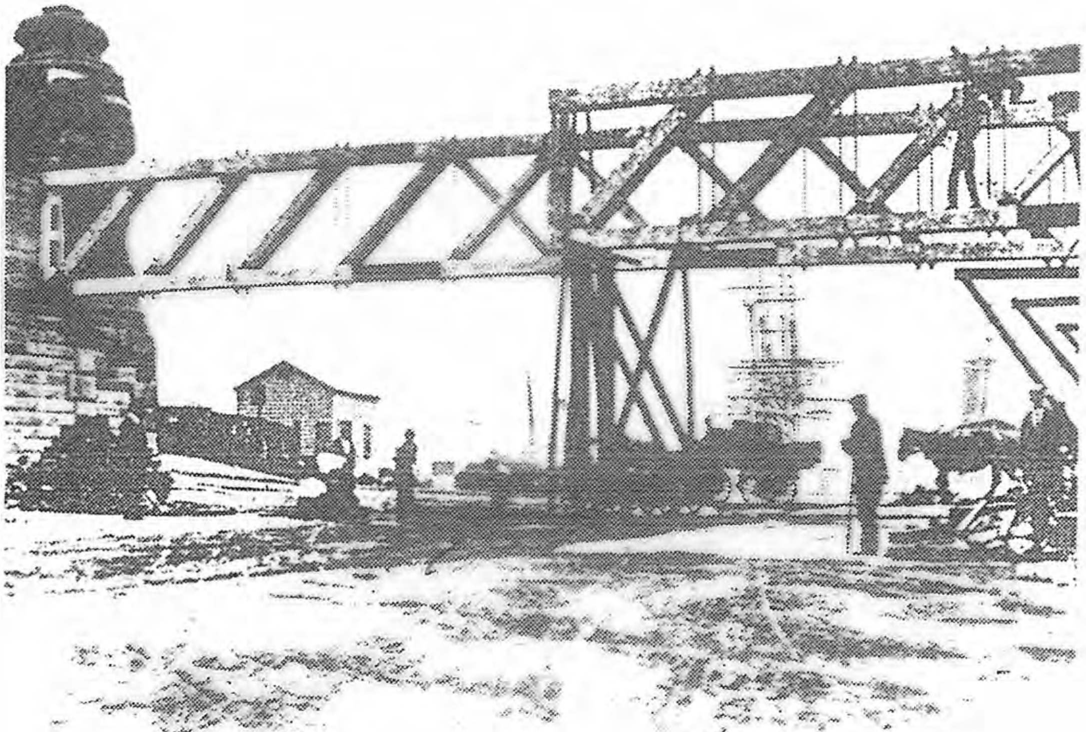
PROPOSAL TO LANDMARK THE

# THE PYRMONT BRIDGE DARLING HARBOUR

AS A

## NATIONAL ENGINEERING LANDMARK



ENGINEERING HERITAGE COMMITTEE
SYDNEY DIVISION, I.E. AUST. 1991

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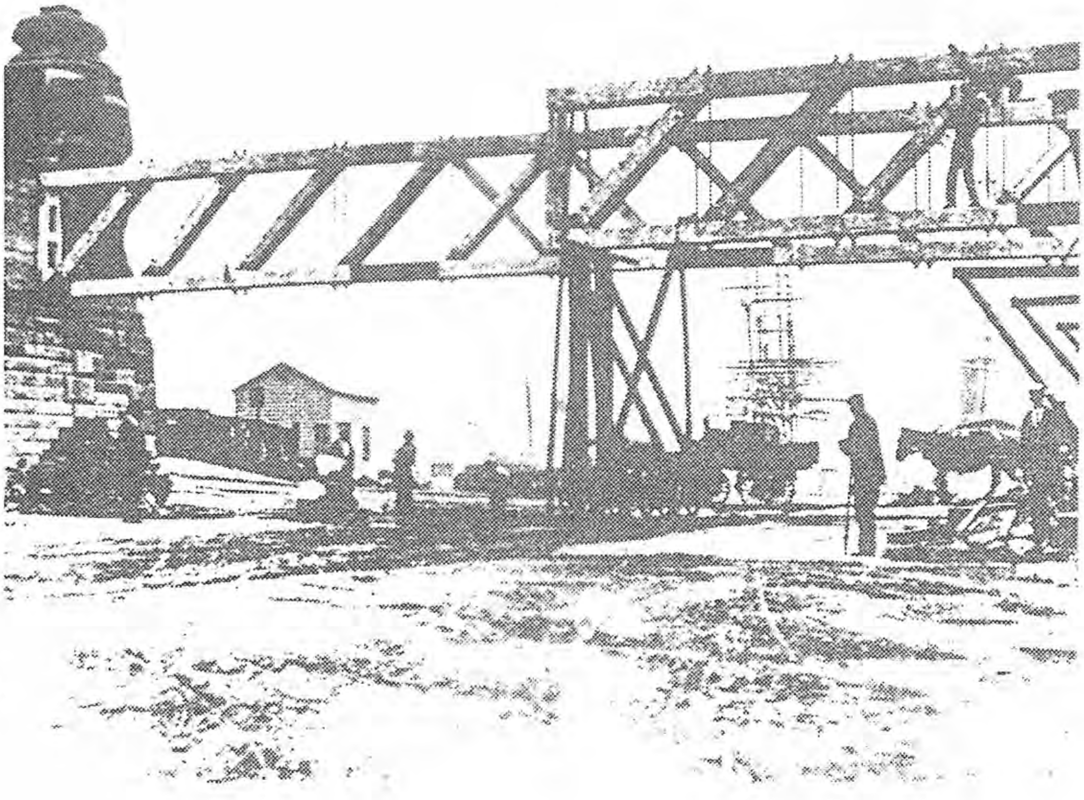

ENGINEERING HERITAGE COMMITTEE
SYDNEY DIVISION, I.E. AUST. 1991

## Commemorative Plaque Nomination Form

Date: AUGUST 1991

To:
Commemorative Plaque Sub-Committee
The Institution of Engineers, Australia
11 National Circuit
BARTON ACT 2600

From SYDNEY DIVISION

(Nominating Division or Branch)

The following work is nominated for an *~~Historic Engineering Marker~~/National Engineering Landmark award:

Name of work PYRMONT BRIDGE

Location, including address and map grid reference if a fixed work

DARLING HARBOUR, SYDNEY

GRID AMG 1000m REF 9130-334506

Owner DARLING HARBOUR AUTHORITY

In support of the nomination the following information is provided:

### For an Historic Engineering Marker (HEM)

(1) Proposed wording ~~on HEM#~~ SEE ATTACHMENT

(2) Justification - please make data as complete as possible.#

### For a National Engineering Landmark (NEL)

(1) Date of construction (or other significant dates). SEE ATTACHMENT

(2) Names of key professional personnel associated with the work.# SEE ATTACHMENT

(3) Historic engineering significance of the work.# SEE ATTACHMENT

(4) Comparable or similar works (a) in Australia (b) overseas.# SEE ATTACHMENT

(5) Features or characteristics setting the work above other engineering works.# SEE ATTACHMENT

(6) Contribution towards the development of engineering and/or
the nation.# SEE ATTACHMENT

**For all Nominations**

The following documentation is attached in support of the nomination:
(List all documents, photographs, etc, and enclose black and photographs).

SEE ATTACHED LIST

The nomination has been discussed with the owner of the work who has indicated
"The Approval of the Authority is readily given in order for this nomination
to go forward". The Authority wishes to approve the wording and location of the plaque.
(Include statement regarding owner's attitude)

A copy of this submission has been sent to the Secretary of the ..............................

Division at ..............................
(For completion by a nominating body other than a Division)

In the event of this nomination being approved the nominating body will organise an suitable presentation/ unveiling ceremony.

..............................
(Chairman of Nominating Committee

..............................
(Secretary of Nominating Committee

* Delete as appropriate
# Where there is insufficient space, attach additional papers

**Date of Construction** 1899-1902

**Key Professional Personnel**

Engineer in Charge: Percy Allan
Assistants include: J.J.C.Bradfield
Gordon Edgell

**Historical Significance**: The bridge was considered extremely innovative for its time, not only in Australia, but in the UK (see the discussion attached to the paper presented to the Institution of Civil Engineers). At the opening, the Minister for Works, Mr. E.W. O'Sullivan, stated that "the bridge is more up to date than any other bridge in the world". (Daily Telegraph June 30, 1902). In his opening speech the Governor, Sir H.H. Rawson compared the area of the swing span (12000 sq.ft.) with other English bridges - Newcastle on Tyne (10600 sq.ft.), Manchester Ship Canal (9400 sq.ft.) and Hawarden (8700 sq.ft.). He also noted that it was 4 ft. wider than the Tower Bridge. At the time, it was compared in many writings with the Tower Bridge, which was finished only 8 years earlier.

Pyrmont has approximately 6,100 sq.m. of area, while Tower Bridge has 4,700 sq.m. Pyrmont was built in 2 years and 9 months, while Tower Bridge took 8 years. Pyrmont opens in 38 seconds, Tower Bridge 90 seconds. Pyrmont cost 1.53 pounds sterling psf including approaches. Tower Bridge, UK 5.4 pounds sterling psf.

The swing span was a very early example of the use of electric power for this function. At the time of construction, Sydney had yet to have electric street lighting. Doubt was expressed at the Institution of Civil Engineers meeting at which Percy Allan's paper was presented as to the reliability of such a new form of motive power.

Percy Allan himself said that, at the time of opening "it was said to be provided with the fastest and most up-to-date swing span in the world."

The timber approach spans use deck-type Allan trusses, of which no other example is known. The development of this truss was probably the highest form that timber bridge trusses ever reached, due to the imminent replacement by steel, which was by then in constant use in Europe and the USA.

Above all, the bridge was Australian designed and Australian built, and was a focal point for national pride at the time of Federation.

**Contribution towards the development of engineering and/or The Nation and Features setting the work above other engineering works**

The bridge was innovative in many ways.

1. The use of electric motive power. (See above).
2. Development of the timber bridge truss. (See above. Also the splice which is a feature of this truss type was tested extensively at Pyrmont and eventually copied overseas including the USA).
3. The bearings of the swing span. The design technique was developed from comparison with earlier bridges and it was considered exceptional in that no bearings were idle.
4. Size (see above) and speed of operation.
5. The caisson construction (see paper by Percy Allan to Institution of Civil Engineers).

# LIST OF ATTACHED DOCUMENTS

1. HISTORY prepared for Darling Harbour Authority by C. Ludlow BA(Hons) Dip MS.

2. THE PYRMONT BRIDGE, SYDNEY, NSW by Percy Allan MICE, Institution of Civil Engineers, 16 April 1907.

3. THE ENGINEER, JAN-FEB 1919.

4. HIGHWAY BRIDGE CONSTRUCTION from Industrial Australian & Mining Standard, August 14, 1924.

5. PYRMONT BRIDGE - CONSTRUCTION & RESTORATION by E.G. Trueman, Institution of Engineers, Australia. Vol GE14 No.1, 1990.

I E Aust
Crest

# PYRMONT BRIDGE

THIS BRIDGE WAS BUILT IN 1899-1902, THE TIME OF FEDERATION, AND WAS A SOURCE OF PRIDE AT THE AUSTRALIAN DESIGN AND AUSTRALIAN CONSTRUCTION. THE SWING SPAN WAS CONSIDERED ONE OF THE LARGEST AND MOST INNOVATIVE IN THE WORLD AT THE TIME, AND WAS POWERED BY ELECTRICITY BEFORE SYDNEY HAD STREET LIGHTING. THE TIMBER APPROACH SPANS REPRESENTED THE HIGHEST LEVEL OF DEVELOPMENT OF THE TIMBER TRUSS. IT WAS DESIGNED BY PERCY ALLAN WITH ASSISTANCE FROM J.J.C. BRADFIELD AND GORDON EDGELL.

THE INSTITUTION OF ENGINEERS, AUSTRALIA
THE DARLING HARBOUR AUTHORITY

# PYRMONT BRIDGE

# HISTORY

PREPARED FOR DARLING HARBOUR AUTHORITY
BY C. LUDLOW BA (HONS) DIP MS

# THE HISTORY AND CONSTRUCTION OF PYRMONT BRIDGE

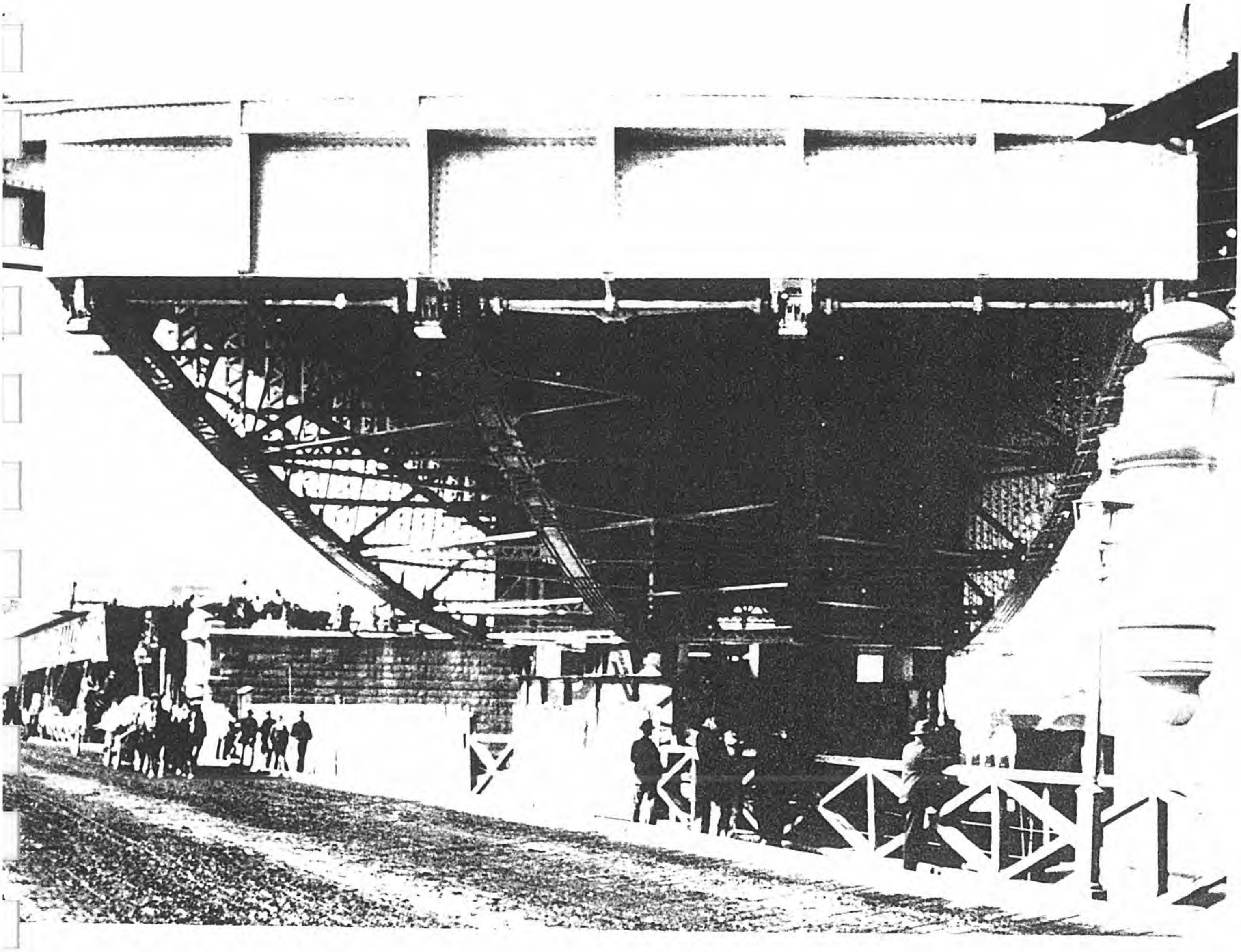

PLATE 1

THE SWING SPAN OF THE NEW BRIDGE

LOOMS LARGE OVER THE OLD

COURTESY DEPARTMENT OF MAIN ROADS

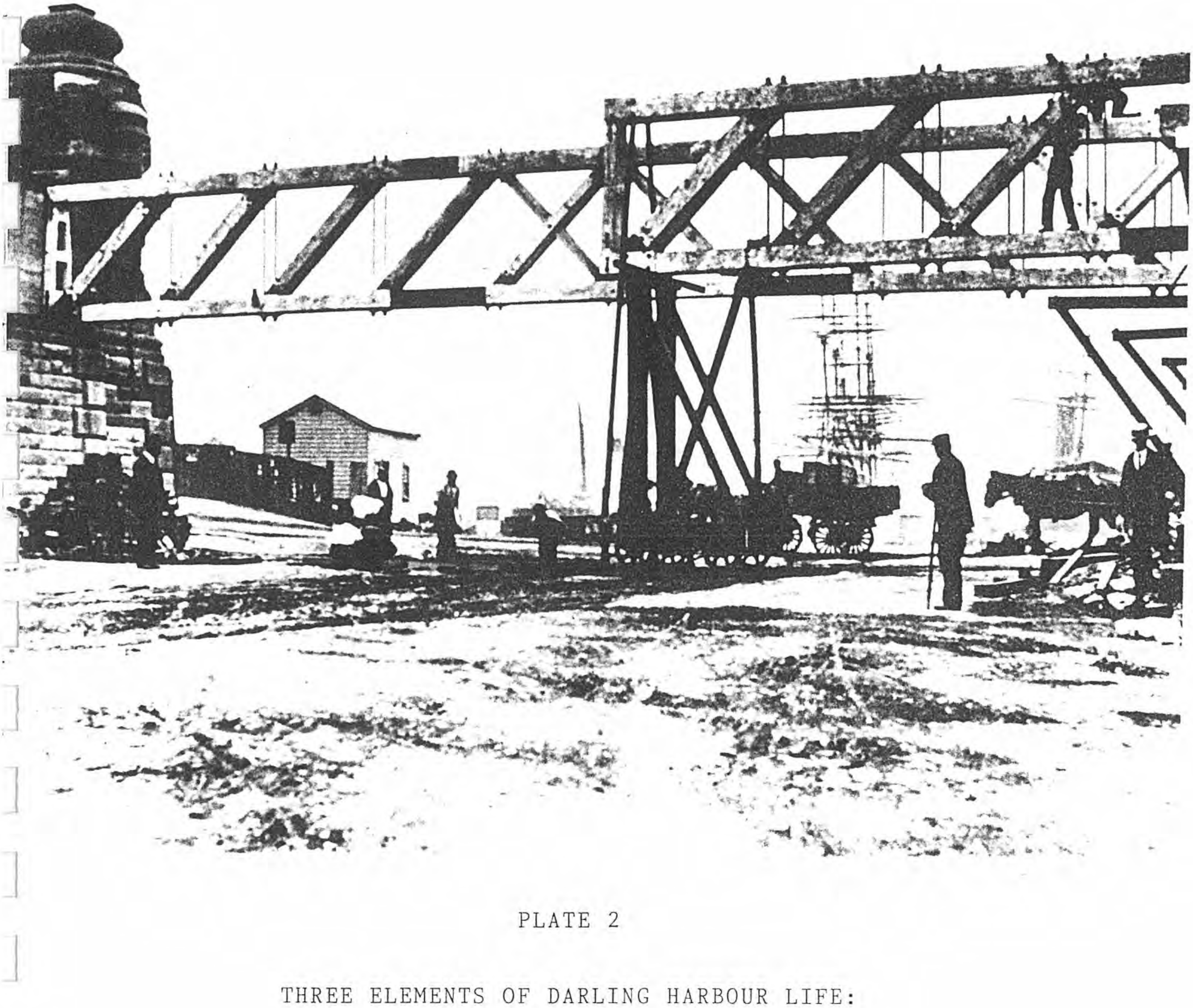

PLATE 2

THREE ELEMENTS OF DARLING HARBOUR LIFE:
SHIPS, DRAYS, AND THE NEW LINK THAT WOULD AFFECT THEM BOTH

COURTESY DEPARTMENT OF MAIN ROADS

# 1. SUMMARY

A crossing between Pyrmont and the city was necessary long before the first Pyrmont Bridge was built by a private company. Darling Harbour was lined with jetties belongong to private individuals and companies, and the area around the Harbour was popular for mills, foundries and shipyards. When the Railway Goods Yard was extended to Darling Harbour, more traffic converged on the area.

