for first lift, that at Inchgarvie being less advanced, while the superstructure at Fife, on the other hand, was already a conspicuous object in the background.	151
Guard Ship.	H.M.S. *Devastation* lying mid-stream may help those acquainted with her dimensions to realise the formidable extent of the gaps to be spanned. As records of progress these pictures are extremely interesting, while the large expanse of water studded with the islets for which the Forth is famous, the ships lying at anchor in St David's roads, and the cornfield forming the foreground of the picture, all combine to contribute to a most pleasing effect.	44 0·52
	No. 7.—Fife Superstructure from Sea Shore.—This view was taken from a spot only approachable two or three times a year, namely at the lowest Spring Tides. It serves well to show the progress of the work since the last of its kind. The bearing is about S.E., and the columns in the foreground scale 12 feet to the inch. The view was secured just prior to a lift, a fact clearly indicated by the plates of tubes above lifting platform, which are finally adjusted and ready for rivetting.	67
Internal Viaduct.	The internal viaduct with one of its main supports on the diagonal bracing is just being commenced.	104 14

Incidental Reference. — | Ref. No. —

It will be noticed that whilst the cages on vertical columns are ascending with the lifting platforms those in the struts are generally at a lower level. This is due to the fact that it was found impossible to finish the rivetting therein without hindrance to the surrounding work; they were therefore left behind, and hoisted independently at a later period. At this level lifts were provided both for men and materials, though for some time many of the former preferred to avail themselves of the substantial staircases already alluded to. The introduction of a safety grip adjusted to each lift, however, gave the men additional confidence, and their use quickly became universal.

Safety Grip.

No. 8.—Queensferry Superstructure, showing Arrangement of Lifting Platforms.—Here we have the work at a stage between that of the two pictures 4 and 7. The picture having been secured from a point a little to the left of the western columns, a good general view showing relative progress at Inchgarvie and Fife is also obtained. As an illustration of the arrangement of lifting platform already described there is no other in the series to equal it, the upward progress not being sufficient to interfere with the perspective. — 102 — 12

No. 9.—Inchgarvie Skewbacks, erecting.—This is the first view in the series of Inchgarvie superstructure. To any one familiar with the island the difficulties in the way of securing good pictures in boisterous winter weather must be obvious, and if this photograph, which was obtained in a storm of hail and sleet, is not therefore all that might be wished, due allowance must be made. The "skewbacks" are here complete, and the connecting members between north and south piers seen at full length. Staging for lifting platforms is in course of erection, a portion of same being already in position. — 34

Island.

No. 10.—Top Member Joint, Detail of.—This picture is exclusively a detail one, and should therefore only be selected

Incidental Reference.		Ref. No.
	by those anxious to become familiar with the method adopted to connect tubes and girders at their various junctions, for whom the fellow copy "No 13" will prove invaluable.	
	The joint illustrated is junction of vertical column with top member, together with a strut and a tie. Dimensions of the various members are given elsewhere. They are here represented by 4¾ in., 6 in., 3 in., and 7 in. respectively. The member is shown upside down, this being the position in which it was built in the yard.	
	No. 11.—Inchgarvie, showing Completion of Lifting Platforms.—This view is much the same in detail as No. 9, a period of three weeks only having elapsed, and represents the mass of material employed in the construction of lifting platforms.	
	The cranes and various machines on same are clearly depicted, and a large amount of the detail, invaluable to anyone	15
Primary Preparations.	requiring information upon primary preparations for erection of this, the largest cantilever, is secured.	46
	No. 12.—Queensferry Cantilever from End of Approach Viaduct.—Here we have a view taken from a point somewhat to the right of centre line and a considerable height above sea level, as a result of which the perspective of the picture is exceptionally good. Considerable progress is evident, the upper	
Upper Ends of Columns.	ends of columns being already above rail level, and owing to	115
	the angle of the former the box girders are beginning to project beyond them.	106
Diagonal Bracing.	At the intersection of diagonal bracing, the first of the uprights carrying the internal viaduct is conspicuous. The	106
End of Platforms.	solid appearance of the end of the lattice girder platforms is due to the fact that, with a view to utilise inside for rooms, offices, &c., they were boarded in. This is the fellow-picture to No. 7, and was the first of the series taken from a point about the centre line.	102

Incidental Reference.