The first bridge (completed 1857) was of ironbark timber with a manually operated swing span. In 1884 the Government bought it and abolished the toll that the public had been charged. Despite growing indications that the bridge had outlived its usefulness and was no longer safe, it continued to be used for almost 20 more years.

In selecting the design for a new bridge, the NSW Government first announced a competition and then turned the matter over to a Parliamentary Committee in 1894.

The new bridge was a contentious issue, as its presence affected shipping use of the harbour above it. By the 1890's it was essential as a link between the city and the western suburbs which had grown in population.

The Engineer in Chief for Public Works, Robert Hickson, wanted to fill in the harbour above Bathurst Street, as the sewage outlets there had polluted the water, which was really too shallow for shipping anyway, and had to be dredged almost continually. His plan was to build an overbridge over the reclamation, rather than another swing bridge.

However, because of the economic depression of the 1890's, few politicians on the Committee were willing to pay for expensive reclamations, and preferred a swing bridge of iron and timber to the recommended one of iron.

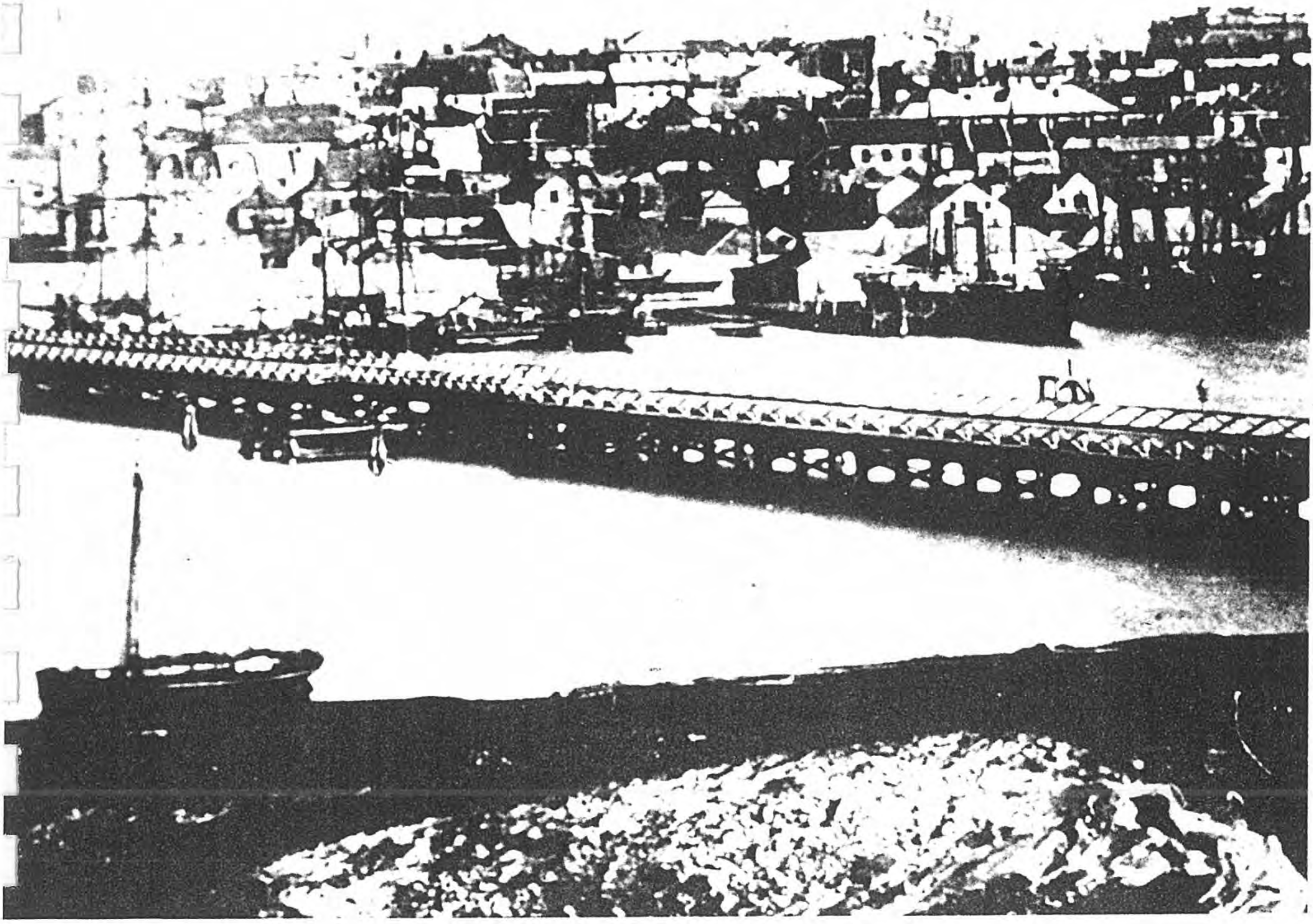

PLATE 3

THE FIRST PYRMONT BRIDGE

Despite the fact that the Opposition denounced the bridge-to-be as "a makeshift, a patchwork, a bridge with which any engineer in ten or fifteen years' time would be ashamed of having anything to do", construction began in 1899. Remarkably, even though the better scheme had been rejected, the bridge itself was a success, both because of the talent involved in its design, and the technology adapted for its operation.

The bridge was design by Percy Allan, who had introduced the American timber bridge practice to the NSW Public Works Department. The Allan trusses of his design are a notable feature of its timber side spans. The Department made use of the electricity and electric equipment used for Sydney's new tram system to power the bridge. Pyrmont Bridge was, in fact, the first swing bridge in the world to be powered by electricity. This and its other innovations (its speed of operation, large surface area, and unprecedented machinery), made it a source of local pride as a purely Australian engineering achievement.

The Australian engineering achievements exemplified in its construction were acknowledged by the Government of the time. As an engineering work, the bridge stands out as an example of good design and technological innovation, and it is also associated with some of New South Wales' premier engineers.

## 2. THE HISTORICAL BACKGROUND

### 2.1 THE NEED FOR A NEW BRIDGE

The first bridge built across Darling Harbour from Market Street Sydney to Murray Street Pyrmont was erected in 1857 by a private firm, the Pyrmont Bridge Company under the direction of E. O. Moriarty, later Engineer-in-Chief for Harbours and Rivers. It was of timber with a manually operated swing span which opened to let shipping reach the wharves of the head of the Harbour. While the bridge was an important link between the city and its western suburbs, it was a source of annoyance to road and maritime traffic alike, because of the delays caused by the opening and closing of the swing span.

Those using the bridge had to pay a toll until 1884, when the Government bought it for £49,600 and abolished the toll. As early as 1881, however, it was pointed out by the designer that the bridge had never been intended to be used in its present state for so long. It had outlasted the usual life of a timber bridge.[1] In 1889 there were signs of infestation by white ant and cobra in the timber. Finally in June 1891 Bruce Smith, the Minister for Works, announced a public competition for designs for a new bridge. The designs were judged by a board consisting of C. W. Darley, Engineer-in-Chief for Harbours and Rivers. Robert Hickson, the Commissioner for Roads, Bridges, and Sewerage, and W. W. Wardell, a well-known builder and architect. Three prizes were awarded, the first two to London firms and the third to a Sydney designer. These designs were for iron and steel bridges, and consequently were expensive; the Department of Public Works' estimate for the winning design was £295,710.

Unfortunately the 1890's were a decade of economic depression in N.S.W. and in the other colonies. Overseas loans were no longer so freely available for grandiose public works as they had been in previous decades; moreover the new bridge would not bring any income to the Government. Thus the results of the competition slipped into a Parliamentary limbo, until the worsening state of the existing bridge forced itself on the Government's attention. The condition and operation of the old bridge in 1894 is provided in an illuminating contemporary description:

"The transit commissioner stands on the centre of the bridge, just where it narrows into the swing, and tries vainly to regulate the stream of vehicles which are crowding on each other's heels ... in their haste to get across to Sydney before the swing opens. All traffic, as a notice at either end informs us, is to proceed across this crazy structure at a walking pace, and the regulation seems a very necessary one. As the great wool waggons, piled high with a topheavy load of bales, rumble by, one can feel every plank vibrate under one's feet; the piles tremble in their oozy bed, and a collapse seems imminent ...

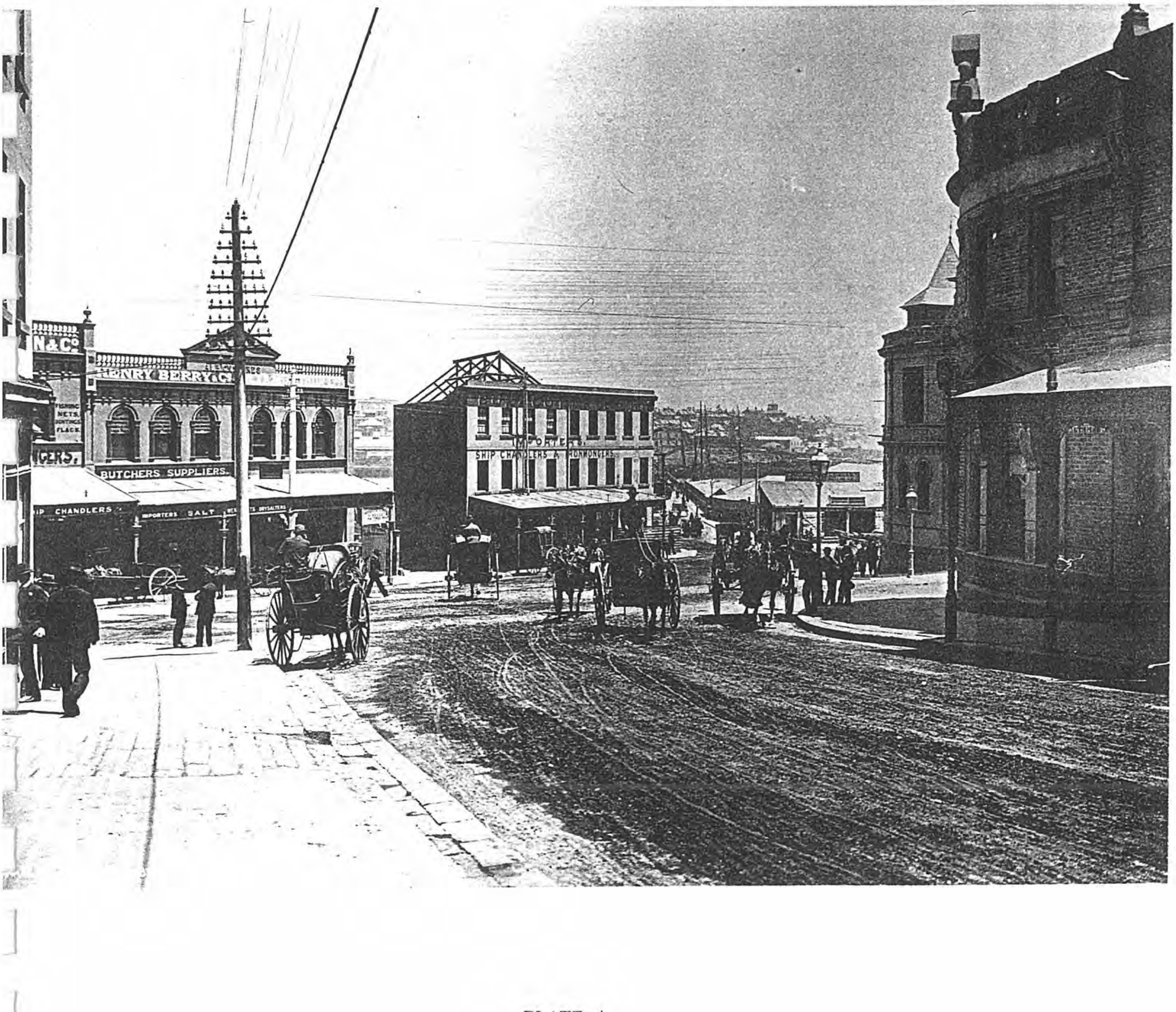

PLATE 4

THE MARKET STREET APPROACH TO THE OLD BRIDGE
IN NOVEMBER 1899, BEFORE CONSTRUCTION BEGAN

COURTESY DEPARTMENT OF MAIN ROADS

By this time the little steamer, which has been frantically whistling her heart out whilst coming up Darling Harbour, has got quite close to the bridge, and the determined note of her whistle shows that she does not intend to be kept any longer. The gates are suddenly closed, and the line of carts, with their discontented and grumbling drivers, backs up on either side until the whole bridge and a portion of its approaches are covered. The swing on Pyrmont Bridge is responsible for a fearful amount of blasphemy, and at the busiest time of the day you will sometimes find the rear of the procession of carts well up into King Street."2

At the beginning of 1894, the question of the Pyrmont Bridge along with that of the Glebe Island Bridge, which was in a similar state, was referred to the Parliamentary Standing Committee on Public Works. This Committee began taking evidence on 11 April 1894. It heard the opinions of wharf owners, shipping captains, the Railways Commissioners and Pyrmont landowners, all of whom as will be seen, had an interest in exactly what sort of crossing should replace the old bridge. It also took submissions from independent as well as Government engineers; many of the former were of dubious qualifications.

## 2.2 THE PUBLIC WORKS DEPARTMENT'S PROPOSALS

In 1894 the Roads and Bridges branch of the Department, led at that time by Robert Hickson, its Commissioner and Engineer in Chief, began preparing three schemes for a Darling Harbour crossing. The first was for an iron bridge of the type specified in the winning designs of the 1891 competition, at a cost of £220,000, to be placed on or near the site of the existing bridge. The second was to fill up Darling Harbour from Market Street to the inner reaches of the Harbour, reclaiming an area of about 38 3/4 acres, and erect an over-bridge or viaduct over this. The third, and that recommended by the Department, was to fill up Darling Harbour from Bathurst Street, (14 1/2 acres), and build an over-bridge or viaduct.

In schemes 2 and 3 the tidal mudflats and the shallower part of the harbour would be reclaimed, thus removing the wharves in that area and in this way a swing bridge to let ships pass would no longer be necessary. By the same scheme, pedestrians and wheeled traffic on the bridge would no longer be delayed waiting for the swing to let ships through.

The inner part of Darling Harbour was also an unhealthy place; one of the city´s principal sewerage mains discharged into it, and had done so since 1859. The shallowness of the harbour added to the malodorous effects of this situation. By reclaiming that part of the harbour south of the old bridge, the waterfront could be made safer for its workers and inhabitants, and also the land thus gained could be used for the extension of the Railway Goods Yard.

## 2.3 THE REACTION

The reactions of several interests in the Pyrmont area to the idea of a new bridge need to be examined before the decision of the Committee is discussed. Frequently the desires of these interests - who included the Railways, the wharf owners, the ship owners, land owners - and merchants, conflicted with what is regarded as "the public interest" - the requirements of public health and safety, and urban planning - a discipline which had barely made its impressions on Sydney as yet.

The Railway Commissioners regarded Darling Harbour as their most important receiving area. From the late 1870´s it had begun to accept wool, hay, straw, chaff and minerals to relieve the congested Redfern terminal. It had long been understood that sometime in the future the Goods Yard would be greatly extended, but almost until the resumption of land at Darling Island for this purpose (as completed in 1896), this understanding limited the land available for the approaches to any new Pyrmont Bridge.[3] When Scheme No.3 was first proposed to the Railway Commissioners, they regarded it as seriously detrimental to the railway; later they removed all their objections.[4]

As the bridge stood, it was very unsatisfactory for the passage of shipping. The opening was 56 feet - too small for the large steamers that sometimes wished to go through. Ernest De Burgh, the supervising engineer for Roads and Bridges, said in his evidence that, having once issued a permit to a steamer with a 48 foot beam to pass through, he "was very anxious till she was out again, for ... if with her bow in the opening, she had been caught by a puff of wind or a current and turned sideways, she would have wrecked a couple of hundred feet of the bridge in a few minutes".5

The main agitators against the scheme to fill up the Harbour to Bathurst Street seem to have been the wharf owners rather than the ship owners; for as Captain John Jackson, the Manager of the Government Wharfs said, the Harbour above that street was nothing but "a mud-hole".6 The owner of the Union Steamship Company concurred in this view, and stated :

´The quantity of the water there, and the formation of that part is so peculiar that it (filling it up) will not make any difference. You cannot move any large vessel there - the space is too narrow."7

The wharf owners were divided into two camps - those who objected totally to the reclamation of the Harbour, because it would take away their wharves and income, and those who approved of it, and of the bridge´s removal to Bathurst Street, because they owned wharves between the present bridge and Bathurst Street. It was obvious that these wharves would increase in value.8

During the Committee´s hearings, Hickson keenly supported the Bathurst Street Scheme, as he did even after he left Roads and Bridges to become the Commissioner of the Sydney Harbour Trust. However the Committee was not well-disposed towards the idea, partly because of the large cost in money and legal research necessary to reclaim the water frontages, but also because it seems to have been against Sydney´s civic mentality to dispose of any of its famous Harbour foreshores. Repeatedly the argument was put forward that other countries seek to increase their foreshores; why should Sydney decrease hers ?9

In the end the Committee decided that the Departmental Proposal should not be carried out, but that when renewal was necessary the present bridge should be replaced by a timber bridge of improved design, with a swing span of 70 feet.

A minority, including the Chairman, Jacob Darrard, and E. W. O'Sullivan (later Minister for Public Works) supported the Bathurst Street scheme, as did the Government of N.S.W. at that time. However soon after the enquiry was over, the Parliament was dissolved suddenly, and the new Government referred the matter once more to a second committee this time chaired by Varney Parkes, on 27 September 1894.

## 2.4 THE SECOND INQUIRY

The second Committee was shown a new design for an iron bridge from the Public Works Department, similar to their Bathurst Street scheme, but reduced in cost, because the Railway no longer wished to use the land that had to be reclaimed in the previous scheme. Percy Allan, the draughtsman responsible for the designs of the eventual Pyrmont bridge, appeared to support the Bathurst Street scheme. A timber bridge, he said, would cost the Government much more in annual charges for repair. Not only would the iron bridge from Bathurst Street be much less, but the Government would achieve an extra £3,000 in rates per year from the wharves between Market and Bathurst Streets, and £1,500 per year from the new government wharf yet to be built.

This committee really surveyed only two possibilities : a new bridge at Market Stret, or the Bathurst Street reclamation scheme.

Varney Parkes, the Chairman, called independent engineers to give evidence at the inquiry, on different methods that could be used to cross the harbour, and at cheaper cost than the Department's estimates. Some of these engineers had scanty qualifications for such a large project. While Parkes managed to find engineers who would offer to build the bridge from £90,000 to £130,000 cheaper, he could not persuade the Committee to accept their tenders.[10] He also attacked Hickson in the hearings, claiming he had ignored independent designs and had made unfair estimates of the private schemes submitted. In exchanges such as the following extract, Parkes' personnel animosity towards the Public Works Department and Hickson himself were clear, Parkes tried to prove

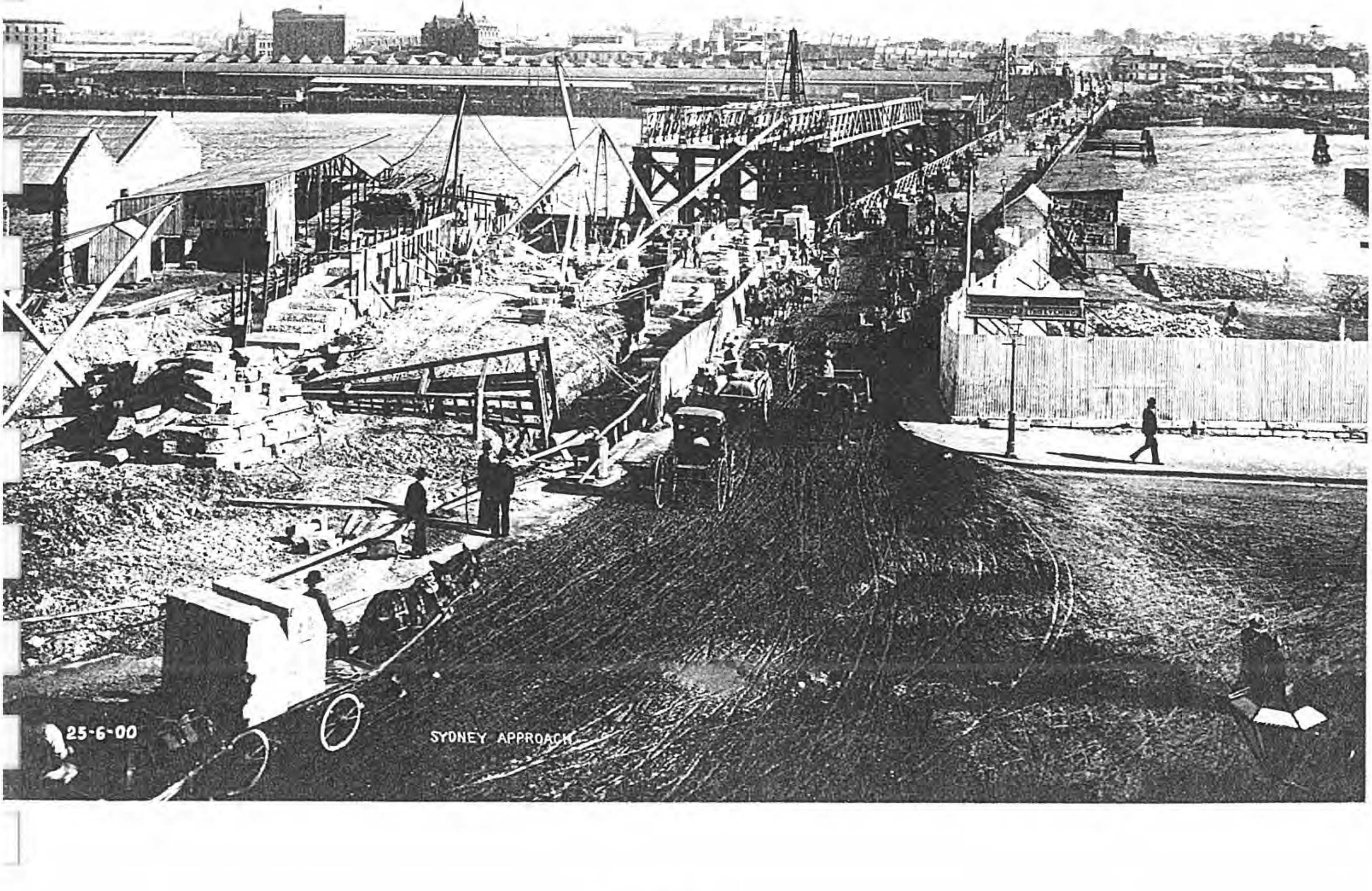

PLATE 5

THE SYDNEY APPROACH TO THE BRIDGE IN JUNE 1900

COURTESY DEPARTMENT OF MAIN ROADS

that Hickson had no regard for economy in his projects, while Hickson continued to defend his scheme and his officers:

Parkes: "Have you never had any experience as to the economy of bridge building ?

Hickson: I hardly understand your question.

Parkes: Why have you not built all Government bridges of wood instead of iron, since that construction is so economical and you have good material in the country ?

Hickson: We have put up very few iron bridges.

..................................

Parkes: Why have you not pointed out where it has been proposed to construct iron bridges that the Government could have saved enormously by constructing wooden bridges ?

Hickson: As a matter of fact 95 or 98 per cent of our bridges are timber bridges "[11]

Towards the end of the questioning of Hickson, which lasted two days, the Chairman established that the Department could build a timber bridge, with an iron swing span, for £88,000, while an iron bridge as part of the Bathurst Street reclamation scheme could not be done for less than £220,000. Hickson realised that the Committee were unlikely to agree to the more expensive scheme, and so at the next sitting he produced a design for the first of the above bridges. The swing span of this design was reduced from 70 feet to 60 feet, to effect a saving of £6,000; however it was later changed back to 70 feet by the Department engineers. The Committee seized on this design with alacrity, and after Hickson had finally recommended it "in the absence of an iron structure" [12] they recommended such a bridge to the Government, at the present site of the old bridge, with no reclamation of the Harbour.

Parkes was not happy with the decision to use a Public Works scheme, and attacked the Department further in Parliament. Lyne, who had supported the reclamation of the harbour, denounced the proposed bridge as "a makeshift,a patchwork, a bridge with which any engineer in ten or fifteen years' time would be ashamed of having anything to do." Despite these criticisms, the motion to go ahead with construction was passed by a majority of 22.[13] On 6 September 1899 the foundation stone of the Pyrmont Bridge was laid by the then Minister for Works, E. W. O'Sullivan.

## 3. THE CONSTRUCTION OF THE BRIDGE

### 3.1 THE STATE OF BRIDGE CONSTRUCTION IN N.S.W. AND OVERSEAS

The nineteenth century saw the parallel development of two streams in engineering practice - scientific theory and testing, and empirical discovery and invention. For most engineers in that century, their training had been through apprenticeship and learning on the job, just as in any trade. Not until the turn of the century did university training on an advanced level begin to take the place of rule of thumb among engineers, and specialization within the profession set in.

Nevertheless on reading the various schemes for a harbour crossing put forward by engineers in the Report of the Parliamentary Committee on Pyrmont and Glebe Island Bridges, it becomes apparent that their actual knowledge of an ability to carry out what they proposed varied as much as did the schemes themselves. One engineer proposed a coffer dam filled with concrete made of equal parts cement, shingle and sand, and using treacle as a binder. Another had designed a bridge in which calculations had little importance, as the transcripts of his evidence show :

> What would be the carrying power of a bridge built according to your design ?
>
> The Bridge would have to be strong enough to bear as many fully loaded vehicles as you could put on to it.
>
> But what weight have you calculated for your estimate ?
>
> I did not go into such details as that.
>
> What I want to know is what would the bridge carry ?
>
> It would carry anything you put on it.
>
> You have not calculated the strength of your girders ?
>
> No.

> This estimate of yours is practically a rough guess ?
>
> I ran it out in my mind at so much a foot. I did not go into details.
>
> You practically lumped it ?
>
> Well, I am used to lumping these things from experience.
>
> Have you had any experience of bridge work before ?
>
> No. All the work of that kind I have had to do has been in connection with P.N. Russell's - such work as the Bathurst Bridge, the Wagga Wagga Bridge, and several others, but it is a good many years ago.[14]

A few years previously the Professor of Engineering at Melbourne University had written these words to a colleague about the Australian engineering profession: "I find ..... a widespread and deep seated ignorance of the most elementary physical laws, so amazing, so extraordinary, that I am almost afraid to describe it lest you should think I was taking leave of my senses."[15]

Such harsh comment was justified at the time by the almost complete lack of structural calculations and testing of materials in the colonies; however, by the 1890's this situation was beginning to change.

The rapid spread of the railways in Europe and America had necessitated the quick, skilful erection of bridges able to stand such loads. The timber truss bridge, originally a European invention of the sixteenth century, was found to be suitable for railway construction, and was adapted by American engineers in the first seventy years of the nineteenth century,in many variations. New South Wales' Government engineers, under the influence of the British military origins of colonial engineering, did not adopt the American trusses, such as the Howe,until the 1890's. However once adopted, the American trusses became the standard structural components of New South Wales bridges.[16]

Bridge construction in the colony was supervised by the Department of Public Works, and carried out by a branch within it created in 1861, and known as Roads and Bridges from 1889 when Robert Hickson became Commissioner and Engineer in Chief of that branch. In 1895 Hickson was made Engineer in Chief for Public works as well as Commissioner for Roads and had control of the Harbours and Rivers Branch as well as his own. In 1896 he became Under Secretary for Works as well. Hickson had only entered the Civil Service of the colony in 1881, as Resident Engineer in Newcastle, but he had had extensive training in England, especially in maritime and harbour engineering. The ten year period for which he was in charge of bridge construction saw the revision of standards for bridges and the general widening of roadways. Nevertheless, all the time ways were sought by which savings could be made, as the 1890's was a period of economic depression.17

## 3.2 TIMBER VERSUS STEEL

Apart from the steel swing span, Pyrmont Bridge is a timber truss bridge. The virtues of steel were definitely well known to the Public Works Department at the time the bridge was built, but despite the importance of the bridge it was decided to construct part of it in timber for several reasons. The major reason was the cost and availability of steel in N.S.W. as opposed to timber. As little steel and iron was made in the colony at the time the bridge was built, most of it would have had to be imported. During the Parliamentary Committee's Inquiry Hickson made it clear he would prefer an iron bridge, but had to bow to the intransigence of the politicians on the Committee, who were unwilling to spend hundreds of thousands of pounds on a non profit-making structure in depressed times.

In 1894, in answer to public pressure, the then Minister for Works, William Lyne, had stated that colonial timber would be used wherever possible in Government contracts.[18] However despite good intentions and due to lack of planning, the N.S.W. hardwoods suitable for building were difficult to acquire in sufficient quantities. In the 1890's N.S.W. was still importing large quantities of timber. Also it was not until 1893 that the full strength of Australian timbers was known, when Professor Warren of Sydney University published his work Australian Timbers, being the results of tests carried out in the University's engineering laboratory.[19]

Percy Allan, the designer of Pyrmont Bridge, always believed in the superiority of timber, and the introduction of American refinements in timber trusses has been attributed to him. He used new methods of structural analysis and testing combined with Warren's results to develop economical and long-lasting timber bridges.[20]

## 3.3 CONSTRUCTION FEATURES

In 1924 the designer of Pyrmont Bridge called it the most important swing bridge built in N.S.W.[21] It had this distinction because of the speed with which the swing span could be moved (4 miles per hour at the ends of the span). This speed was achieved by using electricity as the motive power, instead of the more usual hydraulic power, or manual power as was used on the old Pyrmont Bridge.

The Pyrmont Bridge was in fact the first in the world to be operated by electricity.[22] This was due to a couple of fortunate circumstances; firstly, the ready supply of electricity from the new Ultimo Tramway Power House, and secondly the availability of suitable electric apparatus and motors designed for Sydney's trams, which could be used in the operation of the bridge.[23] Thus it was the electrification of the tramways in the late 1890's which made it possible for electricity to be used as a motive power in the building of Pyrmont Bridge.

Tenders for building the bridge closed in July 1899. The whole bridge was divided into three contracts :

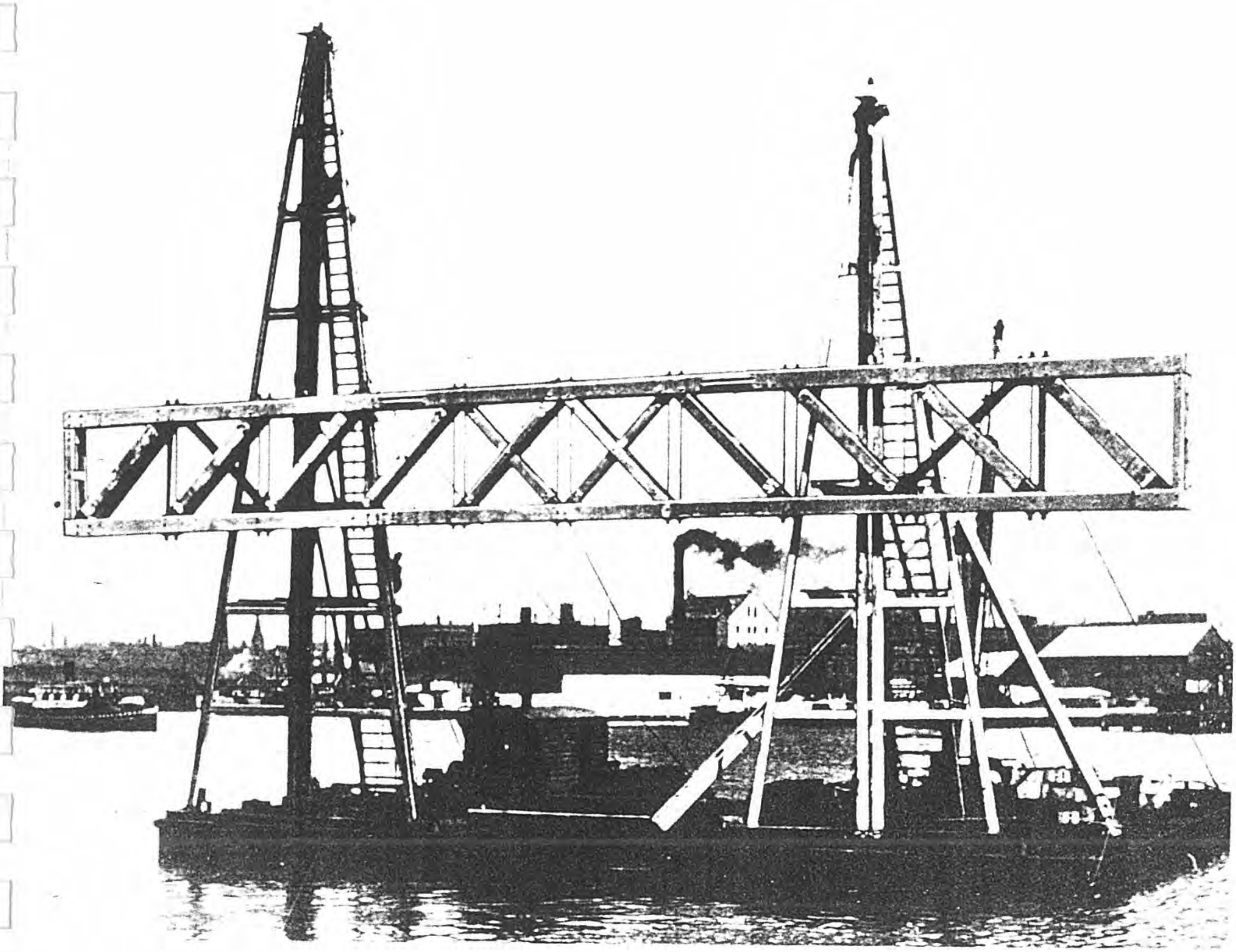

PLATE 6

A TRUSS BEING TRANSPORTED ON A BARGE

COURTESY DEPARTMENT OF MAIN ROADS

1. The masonry and concrete abutments and retaining walls, and embanked approaches.

2. The timber side spans of the bridge.

3. The steel swing span, the pivot and rest piers.

It is not proposed to enter into a detailed description here of the structural and mechanical features of the bridge. However an explanation of the principles and labour involved will assist the reader to appreciate the bridge as it stands today.

A swing bridge is one which is pivoted horizontally about a vertical axis. The swing span opens to allow a ship to pass. Pyrmont Bridge's steel swing span is supported by a central pivot pier and, when the bridge is closed, by two rest piers at either end. The harbour floor where the pivot pier was to be sunk consisted of about 25 feet of clay over the sandstone bottom; because of this the construction of the pivot pier involved a deal of work and trouble. A wrought iron caisson (a cylinder used to keep water and silt out while foundation excavation down to firm ground is being carried out) had to be sunk in the floor, then the silt and water within the caisson was dredged or pumped out. While the foundations were being dug within the caisson, a leakage of water and silt into the excavation occurred, due to outside water pressure, and while the rest of the excavation could have been carried out by divers, a perfectly dry foundation was preferred by the engineers; so another, successful attempt at pumping out the caisson was made.

Once sandstone was reached, the rest of the excavation, so far carried out by dredgers, was done with steel bars with a chisel point, hoisted by a steam crane. The caisson was then filled with layers of concrete and sandstone rubble.

The two rest piers presented fewer problems, but still involved much labour. The pier on the Pyrmont side rested on rock, while that on the Sydney side was carried by 58 piles driven to the rock bottom.