Top Member.

Ref. No.

60
69
141

No. 13.—Top Member (*Detail of Whole Length between Verticals including Junctions*).—It would be interesting to know the number of visitors who have passed through the works and, being brought face to face with the subject of this picture, failed to recognise in it one of the connecting links at the apex of each cantilever. These members being built at the angle they were finally destined to assume, as well as upside down, it is not surprising that they proved somewhat bewildering to the uninitiated. By reference to No. 1 the position of this member is easily seen—on the tops of vertical columns of Fife pier. These members were built in pairs, and invariably erected in the yard prior to permanent fixing. They have a depth of 12 feet. The foreground of the picture presents a wilderness of steel plates and diaphragms stacked and ready for use.

146
153

No. 14.—Queensferry Cantilever at Rail Level.—For the purpose of examining the detail of the cantilevers we have here one of the very best of the series, the vertical columns being represented on a larger scale than any other view and the work far enough advanced to show entire arrangement of lower half of the superstructure.

The lifting platforms are considerably above rail level. As in the case of Fife, it will be noticed that the cages on the struts have been left behind, whilst those on the columns are rapidly approaching their ultimate height.

No. 15.—Inchgarvie Cantilever as seen from the Landing Stage.—Explanatory descriptions of the work at this point are rendered almost impossible by the fact that the views of Inchgarvie superstructure are mostly taken from the same and only locality.

It will be observed that as compared with No. 11 the whole aspect of the structure has changed, a far more pleasing effect being the result.

Incidental Reference.		Ref. No.
Connecting Boom.	A noticeable feature in this picture is the excessive length of the 12 feet tube connecting N and S piers as compared with the corresponding ones on the Queensferry and Fife sides. This great length obviously necessitated additional support, which was duly provided by the lattice-work tie mid-way between the vertical columns.	
	The platforms were put together as shown in former pictures, and the lifting operations conducted in a manner similar to that employed at the other two piers, with, however, additional jacks and cross-girders in conjunction with vertical tie. The steel plates used in the lower portion of this cantilever are the heaviest throughout the structure. To support the diagonal struts during erection was a difficulty arising from the excessive longitudinal dimensions of this pier, their angle being in this case considerably increased, and was met by carrying up the verticals, and finishing the struts independently of same, later on, by means of steel ropes and cranes worked from the platforms above.	
East Side.	**No. 16.—Fife Cantilever from East Side.**—The point from which this view was secured offers absolutely no advantage unless it be variety, since owing to the immense height of the structure and the insignificance of the surroundings distortion is inevitable.	130
	Much progress will be observed in this picture by comparing it with No. 7. The joints formed by intersection of struts are only temporarily made, and about them are shown first lengths of horizontal lattice girder, forming when complete a rectangle some few feet above rail level. The square	
Square Cages.	angle-iron cages at the extreme end of the bottom member correspond to those employed for a similar purpose on the	66 117
Hydraulic Crane.	vertical columns. They are surmounted by a 2 ton hydraulic crane of special design. These cages travel along the tubes as the rivetting progresses, being detached and remounted at each joint.	108