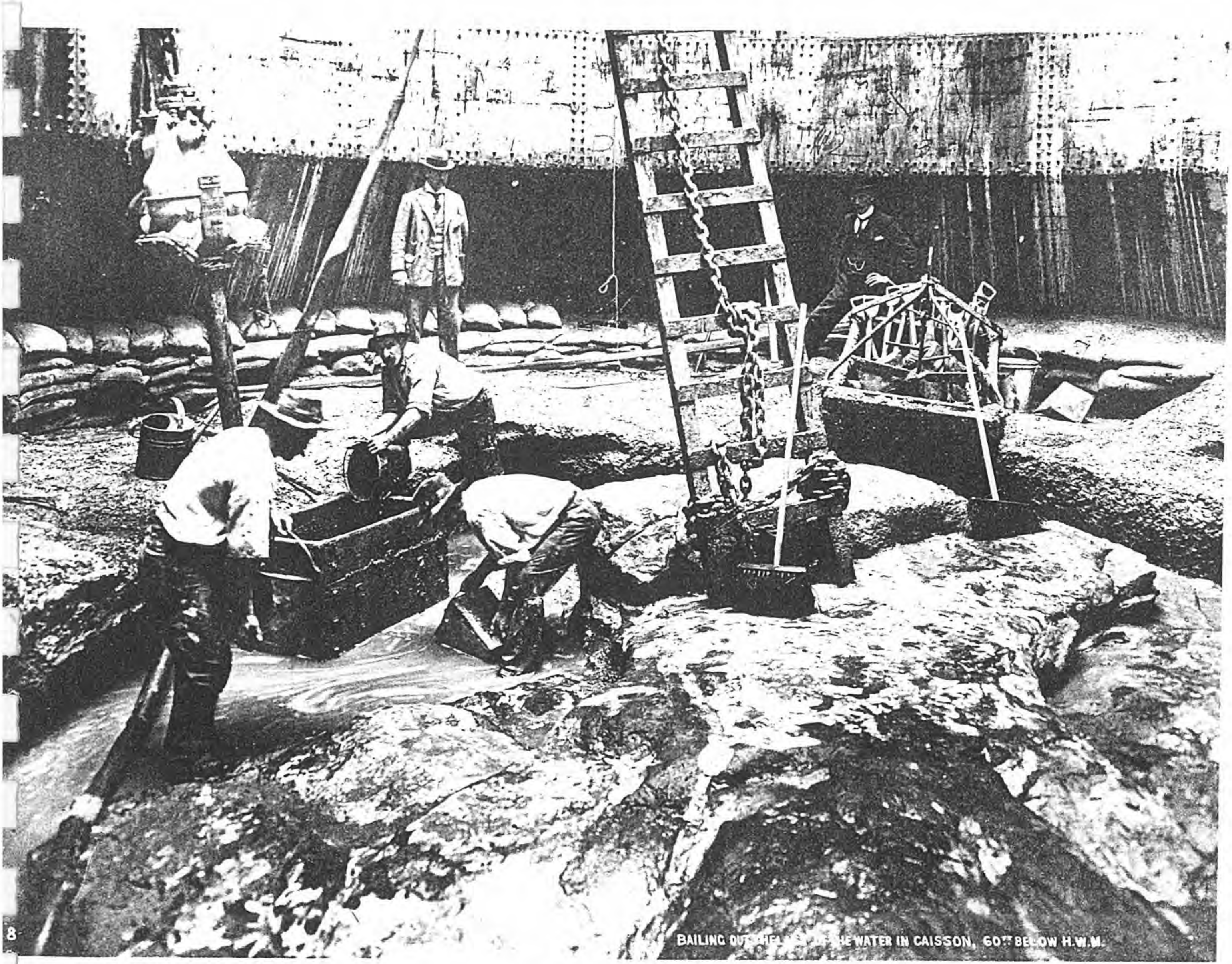

PLATE 7

PERCY ALLAN (LEFT) AND AN UNIDENTIFIED ENGINEER LOOK ON AS THE LAST OF THE WATER IS BAILED OUT OF THE CAISSON FOR THE PIVOT PIER

COURTESY DEPARTMENT OF MAIN ROADS

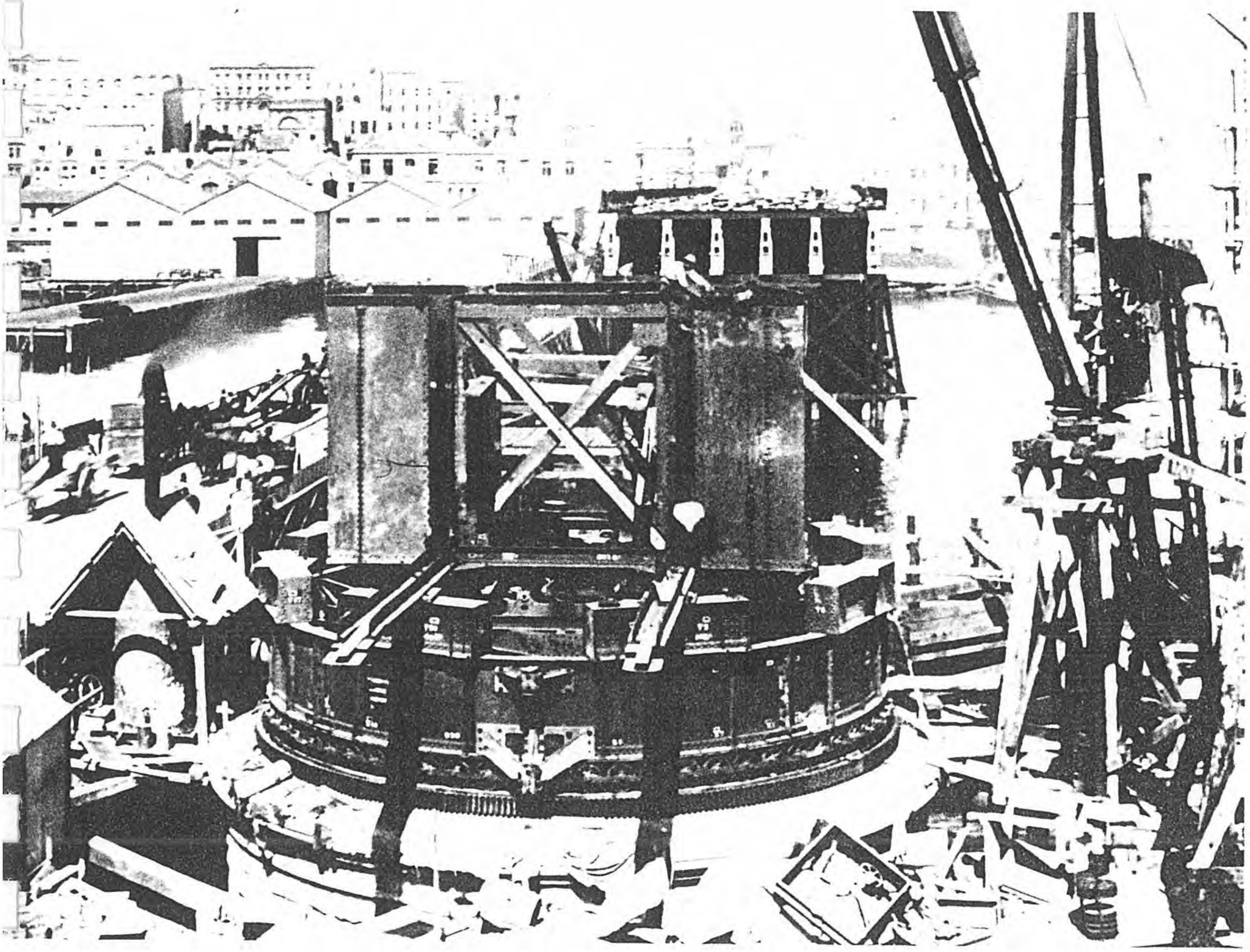

PLATE 8

CONSTRUCTION OF THE CAISSON

COURTESY DEPARTMENT OF MAIN ROADS

The swing span itself was said to be "the fastest and most up-to-date swing span in the world" at that time.[24] It consisted of four main trusses (a frame of steel, timber, concrete or light alloy to carry a bridge, built up wholly from members in tension and compression) supported on eight distribution trusses so that the 800 ton weight is evenly distributed on the turntable or drum, itself bearing on sixty six cast steel rollers. The rollers run between two machined treads, one fixed to the drum, and one to the caisson. These treads were so large that in Europe, where they were made, no lathe large enough to machine them was available, so they had to be made in sections.

The warning lights, end gates, the lowering and freeing of the ends of the span, as well as the slewing motor which swung the span were powered by electricity. This came from the Power House at Ultimo, completed in 1899 to provide power for the electric tram lines from Circular Quay to Redfern and along Harris Street. The electricity was found to be both reliable and cheap; only one stoppage occurred in fifteen years of operation, and that was caused by a mechanical fault; and the power used in 13 years cost only £247 7s 8d.[25]

The side spans are also notable for the use of the Allan truss, so named after the designer of the truss and of Pyrmont Bridge, Percy Allan. The trusses were of ironbark, and had only been used once before in the Hampden bridge at Wagga Wagga in 1895. Allan described his bridge truss as "of the Howe type, in which redundant members have been omitted",[26] and later stated:

"The features of this design are the omission of counter braces and placing of all braces on the same angle so that any shrinkage can be taken up by the tightening of the suspension rods... the bending stress in the bottom chord is eliminated and only a direct stress has to be taken care of (ordinarily the load will cause bending stresses in a truss. The bending force varies with the distance of the load from the nearest support; the greater the distance, the greater the bending force) ...the old trusses were designed to carry a 15ft carriageway, whereas the Allan trusses are designed to carry two 5 ft footways in addition to a 15 ft carriageway. Thus it will be seen that the later design of truss bridge offers greater facilities for traffic at a much reduced cost."[27]

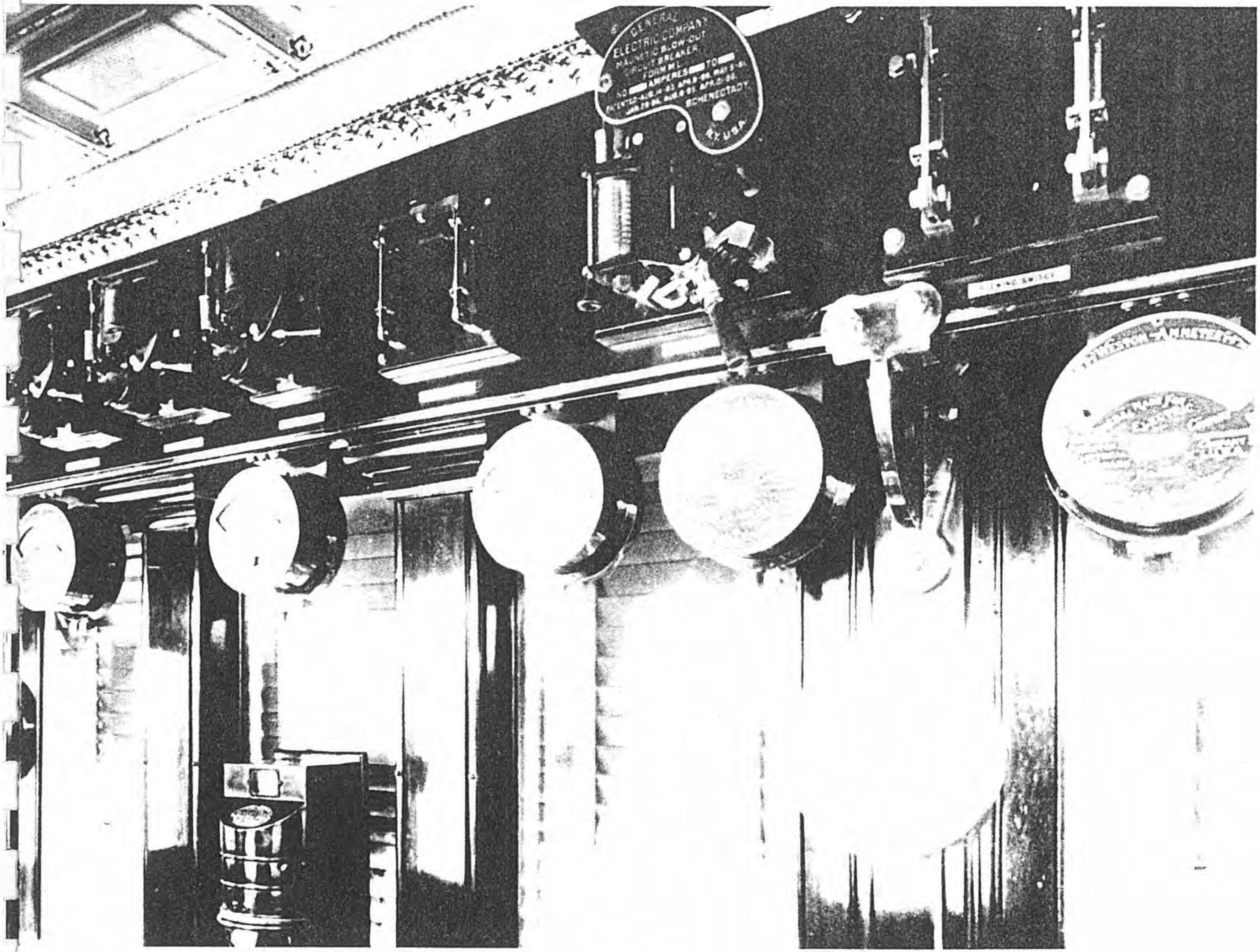

PLATE 9

THE ELECTRIC SWITCH PANEL

COURTESY DEPARTMENT OF MAIN ROADS

The Allan truss superceded the Howe truss, the highest development of the American timber bridge truss, by several stages in safety and economy. Pyrmont bridge offers the most famous and contemporarily acclaimed example of its use, the significance being that the Allan truss bridge was ideal for a bridge carrying a large load of pedestrian and wheeled traffic.

The approaches to the bridge extended from Sussex Street on the city side to Murray Street on the Pyrmont side. The approaches themselves consisted on embankments and concrete retaining walls, and those exposed to the public view were faced with sandstone. A stone parapet extended the whole length of the approaches.[28]

## 3.4 Alterations in the Darling Harbour Area

As construction progressed, the estimated cost of the bridge rose, from £88,500 to £94,000, and then to £112,500 including the approaches. The cost was raised even further by extensions which had their origin in a totally unforeseen event - the outbreak of bubonic plague in Sydney.

The plague was brought to Sydney by infected rats on ships from the Orient. The first reported case was on 19 January 1900. In the end, 103 people died from the disease. Its spread was largely due to the extremely unhealthy living conditions in Sydney's poorer areas, especially in the Rocks and Darling Harbour area, and to the unsanitary state of the harbour wharves.

As a direct result of the shocking conditions revealed by the plague, the Sydney Harbour Trust was created in late 1900, and took charge of the wharves, stores and dwelling houses on the waterfront, many of which were resumed and destroyed.[29]

Robert Hickson was appointed President of the Trust, and saw immediately that the resumptions of the Darling Harbour area would make possible the original Bathurst Street scheme which he had favoured, and stated :

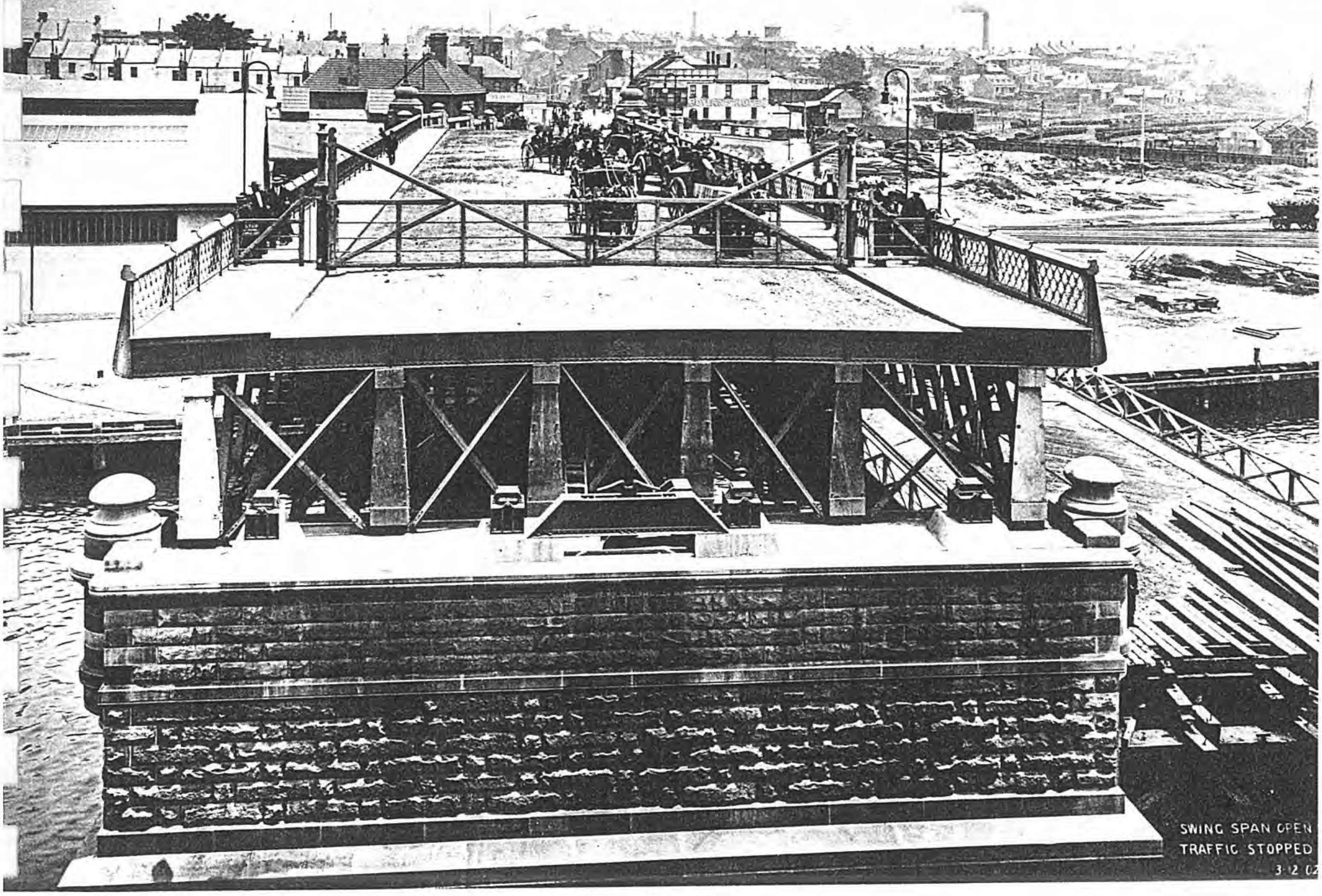

PLATE 10

TRAFFIC STOPPED FOR THE OPENING OF THE BRIDGE, IN 1902.
THE OLD BRIDGE, STILL BEING DISMANTLED, CAN BE SEEN ON THE RIGHT

"... even at this late period in the transaction, it would be better to take steps to cancel the arrangement for the erection of the bridge ... The doing away with the bridge would give a complete harbour capable of being designed for all classes of vessels and the Bathurst Street Bridge ... would be better in every respect than access via Market Street."[30]

The Minister for Public Works, Mr. E. W. O'Sullivan, would not agree to this scheme, although he was favourable to it, because he felt committed to the bridge as it stood; however other plans by the Trust, to have a ratproof wall around the Commercial waterfront, and a street (now Hickson Road) around the Harbour as well as a railway extension, made alterations to the Pyrmont Bridge approaches necessary. [31]

The matter was referred to the Parliamentary Standing Committee on Public Works, effect of their recommendations was as follows :

"The proposed extension of the Pyrmont Bridge, now in course of construction, consists of an alteration in the approach to the bridge at the Sydney end, asked for by the Harbour Trust with the object of increasing the width of Wharf Street to 100 feet, forming a better approach to that street, and permitting in the future of the extension of the street to the head of Darling Harbour, and the construction of a railway along the whole of the Darling Harbour eastern foreshore... To meet future acquirements in that direction it is now proposed, chiefly at the instance at the Harbour Trust, to raise and extend the bridge approach to the western alignment of Sussex Street". [32] Construction went ahead with these alterations.

## 3.5 The Opening Ceremony

The opening ceremony held on the bridge on 28 June 1902 was very well attended, and the photograph taken on the day shows how crowded the bridge was. The privilege of being on the swing span while it was opened and shut for the first time in public was reserved for those of the vice regal party and invited guests, but once the bridge was closed, the public pressed forward, even jostling the guard of honour with their bayonets, which can be seen bristling above the people's heads.

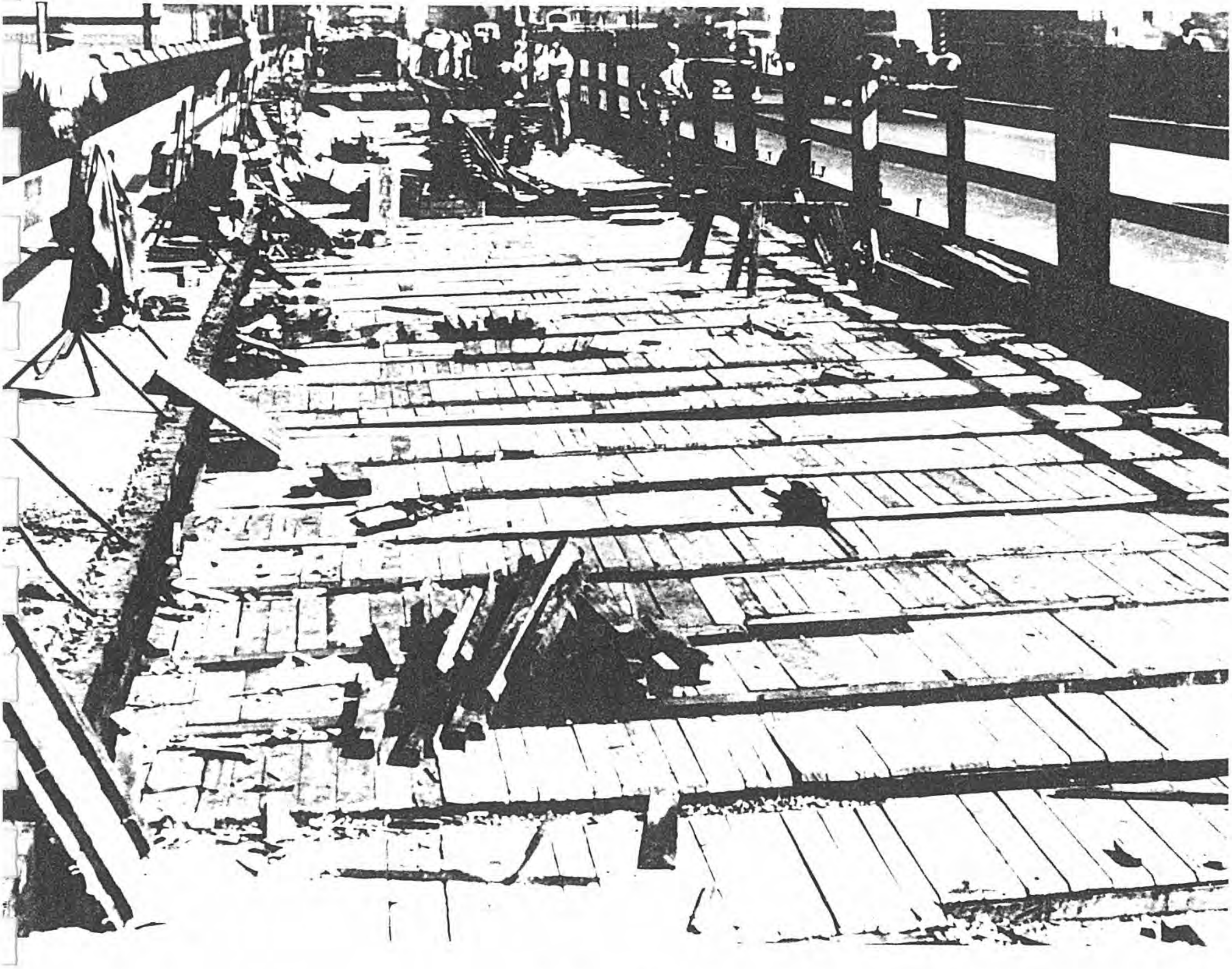

PLATE 11

THE BRIDGE WAS RESURFACED WITH ASPHALT IN LATER YEARS

COURTESY DEPARTMENT OF MAIN ROADS

As Lady Rawson, the wife of the Governor, prepared to cut the ribbon, Works Minister O'Sullivan unwisely remarked that pieces of it were sure to be worth £5 each as mementoes; at this, several people grabbed hold of the ribbon. Once it was cut, every fragment disappeared in a moment.[33]

In the speeches which followed, Pyrmont Bridge was spoken of as a landmark in the development of Australian engineering skills. "I might say the designer in this instance, Mr Percy Allan, is an Australian," said O'Sullivan, "and his work proves that the native born are giving evidence of high ability in every department of engineering, as they have already done in science, art, literature, music, vocalisation, and sport." 34

The Governor also pointed out the Australian achievements encompassed in the design. "You must have men in your midst in connection with your public departments who have shown they are possessed of these qualifications to no mean extent, else you could never have the architectural and engineering triumphs which I, but so shortly in Sydney, have seen so many fine examples of since my arrival. In concluding, there is just one comparison I should like to make. Doubtless, many of you have seen the great Tower Bridge of London, and such of you as have not, have heard of it; well, the roadway of your bridge away out here in Sydney is 4 feet wider than its roadway and will, therefore, give more traffic facilities than that celebrated structure." 35

The date was just over a year from Australian Federation, and Sydney-siders were pleased to hear that their new bridge was a cause for patriotic pride. Not only was Pyrmont Bridge wider than the famous Tower Bridge, it opened faster. The size of the swing span was often remarked on, as was the fact that the slewing of the swing, the lifting of the ends, the operation of the gates, and the lighting of the roadway were all now controlled by one man.

PLATE 12

THE OPENING CEREMONY ON 28 JUNE 1902

AFTER THE FIRST DEMONSTRATION OF THE OPENING OF THE SWING SPAN,
THE CROWD RUSHED FORWARD AROUND THE PLATFORM, UNTIL
THE GUARD OF HONOUR WITH THEIR RAKED BAYONETS WERE LOST AMONG THE PEOPLE.

COURTESY DEPARTMENT OF MAIN ROADS

## 4. CONCLUSION

Pyrmont Bridge was built at a time when urban planning ideas were only just beginning to be applied in Sydney. While the delays afflicting its construction, and the lack of a coordinated plan for Darling Harbour are representative of the ad hoc, unregulated manner in which the Government had acquiesced in the city´s development, men like Hickson saw the wider implications of engineering works and endeavoured to put their ideas into practice. Hickson was not successful in this instance (although his ideas were vindicated later) but as an engineering work the bridge stands out as an example of good design and colonial technological innovation. By using the new electricity from Ultimo Power House as a motive power and the equipment supplied and installed by the Australian General Electric Company, the bridge´s designers minimised the delay to traffic caused by the swing span, and in so doing, created the fastest swing span in the world at that time. This was the cause of much state pride.

Historically also, Pyrmont Bridge is associated with several of New South Wales´ most important engineers. Robert Hickson has already been discussed in detail. Percy Allan, its designer and supervising engineer, designed over 550 bridges in NSW and was the man who introduced Amercian timber bridge practice to the colony; while Henry Harvey Dare, responsible for the unprecedented calculations required, later became Chief Engineer for National Works and Drainage, and was responsible for many water conservation projects. Other engineers associated with it were C.O. Burge, an Englishman who had worked in five continents and was employed on the building of the Hawkesbury Bridge; Gordon Edgell, who designed the swing mechanism and later, having resigned, took up the farming which led to the canned foods company of today; and J.J.C. Bradfield, associated with the Sydney City Railway System, and with Sydney Harbour Bridge.

Apart from its visual appeal and historical importance, a man-made bridge between Pyrmont and the city has its origins in the early years of the nineteenth century. Before the first bridge was erected residents and carriers used ferries; after it was built Pyrmont population tripled in ten years. The importance of the link was shown by the public's impatience with the inadequacies of the old structure. The continual flow of traffic from the city to Pyrmont and so to the western suburbs whether on business or personal errands has been a feature of Sydney's growth since those years.

## NOTES

1. Sydney Morning Herald, 24 March 1894; Parliamentary Standing Committee on Public Works Report Together with Minutes of Evidence, Appendix and Plan Relating to the Proposed Removal of the Pyrmont and Glebe Island Bridges, Sydney: Government Printer, 1894, 1-3.

2. Sydney Morning Herald, 24 March 1894.

3. Alan Roberts, ´Planning Sydney´s Transport 1875-1900´ in Max Kelly (ed.) Nineteenth Century Sydney, Sydney: University Press, 1978, 25-27; W. Francis, Pyrmont, Bachelor of Architecture Thesis, University of Sydney, 1970, 20-25.

4. Roberts, op. cit. loc. cit.
Francis, op. cit, 25; Report... Relating to Pyrmont Bridge, 222.

5. Report ... Relating to ... Pyrmont Bridge, 8.

6. Ibid, 126.

7. Ibid, 188.

8. Ibid, 133, 188 and passim.

9. For example the evidence of Norman Selfe, in Report ... Relating to ... Pyrmont Bridge, 242.

10. One of these estimates was described by the Commissioner of Railways as "altogether absurd" Report ... Relating to ... Pyrmont Bridge, 234.

11. Report ... 295. Parkes' hostility towards the Department of Public Works was marked in the years to follow. In May 1896 he alleged in Parliament that the Department gave unfair advantages to certain contractors, and had defrauded the State. In the subsequent enquiry, Hickson and his officers were completely exonerated. See J. M. Antill, 'Robert Rowan Purdon Hickson : Civil Engineer (1842-1923)' Journal of the Royal Australian Historical Society, 55, (1969), 235-36.

12. Report ... Relating to ... Pyrmont Bridge, 300

13. N.S.W. Parliamentary Debates, 76 (1894-5) 4764 ff.

14. Report ... Relating to .... Pyrmont Bridge, 260

15. W.C. Kernot to Archibald Liveridge, 19 July 1886, Liversidge Papers, Box 19, Sydney University Archives.

16. Carl W. Condit, American Building Art : The Nineteenth Century, New York : Oxford University Press, 1960, 75-89; D.J. Fraser, 'Timber Bridges of New South Wales' Transactions of the Institution of Engineers, Australia, GE9 (1985), 92-101.

17. Department of Main Roads, The Roadmakers, 1976, 44-51; Department of Public Works Register of Officers, 2/8386-8387, Archives Office of New South Wales; Antill, op. cit. 228-235.

18. Building and Engineering Journal, 12 (1894), 91.

19. Henry Harvey Dare, 'Recent Road-Bridge Practice in New South Wales', Proceedings of the Institute of Civil Engineers, 155 (1903-4), 382 ff; Fraser, 'Timber Bridges', 92, 98-100.

20. Percy Allan, 'Highway Bridge Construction: The Practice in New South Wales', (Part I), Industrial Australian and Mining Standard, 14 August 1924, 243; Fraser 'Timber Bridges', 97.

21. Allan, 'Highway Bridge Construction' part VI, Industrial Australian and Mining Standard, 18 September 1924, 433.

22. Fraser, 'Movable Span Bridges in New South Wales Prior to 1915', Transactions of the Institution of Engineers Australia, GE9 (1985), 78.

23. Allan, 'The Pyrmont Bridge, Sydney, N.S.W.', Minutes of Proceedings of the Institution of Civil Engineers, 170 (1907), 11.

24. 'Pyrmont Electric Swing Bridge' The Engineer' 26 January 1917, 75.

25. Fraser, 'Movable Span Bridges', 78; 'Pyrmont Electric Swing Bridge', loc. cit.

26. Allan, 'The Pyrmont Bridge', 17.

27. Allan, 'Highway Bridge Construction', Part II Industrial Australian and Mining Standard, 21 August 1924, 285.

28. The information on the construction of the bridge was taken largely from Allan's own paper 'The Pyrmont Bridge, Sydney, N.S.W.' Mins. and Procs. Institution of Civil Engineers, 170 (1907), 2-91, and from a paper by E.G. Trueman given to a meeting of the Institution of Engineers, Australia.

    Another comprehensive account of the bridge's construction is given in a series of articles titled 'Pyrmont Electric Swing Bridge' in The Engineer 26 February 1917, 75-78, 2 February 1917, 103-106; 9 February 1917, 124-126; and 16 February 1917, 151-53.

29. First Report of the Harbour Trust Commissioners for 1901 Sydney: Govt. Printer 1902, 3 ff.

30. Hickson to the Minister for Public Works, Minute, Hickson Papers, quoted in Antill, op. cit.

31. N.S.W. Parliamentary Debates, 4, (1901), 4508-09.

32. Parliamentary Standing Committee on Public Works, Report together with minutes of Evidence, Appendix, and Plan, relating to the Proposed Extension of the Pyrmont Bridge, Sydney: Government Printer, 1901, 5.

33. Sydney Mail, July 1902; Sydney Morning Herald, 30 June 1902

34. Sydney Morning Herald, 30 June 1902

35. Ibid.

# Bibliography

## OFFICIAL SOURCES

Parliamentary Standing Committee on Public Works, Report together with Minutes of Evidence, Appendices and Plans Relating to the Proposed Removal of the Pyrmont and Glebe Island Bridges, Sydney, Government Printer 1894.

Parliamentary Standing Committee on Public Works, Report together with Evidence, Appendix and Plan Relating to the Proposed Extension of the Pyrmont Bridge, Sydney: Government Printer, 1901.

Sydney Harbour Trust, First Report of the Sydney Harbour Trust Commissioners for 1901, Sydney: Government Printer, 1902.

New South Wales Parliamentary Debates, 1893-1902.

Department of Public Works Register of Officers, 2/8386, 2/8387, Archives Office of New South Wales.

## SECONDARY SOURCES

ALLAN, Percy, ´The Pyrmont Bridge, Sydney, NSW, ´Proceedings of the Institution of Civil Engineers, 170, (1907) 2-91.

ALLAN, Percy, "Highway Bridge Construction: The Practice in New South Wales´, Industrial Australian and Mining Standard, (1924) 14 August, 243-46; 21 August, 281-85; 28 August, 318-85; 4 September, 356-58; 11 September, 394-96; 18 September, 432-36.

ANDERSON, Gordon F, ´Fifty Years of Electricity Supply - The Story of Sydney´s Electricity Undertaking, Sydney: Sydney City Council, 1955.

ANON, ´Pyrmont Electric Swing Bridge´, The Engineer, 26 (1917) 26 January, 75-78; 2 February, 103-106; 9 February, 124-26; and 16 February, 151-153.

ANTILL, J.M., ´Robert Rowan Purdon Hickson: Civil Engineers 1842-1923´, Journal of the Royal Australian Historical Society, 55, (1969) 228-244.

APLIN, Graeme and STOREY, John, Waterfront Sydney 1860-1920, Sydney: George Allen and Unwin, 1984.

BURROW, ´Bridge Construction in New South Wales´, Minutes of Proceedings of the Engineering Association of New South Wales, 33, (1918-19), 131-190.

CONDIT, Carl W., American Building Art : The Nineteenth Century, New York: Oxford University Press, 1960.

DARE, H.H., ´Recent Road-Bridge Practice in New South Wales, Proceedings of the Institution of Civil Engineers, 155, (1903-4) 382-400.

FRANCIS, W., Pyrmont, B. Archit. Thesis, University of Sydney, 1970.

FRASER, D.J., ´Timber Bridges of New South Wales´, Transactions of the Institution of Engineers, Australia - Multi-Disciplinary Engineering, GE9 (1985), 92-101.

FRASER, D.J., ´Movable Span Bridges in New South Wales Prior to 1915´, Transactions of the Institution of Engineers, Australia - Multi-Disciplinary Engineering, GE9 (1985), 71-81.

KELLY, Max, Plague Sydney 1900, Paddington: Doak Press, 1981.

LENNON, Brett and WOTHERSPOON, Garry, ´Sydney´s Trams, 1861-1914: The Rise of an Urban Mass Transport System in Wotherspoon (ed.), Sydney´s Transport: Studies in Urban History, Sydney: Hale & Ironmonger, 1983.

MATTHEWS, Michael R, Pyrmont and Ultimo: A History, Glebe: Southwood Press, 1982.

NSW DEPARTMENT OF MAIN ROADS, The Roadmakers, Sydney: The Department, 1974.

ROBERTS, Alan, ´Planning Sydney´s Transport 1875-1900´ in Max Kelly (ed.) Nineteenth Century Sydney, Sydney University Press, 1978.

ROSE, P, and BRITTON, S, The Corn Exchange and Sussex Streets Precincts, Sydney, B. Archit. thesis, University of Sydney 1976.

STEPHENSON, P.R., The History and Description of Sydney Harbour, Adelaide, Rigby, 1966.

TRUEMAN, E.G., Timber Bridge Construction in New South Wales, a report available from Hughes-Trueman-Ludlow, Consulting Engineers, St Leonards.