Incidental Reference.		Ref. No.
Cage on Member.	**No. 17.—Fife from Village Pier (West Side).**—The rivetting cages alluded to in the preceding picture can here again be seen on both the bottom members which were carried out to a distance of about 100 feet without any external support. The upper ends of verticals are rapidly nearing each other, which accounts for the lengths of box girder projecting on either side, the shortening of which has already commenced, as is evident from the eastern arm of same.	117
	No. 18.—Inchgarvie after first three Lifts.—Just one month has elapsed since last view of Inch Garvie was secured. The picture is taken from a point a little south of line running between the vertical ties, thus closing the southern main tubes, and consequently affording a clear view of the work. The platforms are rapidly creeping away from the struts, which have now to be supported by chains from above. Though there are more imposing pictures in the series, there are none which afford a more detailed view of the working arrangements at this point.	
	No. 19.—Queensferry Cantilever two-thirds Full Height.—Similiar to No. 14, but showing the work much advanced. The 12 feet tubes are represented by rather more than 1 inch on the paper, and the whole arrangement of lower bracing supporting internal viaduct is shown in every particular. By reference to No. 1. an idea of how far the work had advanced when this picture was secured will easily be obtained, as of the three diamonds formed by wind bracing, this view just includes the lower two.	
Wind Gauge.	**No. 20.—Inchgarvie from Wind Gauge on Castle Ruins.**—Here we have a picture similar to No. 18, but with a rather different foreground and less detail. The staging being parti-	0·27 31

Incidental Reference. | Ref. No.

ally removed, the lower portion of the structure stands out boldly, and the general effect is pleasing.

Sheds to the right in the foreground are those containing electric light machinery, &c., while the platform to the left is the landing stage for passenger boats, with a background conspicuous in which will be noticed top of a temporary Caisson still intact.

The method adopted for supporting diagonal struts independently of chains is here shown in the shape of the small lattice girders running parallel to the portion of bottom members directly underneath.

No. 21.—Queensferry Cantilever at Full Height from North End of Approach Viaduct.—By many this picture is considered the finest in the series, and in addition to its artistic merit, the gigantic proportions of the structure are presented in a manner that cannot fail to prove imposing.

It was taken from a point about 100 feet above the water level, and a little to left of centre line looking due North, thus permitting the verticals to show clear of each other.

Inchgarvie superstructure is plainly visible through the wind bracing, as is also the whole of the island itself. At the time the photograph was taken the work was suspended, hence its exceptional clearness, and the general absence of workmen. The columns appear far in advance of the bracing, though the points it will strike are indicated by temporary stages or cross struts.

A curious effect is produced by projecting end of box lifting girders, which have not been shortened since the lifting commenced.

Point of Selection. From top to bottom of this picture each plate can be seen distinctly, and though the point of selection was over 600 feet from the columns, the rivet heads can for the most part be counted. As a general picture this view is to be highly recom-

Incidental Reference. | Ref. No.

mended, as the particular effect can never be reproduced in the future owing to the nature of the design.

Nos. 22 and 23.—General Views of the 3 Cantilevers from South Shore.—These views were taken about the same time, viz., on the occasion of Queensferry superstructure attaining its full height, hence the flags thereon. They differ only in respect of bearing, No. 23 making the larger angle with centre line of bridge. 25

No. 24.—Fife at Full Height from Village Pier (Fellow-Picture to No. 21).—A picture taken from a North-Westerly position, so that the 4 vertical columns and 2 pairs of struts are all clear of each other.

The foreground is exceptionally fine, for the day having been absolutely still, the heavy shadow of the tubes are reflected in the smooth water, which, together with the steamboats lying at the pier, produce an effect rarely seen in a picture of this class, and combine to make this view one of the most popular.

No. 25.—General View from Port Edgar.—This is a distant view through the trees, showing Queensferry and Fife piers at their full height. The angle made with centre line of bridge is such that the south vertical columns of Queensferry close upon each other, a very open picture being the result, and an excellent one for illustrating the relative proportions of the height of superstructure and the extent of spans. 89

The chain stretching from rail level to bottom member was a temporary tie, of which more hereafter. The foreground of foliage affords a good contrast to the expanse of water beyond, and this picture is therefore to be recommended to those who set more store on artistic effects than scientific records.

Artistic Effects.