**PERIODICALS**

Building, Engineering and Mining Journal

Sydney Mail

Sydney Morning Herald

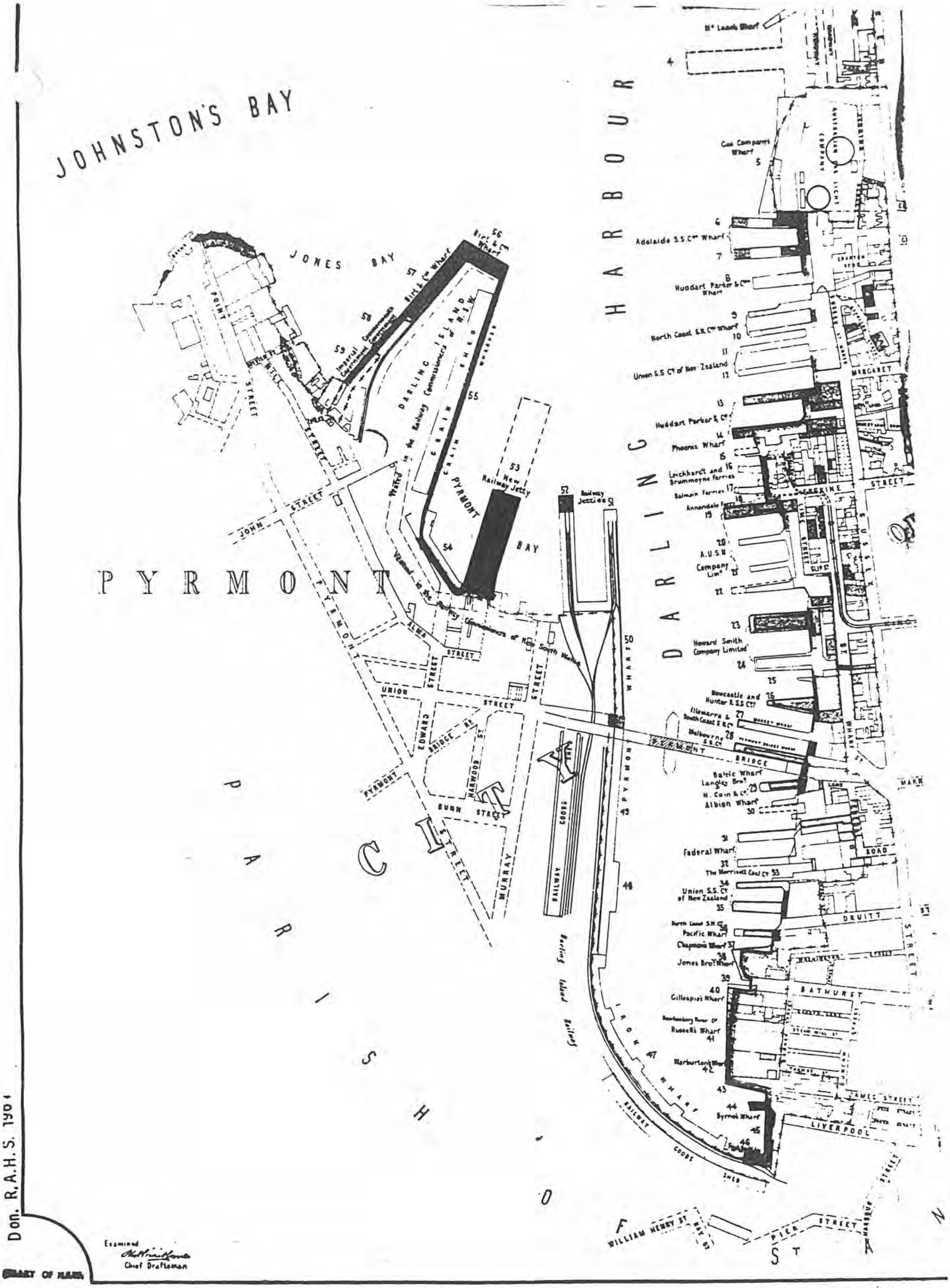

PLATE 13

THE DARLING HARBOUR AREA IN 1907

COURTESY MITCHELL LIBRARY

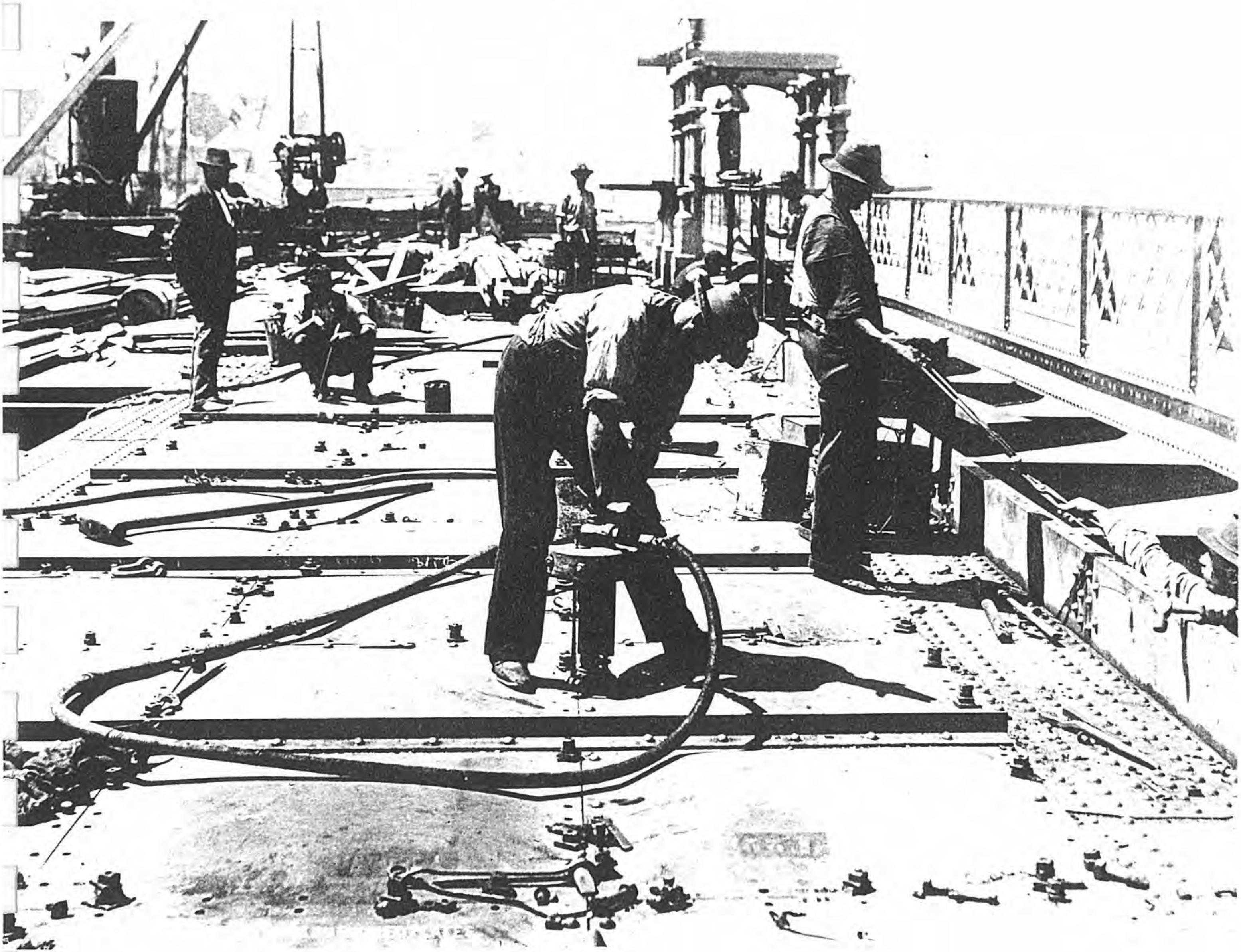

PLATE 14

RIVETTERS AT WORK ON THE BRIDGE.
THE WATCHHOUSE IS PARTLY BUILT

COURTESY DEPARTMENT OF MAIN ROADS

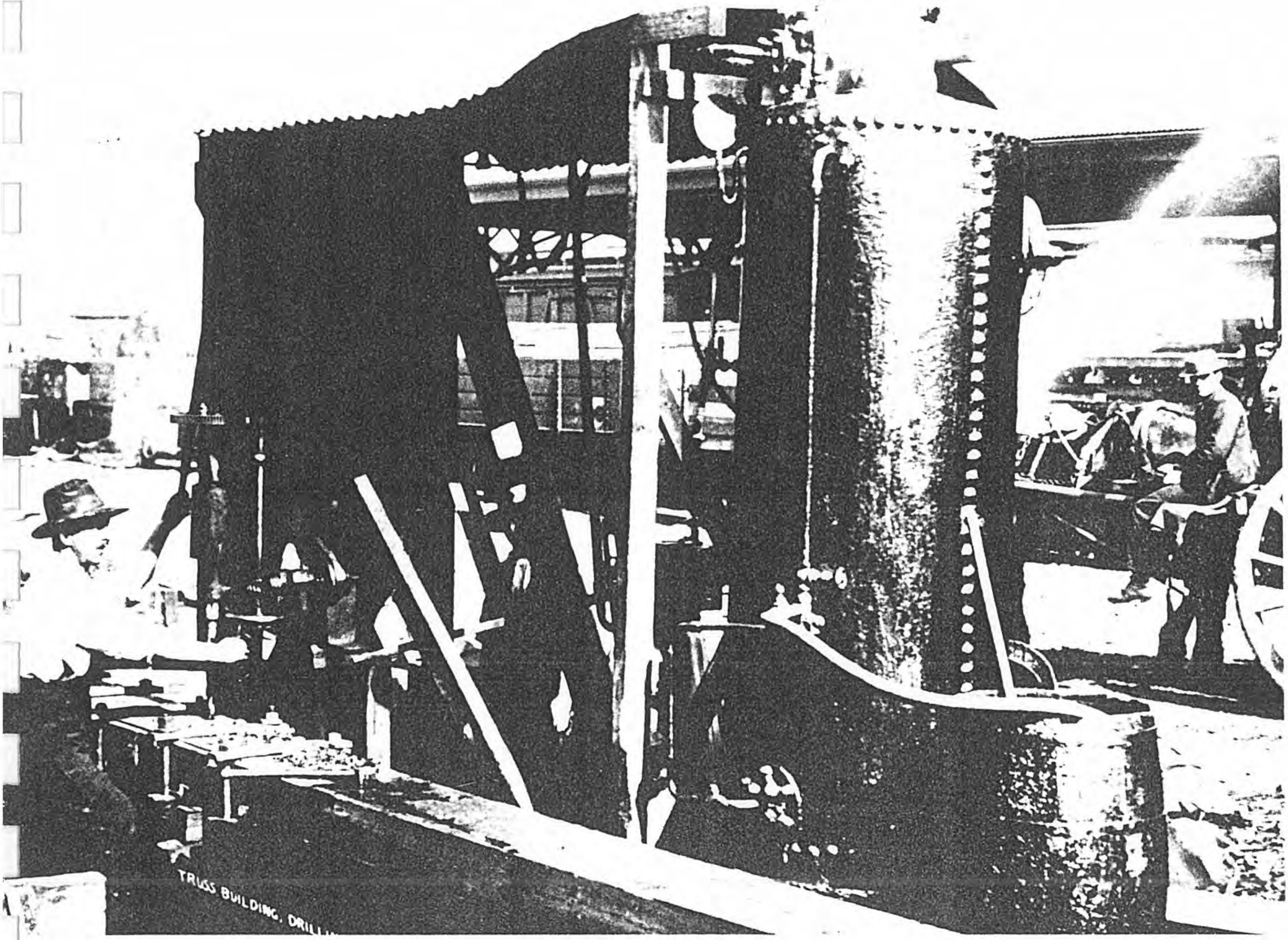

PLATE 15

DRILLING EQUIPMENT

COURTESY DEPARTMENT OF MAIN ROADS

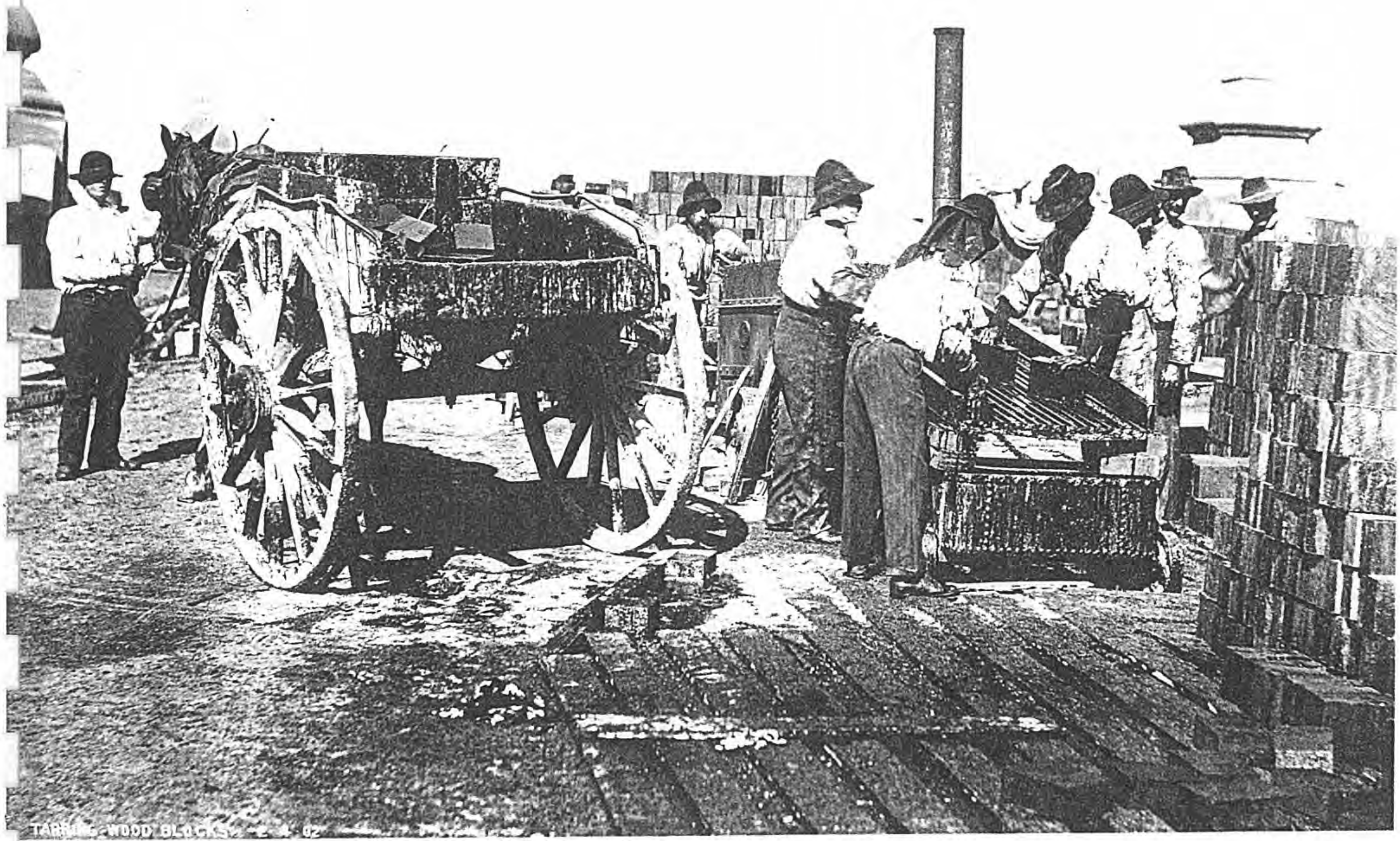

PLATE 16

TARRING WOODBLOCKS FOR THE ROAD SURFACE OF THE SWING SPAN. TARRED METAL WAS USED ON THE SIDE SPANS, ALTHOUGH THIS WAS LATER REPLACED WITH WOOD, AS METAL WAS NOT SUCCESSFUL WITH HEAVY TRAFFIC. TARRING WAS A VERY UNPLEASANT JOB.

COURTESY DEPARTMENT OF MAIN ROADS

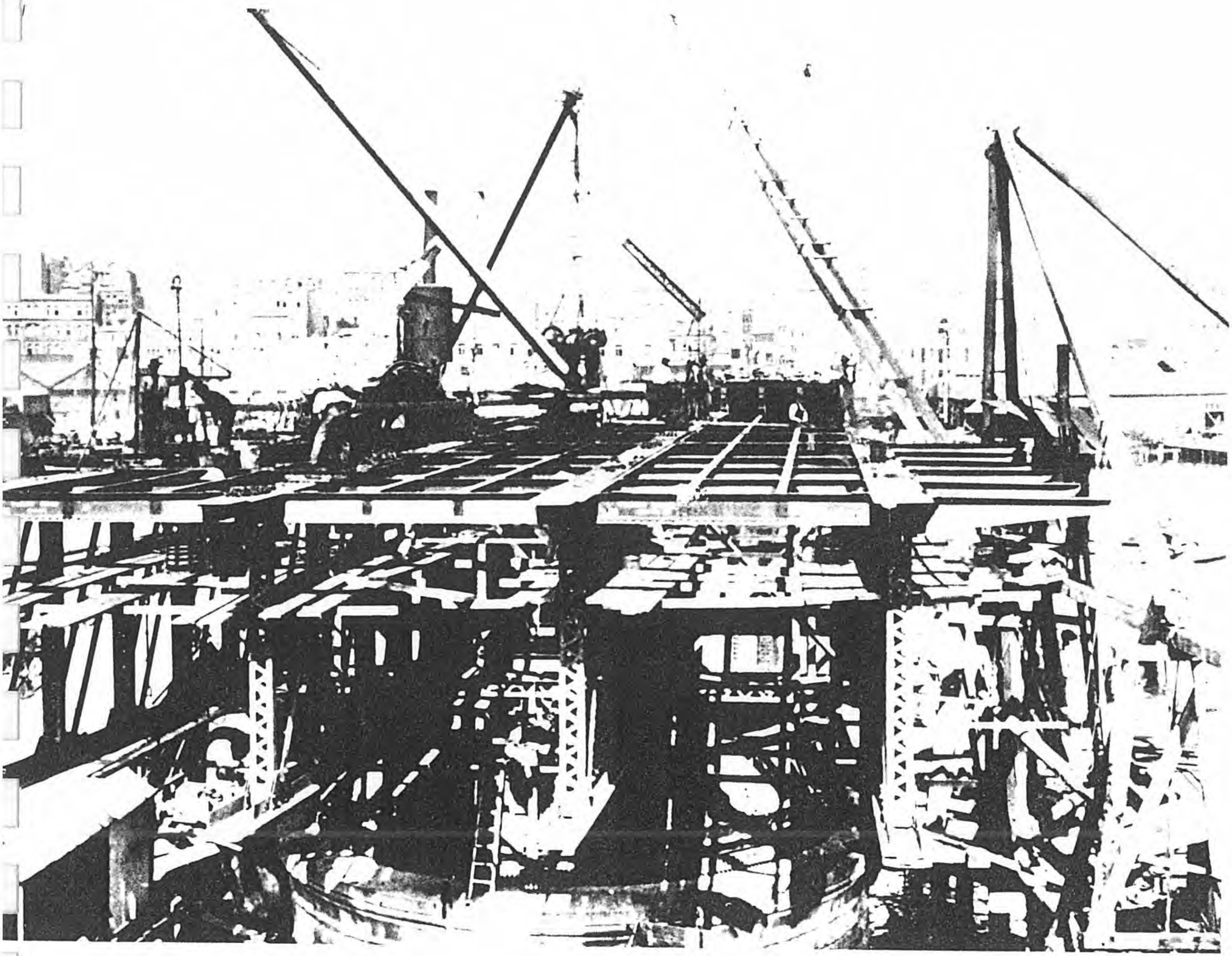

PLATE 17

THE IRON FRAMEWORK OF THE BRIDGE. SYDNEYSIDERS HAD
NEVER BEFORE SEEN A BRIDGE OF THIS COMPLEXITY AND MAGNITUDE
BEING RAISED IN THEIR CITY

COURTESY DEPARTMENT OF MAIN ROADS

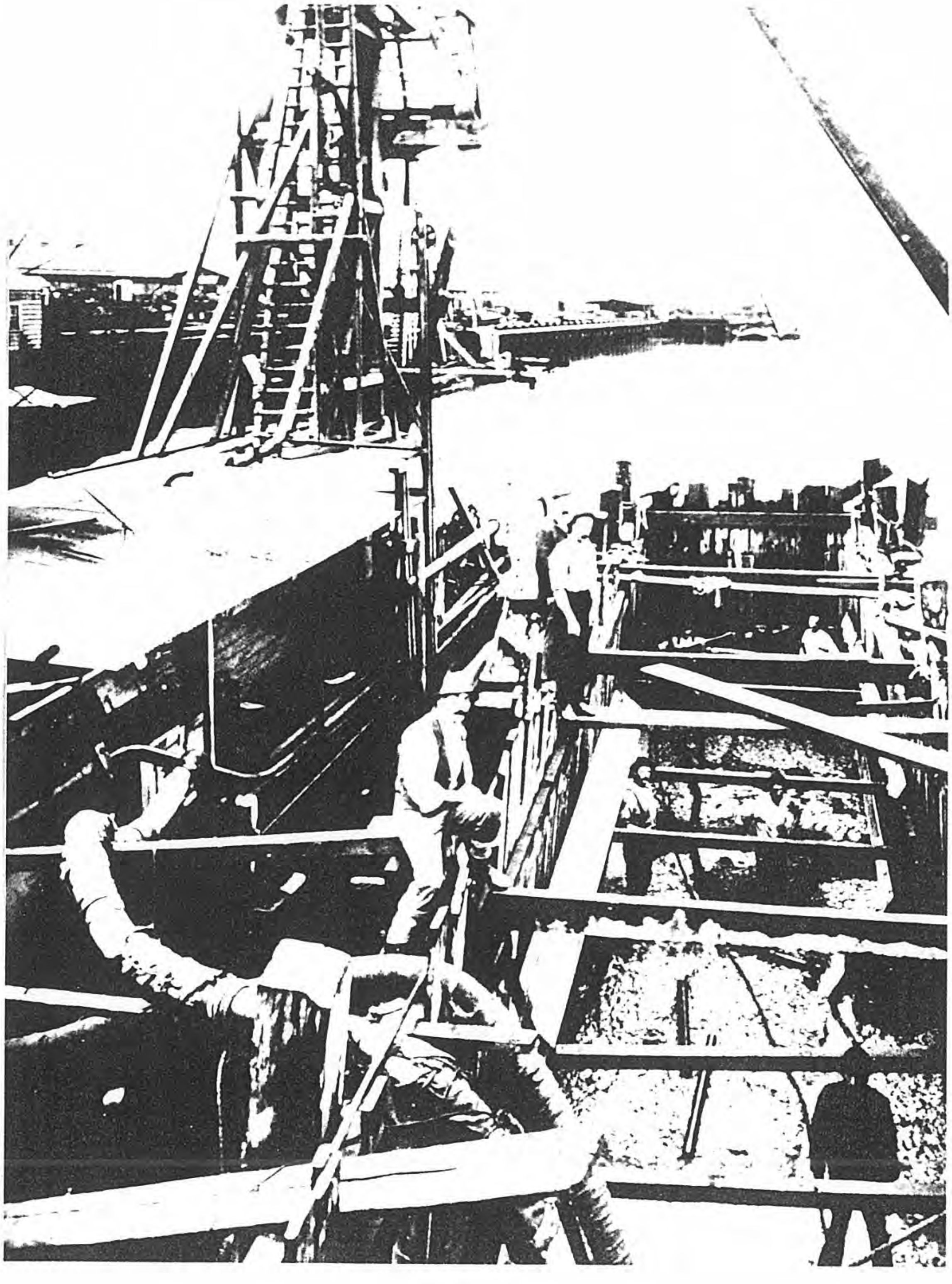

PLATE 18

THE BRIDGE WORKERS PHOTOGRAPHED DURING CONSTRUCTION

COURTESY DEPARTMENT OF MAIN ROADS

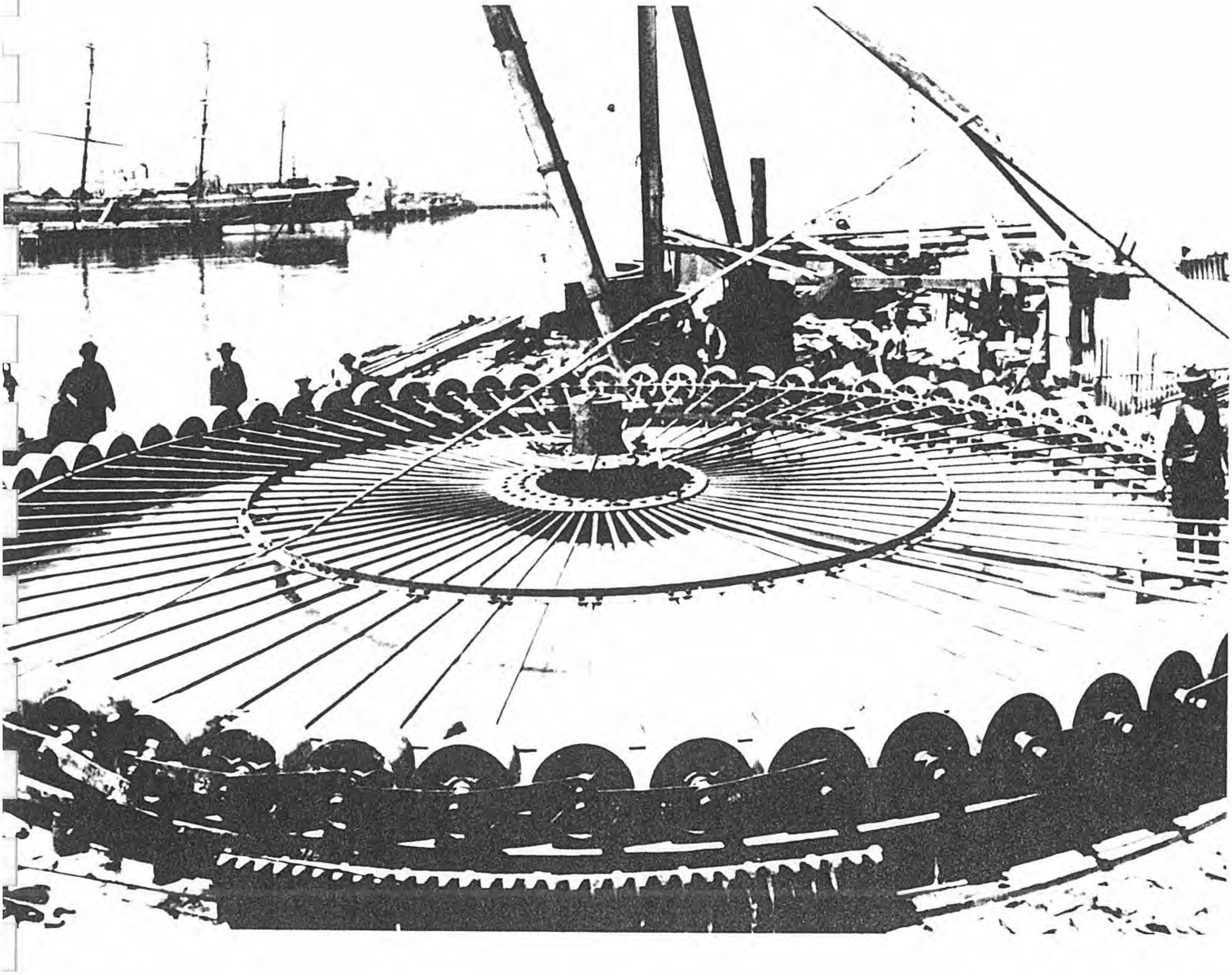

PLATE 19

THE HUGE DRUM REQUIRED FOR THE PIVOT PIER OF THE SWING

COURTESY DEPARTMENT OF MAIN ROADS

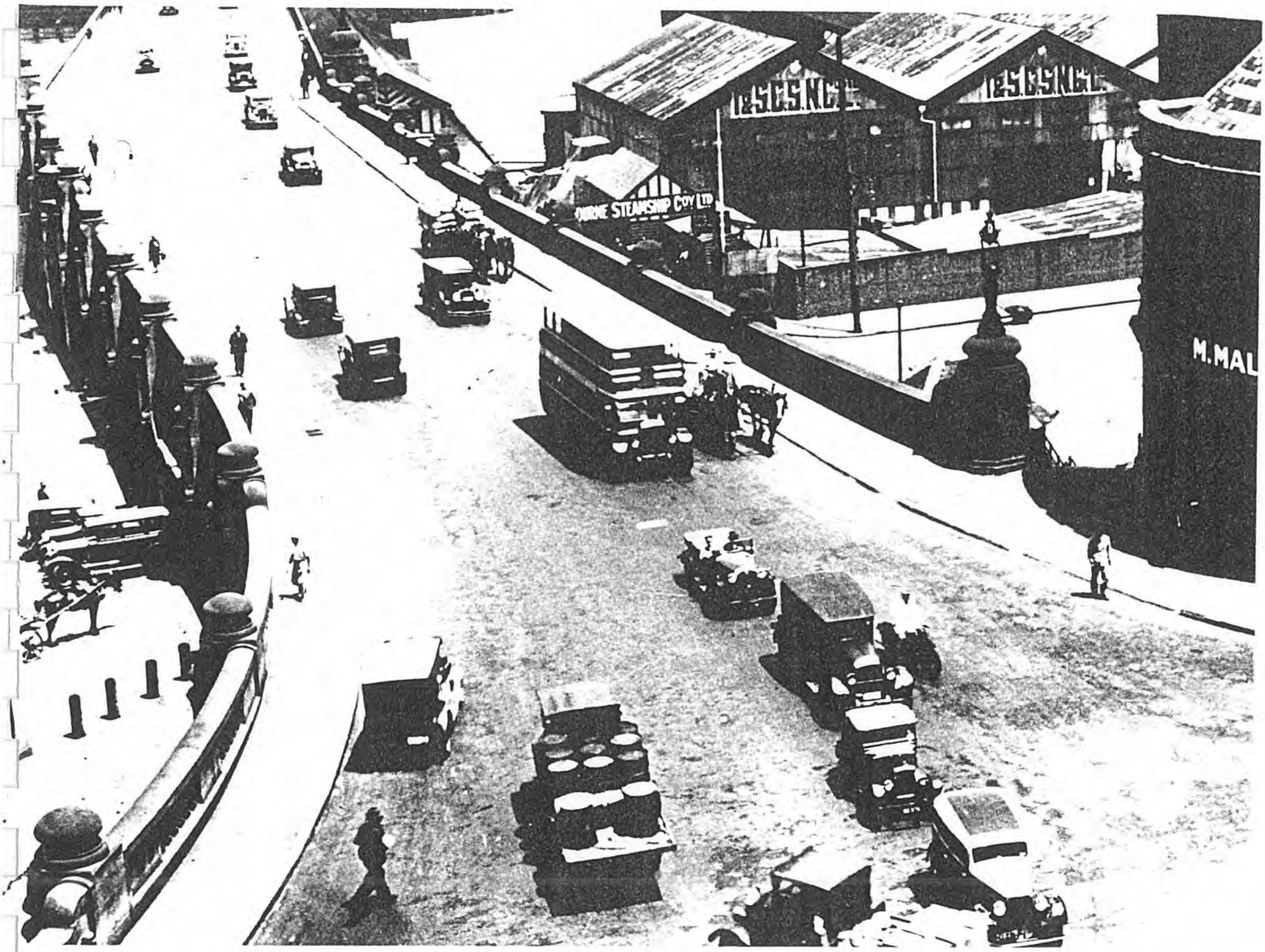

PLATE 20

PYRMONT BRIDGE IN LATER YEARS

ITS ROAD SURFACE WAS ALTERED TO SERVE THE NEEDS OF MOTOR TRAFFIC

COURTESY DEPARTMENT OF MAIN ROADS

# THE PYRMONT BRIDGE, SYDNEY, NSW

BY PERCY ALLAN MICE
INSTITUTION OF CIVIL ENGINEERS
16 APRIL 1907

## ADVERTISEMENT.

LONDON : PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
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# THE INSTITUTION OF CIVIL ENGINEERS.

## Sect. I.—MINUTES OF PROCEEDINGS.

16 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3483*).

## "The Pyrmont Bridge, Sydney, N.S.W."

By Percy Allan, M. Inst. C.E.

The old Pyrmont Bridge crossing Darling Harbour—an arm of Port Jackson extending into the heart of the City of Sydney—was constructed by a private company in 1857 at a cost of £75,830.

The Government purchased the structure in 1884 for £49,600, when the tolls—then valued at £10,000 per annum—were abolished. Seven years later competitive designs were invited for a new bridge on the south side of the old structure, and, after adjudication, premiums amounting to £1,200 were awarded by the Advisory Board of Engineers. No further action was taken until early in 1894, when the question of "the removal of the old bridge and the construction in its place of certain other means of communication" was referred by the New South Wales Parliament to the Parliamentary Standing Committee on Public Works for inquiry and report.

The conditions upon which the competitive designs were based only called for a swing-span affording a 38-foot deck and two 60-foot fairways, which—in view of the vehicular traffic having increased by 40 per cent. in 5 years, and the utilization of the harbour by vessels of 4,500 tons—was considered inadequate, and led to the Department of Public Works submitting to the Committee a design for a steel bridge with a swing-span of 54 feet, affording two 70-foot clear fairways.

After prolonged inquiry and the consideration of about twenty-six schemes, the Committee decided in favour of the design submitted by the Public Works Department, with timber in lieu of the steel side spans originally recommended.

The foundation stone of the new bridge was laid by the Hon.

E. W. O'Sullivan, State Minister for Works, on the 6th September, 1899; and the bridge was opened for traffic on the 28th June, 1902, by His Excellency Vice-Admiral Sir Harry Holdsworth Rawson, K.C.B., Governor of New South Wales.

The new bridge and its approaches extend from Sussex Street on the City side to Murray Street on the Pyrmont Shore (Fig. 1, Plate 3), a distance of 1,825 feet, the length of the main bridge being 1,210 feet. A steel overbridge, affording three 30-foot clear openings for the vehicular traffic to the wharves, is provided in the Sydney approach, whilst on the Pyrmont side the railway to Darling Island passes under a steel bridge of 25 feet span. The clear headway under the side spans is 26 feet above high water, which meets the requirements of the tugs and lighters visiting the railway wharves above the bridge.

*Pivot-Pier* (Figs. 2 and 3, Plate 3).—The five bore-holes sunk on the site of the pivot-pier passed through an average of 3 feet of mud and 25 feet of arenaceous clay before reaching the sandstone rock, which had a dip of 8 feet in the diameter of the pier. With such a large body of clay it was determined to sink a wrought-iron caisson to the rock by open dredging, to pump out then the water within the caisson, and to excavate a trench in the sloping rock sufficient to enable the whole periphery of the cutting edge to be bedded on the solid.

The caisson, 42 feet in external diameter, 32 feet in internal diameter, and 53 feet $1\frac{1}{2}$ inch long, is founded 54 feet below low water, and is formed of two concentric rings of plating connected with angle-bar bracing, the inner ring being splayed out at the bottom to form the cutting edge. The plates vary in thickness between $\frac{1}{2}$ inch and $\frac{5}{16}$ inch, the outer ring—to ensure verticality in sinking—being plumb for a height of 27 feet, with circumferential butt joints and countersunk rivets; in the remaining length of outer ring and in the inner ring from bell mouth to top, the circumferential joints are lapped "in and out" with cup-headed rivets. All the vertical joints are butted, with cup-headed rivets for the whole length of the caisson, it being considered that the clay would swell sufficiently to prevent leaks in sinking due to the projecting heads. All joints were caulked, and most of the rivets were closed with pneumatic riveters. The walls of the caisson were remarkably dry under 29 feet of water.

The first section of the caisson, weighing 50 tons, was put together directly over the pier-site on a square ironbark frame, the ends of the four sticks being allowed to project and form the eight points from which the frame with its load was suspended by wire ropes from the protecting platform, already in position. The ropes were simply passed over and under rounded timbers spiked to the top of the platform and the underside of the frame, and were eased away by hand by twelve men until (after 4 hours) the caisson floated with a draught of 7 feet 3 inches. Fresh sections were quickly built on, and sinking was proceeded with by depositing concrete between the shells, each foot of concrete increasing draught by 2 feet 1 inch. When within a few inches of the bed of the harbour, the caisson was brought into correct position by folding wedges working between long timber guides bearing against the side of the caisson and the piles of the platform; concreting was then rapidly proceeded with at the bottom of a tide, so that with the next ebb the caisson was quietly grounded in a true position and with sufficient weighting to prevent it from lifting.

The material within the caisson overlying the rock was excavated with a bucket dredger worked by a floating crane, and no difficulty was experienced in controlling sinking or keeping the caisson level, a result which the Author considers to be due to the plumb sides adopted as much as to any uniformity in the strata. Advantage was derived from the expedient of having four draught-gauges painted on the inner wall, the cut of the water showing at a glance any movement out of level, and enabling prompt action to be taken by dredging and weighting to counteract the deviation. The greatest amount out of level up to the time of pumping out was $5\frac{7}{8}$ inches in 42 feet. By excavating in the middle below the level of the cutting edge, it was generally found that the weight of the caisson forced the material into the "well" and allowed of very gradual and uniform settlement, working within 5 feet of the inner wall being rarely necessary until nearing the rock, when dredging on the high point of the rock was conducted as close to the inner wall as possible, a good band of clay being left on the low side for the cutting length to bed in when the water was pumped out of the caisson.

Upon pumping out, the caisson listed 11 inches out of level, but only two small leaks showed, and these were easily dealt with by a small pulsometer. No time was lost in excavating the rock on the high side, and in 48 hours the caisson was lowered 2 feet, when a blow occurred, the water filling the caisson in 20 minutes and bringing with it a small quantity of sand and mud, the vertical line of the caisson, however, not being altered.

The Author is of opinion that had some clay been available for placing round the caisson, the leaks, small as they were, would not have developed into a blow.

Although the contingency of excavating the rock by divers and depositing the bottom 12 feet of concrete through the water had been provided for, yet the advantages of a dry foundation were considered so desirable that another effort to pump out the caisson was decided upon. A large bank of clay was placed in position surrounding the caisson, and the excavation of the remaining 6 feet of rock by "jumpers" was proceeded with.

A jumper formed of an ironbark pile 64 feet long, carrying on its end a heavy steel casting provided with three steel cutters, was used for excavating the rock from the line of the inner wall 5 feet inwards; the jumper was hoisted vertically by a steam crane and was tripped in the usual way with a 6-foot to 8-foot drop. On obtaining a face with the vertical jumper, the rock under the bell-mouth and cutting edge was removed with a jumper formed of a flat-footed rail having a steel chisel-point bolted to its lower end; this jumper worked within a hollow chute furnished with a wrought-iron plate upon which the flat foot of the rail rested and worked. By means of guys fastened to the bottom and top of the chute, the jumper could be set at a sufficient angle to reach anywhere under the bell-mouth or cutting edge, the position of the cut being directed by a diver; the jumper was hoisted with a steam-crane and was tripped with a drop of 10 to 12 feet. The jumpers, although slow, did their work well. Divers were employed to clear the rock at the back of the butt straps, the cup-headed rivets in these straps, as well as in the vertical seams, causing some trouble and necessitating more cutting back than would have been required had flush riveting been adopted.