Incidental Reference.		Ref. No.
	No. 26.—General View from East End of South Queensferry.—We have here a view taken in the vicinity of Queensferry Station. It embraces the three Cantilevers, the northern approach Viaduct, and a few spans of the latter on the south side. The foreground is again comprised chiefly of foliage, the Queensferry superstructure standing out well against the distant hills. Respecting the progress of the work, Fife and Queensferry Cantilevers are at their full height, and that at Inchgarvie 200 feet above water level.	
	No. 27.—General View from Dalmeny Park at Water Level.—With the exception of one detail Photograph, this is the only picture secured from the East side of Bridge, owing to the receding character of the shore. Having been obtained from a point at a large angle with the centre line, without being too far distant, it is another suitable view for the pur-	16
Span.	pose of showing the gigantic nature of the span. A very good idea of the shape of the Cantilever can be had from this picture, as a few pencil lines joining the upper and lower members with the Queensferry masonry pier show the precise position it will occupy when complete.	9
	At her moorings midway between Inchgarvie and the mainland lies H.M.S Devastation, which, though not half-a-mile to the west of the Bridge, is scarcely more than a speck, whilst the island and its castle—the highest part of which is 100 feet above the water level—is fast dwindling into insignificance.	
Temporary Tie.	Another interesting feature of this view is the temporary tie already referred to, which is here very prominent.	137
	By reference to No. 1 and the general description of same, it will be seen that the distance from centre of vertical column	
1st Tie.	to the point on the bottom member at which the first tie strikes it is 180 feet in a horizontal line. Though owing to their dimensions and general design these 12 feet tubes were	149

Incidental Reference. —

Ref. No. —

able to support themselves with facility, it was considered expedient to limit the unsupported length not only on account of its own weight and the cage it carried (*vide* No. 17), but because such provision would forward subsequent operations. 33

The most satisfactory plan that could be adopted for this purpose was to bring into use some of the permanent work already fixed, and with this end in view the method employed was as follows:—

At a point in the vertical columns some few feet above rail level were bolted plates, to which was attached a chain (comprised of links which had once played a leading part in the construction of old Hammersmith Bridge) stretching to the extreme end of bottom member and screwed up tight. This chain, however, was not, as commonly supposed, intended to take any considerable strain, but merely to prevent any sagg in the tie subsequently constructed. Accurately speaking, therefore, it was a temporary tie to support a permanent one during construction, that actually devised to take the weight of the tube being composed of a portion of top member for Bay 3 (*vide* No. 33).

No. 28.—General View.—We have here a view taken late in the evening, which accounts for the smoothness of the water and the depth of the shadows. This view is chiefly remarkable for effect, much detail at the base of the Cantilevers being lost. 147 132

The picture embraces the whole of Bridge up to date, North of South Cantilever and on a considerable scale.

Approach Viaduct (S. Side).

No. 29.—Queensferry Cantilever and 8 Spans of Approach Viaduct.—One of the few views showing approach Viaduct South Side, but has a slight defect in its perspective, on which account a better view (No. 34) was afterwards secured, and is therefore to be preferred. 133

Incidental Reference.		Ref. No.
	No. 30. — Inchgarvie Cantilever, Three-fourths Full Height.—Here is Inchgarvie Cantilever at about three-fourths of its full height, taken from the Windgauge situated on the	
Castle.	upper part of the old Castle.	0·39
	Three months having elapsed since the last picture of the superstructure of this point was secured much progress is here visible.	
	A large portion of the temporary work in the lower parts having been removed, the joints formed by vertical ties and lower member may be seen to advantage. The completion of horizontal girder work above rail level shows progress that has been made, though at present there are no signs of the internal Viaduct.	
Bottom Member.	The bottom members projecting over the water are here represented as far out as they were carried without external support, as are also the cages used for purpose of rivetting.	117*a*
	The lower half of struts between columns are now supporting each other, the temporary girders represented in No. 20 holding them apart having been removed, but only to play another *rôle* in connection with these same struts at a higher level, for whereas they were originally in compression they are now in tension.	20
	This is another of the views by which the enormous proportions of the structure may be readily realised, for notwithstanding that the picture covers the whole of the paper it is some minutes before a single man can be found, though a little patience will prove the presence of many dozens.	
	No. 31.—General View from North Queensferry Hills.—A view depicting the three cantilevers at very nearly their full height. The rising ground some 100 feet above sea level at point from which it was taken being well adapted for securing a good position, the artistic qualities and perspective of this picture leave nothing to be desired.	
	The foreground, chiefly composed of foliage, is somewhat	

Incidental Reference.		Ref. No.
	hazy, a result due to an almost imperceptible motion imparted to it by the wind, though, so far from detracting from it, this feature adds to the general effect of one of the most successful pictures yet secured. To the west of Inchgarvie may be seen what appear like a few sticks floating in the water, which prove, however, upon close inspection to be the most formidable Oregon spars, no less than 100 feet in length and 3 feet in diameter, strapped together with iron bands in bundles of three each to form a protection to the piers on Inchgarvie. As they were exceptionally fine spars, their combined weight was considerable, and offered much resistance to the rough water and strong down tides, and therefore necessitated moorings of exceptional strength and character laid down in over 200 feet	32
Moorings	of water. The essential part of these moorings was a block of concrete weighing some 30 tons, surrounded by an iron frame, the ribs of which projected and were turned at an angle, thus forming a species of grapnel. This is the fellow-picture to No. 36.	0·8
	No. 32.—Bird's-eye View of Inchgarvie and surrounding Country.—A result obtained from the apex of Queensferry Cantilever after it had reached its full height, and a novel effect well worth securing both from an engineering and artistic point of view, the occasion being that of a visit of the Institute of Mechanical Engineers, as a record of which	
Panoramic View.	event this panoramic illustration was selected.	109
	The weather proving favourable, the Ochil Hills and the high ground in the proximity of the Firth of Tay and far beyond is shown very plainly, whilst looking across Inverkeithing Bay and to the north shore, objects appear to be immediately beneath us. The structure of Inchgarvie, and indeed the island itself, presents a most interesting spectacle, and one that will not in all likelihood be secured again for a very long time to come.	

Incidental Reference. —

Ref. No. —

No. 33.—Fife Cantilever, showing arrangement of Platforms for construction of Struts and Ties.—In the way of detail pictures it would not be easy to obtain a more satisfactory view of the Fife south-east skewback and the five tubes uniting at this point than that under consideration. The vertical columns are here represented on a scale of over an eighth of an inch to the foot.

As regards the arrangement of platforms for construction of struts and ties, it will be seen by reference to No. 1 that at a point on the bottom member directly under the junction made by the intersection of each strut and tie there is a lattice girder. These girders are known as vertical ties, and in the permanent structure serve the purpose of preventing any sagg in the lengths of the bottom member.

Vertical Ties.

During the erection these ties were temporarily utilised in the manner shown in this picture, where two of them appear about 3 inches from the outer end of bottom member. Between these a girder of somewhat solid appearance was constructed corresponding to some extent to the box girders used in the main column for lifting, and in fact working parallel to them. Upon the ends of these girders rest others larger in construction and running in the same plane as tubes below. Beneath the former were placed lifting jacks. The end of the platform butting on to the vertical column was operated upon by jacks on the platform above, and as the struts and ties progressed the girders were drawn up at one end and thrust the other, this operation being repeated till nearly the height of rail level was reached, for which *vide* No. 37, where they are shown at their full height.

No. 34.—Queensferry Approach Viaduct and half Span of Cantilever.—This picture embraces all between Inchgarvie and the shore of Dalmeny Park looking east. Its principal merit is to show the relative heights of the cantilever and the viaduct, for which purpose it was secured. The foreground is

139

Incidental Reference. | Ref. No.

comprised of a wide expanse of shingly beach with the tide half out. The viaduct is here shown at its full height.

No. 35.—General View from High Ground situated S.-W. of South Queensferry.—This is a more distant view than the last described, and includes the north span. The foreground of picture is comprised of the old fashioned houses and gardens between the High Street and railway embankment.

No. 36.—General View from Back of Newhalls Inn.— 125 144
A view obtained to meet a continual demand for a picture showing more of the approach viaduct and less of the bridge itself. To this end it was necessary to take up a position which would considerably foreshorten the whole structure. The three cantilevers are shown quite clear of each other, and the left of the picture is bounded by a portion of the Hawes Pier. *Viaduct, detail of* The detail of viaduct piers can here be seen to perfection, including the platforms used in connection with lifting arrangements. The piers in the foreground have a measurement of rather more than 2 inches at the base, and are about 7 inches in height, the girder about 1½ inches, the Queensferry cantilever 3 inches at the base and 6½ inches high. With these dimensions there should be no difficulty in forming a correct idea of the scale of this really excellent photograph.

No. 37.—Fife Cantilever with No. 1 Strut and Lifting Platform nearly up to Rail Level.—The preceding illustrations of the series have been chiefly confined to representing the progress of the superstructure in an upward direction, but a glance at this view will be sufficient to enable the observer to perceive that growth in that direction is now hereafter substituted by progress north and south, and that in spite of the formidable nature of work hitherto depicted the real difficulties of the design are yet to be encoun-

Incidental Reference. — | Ref. No. —

tered. The vertical ties here represented upon such a small scale are those referred to in No. 33, near the end of 12 feet tube.

The internal viaduct has been carried out some feet beyond the verticals, and No. 1 struts are well up to rail level. The last month's work has produced a considerable change in the appearance of the upper part of the structure.

The first sign of top member and tie No. 1 will be noticed projecting some ten feet beyond upper part of north vertical columns, and the whole length of connecting members appears complete.

No. 38.—Queensferry Cantilever from End of Hawes Pier.—In this picture we have one differing from any of the preceding. As its title denotes, the principal feature in it is the cantilever itself, together with the masonry pier on which its south arm is to rest. 150

Masonry Pier.

The progress of the work as illustrated by this picture compared with similar preceding views is striking, for here we have No. 1 struts more than half completed, and the internal viaduct already leaving the cantilever far behind. The rectangular staging growing up between the bottom members is to carry a crane in such a position as to command the first joint thereof. The foreground is chiefly occupied by temporary staging, details of which will amply repay attention.

No. 39.—Inchgarvie Superstructure at Full Height.—Owing to its increased dimensions and its insular position this cantilever was naturally the last to attain its full height.

We have here a very perfect picture, showing the diagonal struts, the vertical ties, and a large section of the internal viaduct complete, the depth of which at this point is 12 feet. Attention is called to this fact, as in future illustrations it will be observed to decrease rapidly as it nears the extremities of the cantilever arms.

Incidental Reference.

Ref. No.

The lifting girders for struts referred to in No. 33, and which will be observed above the bottom member in course of construction, speak for themselves.

The whole of the wind bracing is complete as far as position is concerned, but much rivetting has yet to be done.

No. 40.—Part of Inchgarvie and Queensferry showing Span to be Bridged.—The only picture in the series taken expressly to illustrate the phenomenal dimensions of the gaps to be crossed, and except in conjunction with others, one that is therefore scarcely to be recommended, as three-fourths of the picture is a blank.

Arms of Cantilever.

Of the space represented by 20 inches on the paper only 4 inches was at this date covered by projecting arms of cantilever, but as progress continues this picture will become one of the most valuable of the series, for not only is it a view which can never be hereafter secured, but the one of all others to emphasise and bring home to the least observant the unprecedented dimensions of the two giddy leaps which form the special feature of the great Forth Bridge.

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