During the course of excavation, the water was usually kept near the top of the inner wall, and upon the rock being cleared for 10 or 12 inches in depth the water was pumped down about 23 feet and the caisson was allowed to settle; this process was followed until the contract-depth was reached, the caisson having in the meanwhile been gradually straightened until it was finally only 2¼ inches out of level with the cutting edge in its correct position, and the top was well within the margin of 12 inches allowed for errors in placing and sinking.

The few places where the cutting edge was not bearing on the rock were cleaned with a water-jet, and the space was filled with fine rich basalt concrete deposited in bags and packed by divers. Around the caisson, for a distance of 4 feet from the outer shell, rings of concrete bags were laid, headers and stretchers, to a height of 4 feet, the space between the ring of bags and the cutting length being filled with concrete deposited loose by means of a bell-mouthed canvas bag

lowered through the water and tripped by divers when in position. This work was carried out in eight sections to ensure the rock being well washed off with the jet before concreting. In order to stiffen the concrete under the bell-mouth, a circular sand-bag wall was built 11 feet inwards from the outer shell, and concrete was deposited in the space through 50 feet of water by automatic self-tripping boxes. This work also was carried out in sections, and after it had been allowed to set for 9 days the water was pumped out of the caisson in 12 hours.

After the water had been pumped out the sand-bag wall was removed and the rock and concrete were thoroughly washed with a jet the concrete being found to have set very hard and to have been well placed by the divers. Three small leaks were apparent, and were collected in 3-inch iron pipes surrounded with neat cement and led to a sump. Sandstone concreting was then carried on night and day up to 12 feet above the cutting edge. From this point to the top, the interior of the caisson was filled with rubble sandstone concrete, the plums weighing up to 3 tons. The water in the sump was easily kept down, and the concrete was laid in the dry without trouble. The sump was carried up to low-water mark before being finally filled.

On the completion of the masonry the temporary caisson which extended 2 feet above high-water mark was removed, leaving nothing but the stonework of the pier visible.

The proportions and cost of concrete used in the pier are given in Table I of the Appendix.

The total weight on the foundations of the pier, neglecting friction and buoyancy, is 6,800 tons. The time taken in sinking the caisson was 9 months, of which 7 weeks were occupied in reaching the bed of the harbour, 11 weeks in passing through the 24 feet of material overlying rock, and 4½ months in sinking the last 6 feet to the contract-depth.

*Rest-Piers.*—The Pyrmont rest-pier is founded on the rock, whilst the Sydney rest-pier is carried on fifty-eight piles driven to the rock bottom about 64 feet below low-water mark.

At the site of the Sydney rest-pier an area somewhat larger than the pier was excavated with a ladder dredger until a level clay bottom was obtained 32 feet below low-water mark. The foundation-piles —finishing alternately 2 feet and 3 feet 6 inches above the excavated bottom—were then driven with a follower until the rock was reached, when, by tapping out bolts which passed through the four projecting flitches and the pile-head, the follower was released by a diver. Some of the piles, with the follower, measured 78 feet in length, but no difficulty was found in pitching or keeping them in place. The follower, which was used repeatedly, was provided with a ring at top and bottom, but no ring was used on the pile heads, the toughness of the ironbark timber preventing trouble from brooming or splitting.

To ensure the guide-piles being driven correctly, a rectangular hardwood frame was lowered on to the bottom and was held in place while the guide-piles were driven 10 feet. The frame was then removed. Each set of horizontal walings, after being fitted with a guide passing round each pile, was bolted to vertical Oregon runners, by which the walings were forced below water. Successive sets of walings about 5½ feet apart were bolted to the runners and forced down until the bottom was reached. Vertical sheathing of hardwood was next lowered in 6-foot sections, the back of each section being provided at each waling with two battens blocked off and set at an angle, so as to draw the sheathing hard up against the waling when forced down from the top.

When the sheathing was completed, the silt which in the meanwhile had settled between the heads of the foundation-piles was removed by divers, the marine growth being also cleared off the pile-heads. Sand equivalent to a depth of 6 inches was then deposited over the whole area of the pier and a clean bottom was thus obtained.

Between the pile-heads, the concrete was deposited through the water in long timber boxes, fitting the space between the piles and provided with top and bottom doors: these boxes were guided into place by divers and pumping. Above the pile-heads and up to within 2 feet of low-water mark the concrete was deposited through the water in single-rope self-tripping iron boxes designed by the Author with a view to reduce disturbance. Each box, holding 22 cubic feet of concrete, was provided with top and bottom doors, the latter being set on an angle and suspended on the outside of the box from the crane-rope, so that on reaching the bottom the slackening of the rope allowed the weight of the concrete to force open the doors and to bring into engagement the two hooks with which the box was hoisted with the doors hanging free. Although these boxes did their work well, the Author is of opinion that, where suitable gear is available, boxes of a larger capacity would be preferable. The work of concreting was carried on continuously through the water until its completion, the 1,850 cubic yards in the bases of the two piers being finished in 19 days.

This expeditious placing of the concrete minimized trouble from slurry, but in a few instances slurry formed and was removed by divers. In depositing the concrete, it was generally kept with a slight dip towards the centre so as to avoid the risk of slurry forming face cavities. After the concrete had been allowed to set for 14 days the dam was pumped out, and a fair amount of slurry of the consistency of chalk was removed before the remaining 12 inches of concrete in the bases of the piers was deposited in the dry; the masonry work starting from 1 foot below low-water mark was also laid in the dry.

On the completion of the piers the timberwork was removed and a rigid inspection of the surfaces was made by a diver, the piers being reported to have a smooth face and to have set very hard, a report which the Author's subsequent inspection of one of the piers confirmed. The proportions and cost of concrete and the prices of materials are given in Table I (Appendix).

*Swing-Span* (Figs. 2 and 4, Plate 3).—The swing-span consists of four main girders with horizontal top and curved bottom booms, 223 feet long, 15 feet deep at the centre and 5 feet deep at the ends, spaced 13 feet 4 inches apart and rigidly braced together over the pivot-pier and at the ends, whilst vertical and diagonal bracing connect the top and bottom booms at intermediate points. The girders are also connected at their upper panel-points by cross girders carrying a rolled-joist and buckled-plate deck, the buckled plates being riveted to the projecting bottom flange-plates of the top booms, which gives the rigidity so desirable in a high-speed swing-span. Upon the steel deck is laid coke concrete, covered with tallow-wood blocks on the carriage-way and asphalt on the footpaths.

The swing is of the rim-bearing type, the whole weight, 800 tons when swinging, being distributed by means of eight small girders to sixteen equidistant points on the drum.

The swing-span is designed to carry a distributed live load of 100 lbs. per square foot of deck, and a concentrated load of 20 tons on a 10-foot by 5-foot wheel-base. The main girders were calculated to have a deflection of 4 inches, and the actual deflection is 4¼ inches; but as the maximum stresses over the pivot-pier occur when the bridge is swinging, the ends are lifted only 1¼ inch, the dead load taken by the cams at each end being about 40 tons, which reduces the time of lifting, and is sufficient to prevent chattering due to heavy loads concentrated at the ends.

The span was built out from the pivot-pier without staging, a stationary crane on the platform alongside raising the material to a crane travelling on the top of the span, by which the different members were placed in position.

To avoid the cracking of the cement rendering upon which the wood blocks are laid, the ends of the swing-span were weighted to give an equivalent deflection to that produced by the blocks, the rendering was then completed, and the weighting was gradually removed as the laying of the blocks proceeded.

*Turn-table.*—The drum, which is 35 feet in diameter and 5 feet deep, is provided with sixteen radial struts connected at their inner ends to two disk plates fitted over and revolving about the cast-iron pivot. A steel coned tread is secured to the underside of the drum and bears on sixty-six cast-steel rollers, 10½ inches wide over all, with a bearing width of 10 inches face. The rollers are connected with 1¼-inch radial rods to two circular disk plates revolving about the pivot with ¼-inch play, the whole forming a flexible turn-table.

The bottom tread is of the same section as the top tread, and is secured to a cast-iron track of bridge section machined top and bottom, and bedded hard on the masonry. It was not found practicable to machine the treads and track without building a special lathe with a rigid face-plate or table at least 37 feet in diameter. It was therefore determined to construct a special attachment to a planing-machine, and to plane each section of the tread separately to the correct radius, and to fit the sections together afterwards to form the circle.

Some weeks after the opening of the bridge for traffic, the pivot was found to be moving with the turn-table, due to the drawing of the holding-down bolts and some slackness in the bolt-holes. This was rectified by the addition of four wrought-iron keeper-plates 8 inches wide by 1¾ inch thick, with the outer edges turned down 3 inches. The plates rested on the bed-stone, the lip being let down into the stone, whilst the circular inner edge bore against the bottom flange of the pivot, the thrust from the pivot being taken by the back of the lip bearing against the bed-stone, and the keeper-plates being held down by a couple of 1¼-inch bolts run in with lead. Very great care was taken in fitting these plates, and when in position, the bed-stone was covered, and the pivot surrounded up to the top of the bottom flange, with rich concrete.

Much trouble was experienced through the rollers seizing and tearing off the ends of the radial rods, caused by the iron borings which had not been thoroughly cleaned out of the tapped holes for the grease-cups finding their way with the grease on to the rods. This caused scoring and eventually seizing of the rods, which in the first instance were too neat a fit. Also, the gun-metal nuts against which the rollers bear had no oil-runs; and whilst the lock-nut was effective when opening the swing, yet, in closing it, the friction of some of the rollers was sufficient to make the gun-metal nuts revolve with the rollers until the ends of the radial rods were torn off.

Accordingly the rods were straightened, some were welded, and all were turned down 1/16 inch. Oil-runs were also cut on the rods and gun-metal nuts, whilst the links connecting the outer ends of radial rods were slotted ½ inch at each end and provided with machined fillers; so that by knocking back a filler the links can now be taken off without having to free three radial rods, as was previously necessary for the removal of a single roller.

A long delay was occasioned through the rods and rollers not being interchangeable, as it was necessary to replace every roller on its own rod. To prevent the running back of the bearing nuts, small inverted U-shaped steel castings have been provided, with a claw fitting the nut like a spanner, whilst lugs on the castings, machined to fit under the bottom edge of the connecting links, take the pull. During 3 years after these alterations were made the bridge was swung 18,816 times without a hitch, or any expenditure on repairs, whilst the even distribution of the weight on the rollers is shown by the absence of any idle roller in the ring.

*Motive Power.*—The machinery both for sluing the swing-span and for lifting its ends, as well as for working the roadway-gates on the side spans, is actuated by electric motors driven by current supplied from the tramway power-house about 1½ mile from the site, and controlled from a small house situated over the footpath at the centre of the swing-span. The motors, controllers, and electrical apparatus generally, so far as the conditions permitted, are of the tramway type adopted by the Railway Commissioners of New South Wales, which ensures duplicate parts being always available, and speedy replacement or repairs. The potential of the current ranges from 550 to 600 volts.

The two 50-HP. series-wound motors for sluing the swing-span are of the General Electric Company's standard "G.E. 57" type, and were guaranteed capable of exerting together a starting-effort of 5,384 lbs. at 3·143 inches radius from the centre of the armature-shaft, and, with this load, of attaining an armature-speed of 509 revolutions per minute at the end of 24 seconds without the current exceeding 130 amperes in either motor. An allowance of 100 per cent. upon the calculated maximum effort required at the pitch-circle of the rack in a heavy wind is included in these figures to cover the friction in the gear between the motors and the rack.

The motors are fixed to the machinery-platform within the drum, and drive, through cut steel spur-gearing, a main horizontal shaft carrying at each end a bevel-pinion meshing with bevel-gears (one looking up and the other looking down) keyed to the tops of the two vertical shafts on the outside of the drum. The vertical shafts carry pinions on their lower ends, which tooth into the rack fixed to the cast-iron track running right round the pivot-pier.

The shafting and gearing is so designed as to allow of either or both motors driving through one vertical shaft, whilst the gear reduction is 1,223 revolutions of the armature to one complete revolution of the swing-span.

In Table II (p. 20) are given the results of twenty runs at different speeds, the maximum effort exerted by the motors to slue the span in 30 seconds having been 89 HP., at a cost of 0·357*d.*; whilst 15 HP. was exerted by the motors for a 69-second run at a cost of 0·221*d.*; the most economical run of the series was one in 55 seconds, at a cost of 0·183*d.*, with a maximum motor-effort of 48 HP. The smoothness of the track and the easy running of the turn-table is shown by the tests, the span in some cases having "coasted" through 70 degrees after the current was cut off.

Auxiliary hand-gear is provided, the 6-foot capstan-bars on deck working two vertical shafts carrying on their lower ends mitre-wheels driving two horizontal shafts having cut pinions meshing with the large cut gears keyed to the main horizontal shaft. The reduction is 352 revolutions of the capstan-head to one complete revolution of the swing-span.

The armature-shaft of each motor is extended at the commutator end to carry a brake-wheel, the two brake-straps being connected with levers actuated by a screw and hand-wheel worked by the man in the controlling-house. Before the brakes were in working order, the swing-span was occasionally stopped by reversing the controller, but with the amount of back-lash in the gearing this was found to strain the machinery seriously, and resulted on one occasion in the outer bearings of the horizontal shaft being lifted and broken. Heavier cast-steel brackets were substituted, and reversing whilst the span is in motion has been avoided, the hand-brakes alone being now used for slowing the swing.

A mechanical tell-tale driven off the main horizontal shaft shows on a dial in the controlling-house the position of the span, and by this means the point of cutting-off of the current, and the time for application of the hand-brakes is determined. Whilst the wind has an effect on coasting, yet the constant practice enables the operator, after a couple of swings, to ascertain the allowance to be made according to the weather.

In order to take up the back-lash in the gear and to stop the span in its correct position without jar, a latch and catch is provided over

each rest-pier. The latch, carrying on its end a small wheel, is free to move vertically upwards in brackets secured to the swing-span, and is so adjusted by a counterweight as to drop into the recess in the catch with the required velocity. The catch is pivoted and secured at its lower end to a girder on the rest-pier, whilst near the upper end of the catch are placed two heavy coil springs. In closing the span, the latch-wheel meets and rolls up the inclined plane at the top of the catch and drops into the recess, when the momentum of the span brings into play the coil springs, which either bring the ends of the span back into their correct positions, or move enough to allow the latches to release themselves, when, by reversing the controller, the latches are again brought into engagement. If the span be travelling too quickly, the latch-wheels jump the recess in the catches. Preparatory to opening the swing-span the latches are drawn by means of a hand-lever in the controlling-house.

The 35-HP. series-wound motor for operating the end lifts is of the "G.E. 1,000" type with nose suspension, and is situated at the centre of the swing-span. It drives through a cut pinion and spur-wheel a longitudinal shaft actuating at each end, by means of right- and left-hand worm-gearing, two transverse shafts each provided with four cams having $1\frac{1}{2}$-inch throw, which raise or lower the ends of the span $1\frac{1}{4}$-inch, the remaining $1\frac{3}{4}$-inch vertical movement in the cams being for lifting the foot-blocks clear of the pedestals on the rest-piers. The gear-reduction is 147 revolutions of armature-shaft to one complete revolution of the cam-shaft. In Table III are given the results of six tests, the cost of raising ends having in one trial been 0·044*d.*, the time taken 8 seconds, and the maximum effort exerted by the motor 29 HP.

For stopping the cams in their correct positions a solenoid brake is provided, with a weighted lever attached to a strap passing over the brake-wheel keyed to the armature-shaft. The solenoid is arranged in series with the motor holding up the weighted lever, and releases it when current ceases to pass, thereby applying the strap brake and stopping the motor, the worm-gearing being suitable for this quick action.

A mechanical tell-tale worked off the main longitudinal shaft shows on a dial in the controlling-house the position of the cams, from which the time of cutting off the current is determined. Although the cams can be worked either way, in practice they are run in one direction.

No difficulty was encountered in ensuring the ends of the span being lifted exactly $1\frac{1}{4}$ inch, the wedges in the pedestals over the rest-piers permitting of adjustment to the required amount. As designed, each foot-block was provided with two light springs to keep the pin at the bottom of the eccentric in line with the centre of the cam-shaft; these springs were, however, ineffective, allowing the eccentrics to slide the foot-block along the pedestal without lifting the ends. This was rectified by the provision of four $\frac{3}{8}$-inch coil springs to each block, which kept the pins vertically in line, and allowed the cams to do their work without subsequent trouble. Auxiliary hand-gear is provided, worked by capstan-bars on the deck by three men, the ratio of the gearing being 32 revolutions of the capstan-head to one complete revolution of the cam-shaft.

At the junction of the swing with the side spans, the camber of the roadway is worked out so as to give a level cross section of deck. The chequered plates on the terminal girders of the fixed spans overhang the terminal girders on the swing-span and give $1\frac{1}{4}$ inch vertical clearance when the swing is ready for opening; the lifting of the ends brings the terminal girders on the swing-span hard up against the underside of the chequered plates on the fixed span.

*Gate-Machinery.*—To avoid the provision of separate mechanism, the hinges of each footpath-gate are keyed to the spindle of the roadway-gate: the two gates thus work as one, the spindle being extended to the machinery-platform underneath the deck of the side spans.

For each pair of gates a 5-HP. four-pole series-wound motor of General Electric type, running at 1,200 revolutions per minute, drives, through a bevel-pinion and gear, a longitudinal threaded shaft, carrying a gun-metal travelling nut having projecting pins at top and bottom. These pins pass through, and work in, long slotted holes in two wrought-iron bars, the upper one being cranked down and bolted to the lower, which is extended and is keyed firmly to the bottom of the gate-spindle, and forms the lever for moving the gates. Attached to the underside of the lever is a copper loop which—at the open and closed position of the gates—engages with and short-circuits two adjustable brass springs secured to the floor of the platform, thereby energizing an auxiliary tripping-coil on the circuit-breaker in the controlling-house, which cuts off the current from the motor. The motor being supplied with a solenoid brake, the cutting off of the current causes a weighted lever to drop and stop the motor: the brake-lever is attached to a strap passing over a brake-wheel keyed to the armature-shaft. When the controller is reversed and current applied, the solenoid, which is in series with the motor, lifts the weighted lever and releases the brake. For $3\frac{1}{2}$ revolutions of the armature-shaft, the nut on the threaded shafts moves 1 inch. Although the gate-machinery will not permit of movement of the gates other than by revolving the threaded shaft, automatic latches are provided, the gun-metal nuts towards the end of their travel engaging small levers which force up through the centre of the roadway a pair of wrought-iron pins behind and in front of the gates. In Table IV (p. 22) are given the results of nine runs; the time of opening the gate in one of the trials was 18 seconds, at a cost of 0·014*d.*, with a maximum motor-effort of 2·9 HP.

The controller for the sluing-motors is of the standard "G.E., K 11" series-parallel type. The controller for the end lifts and the four for the gate-motors are of the usual rheostatic type, having a separate reversing-barrel on which are placed the additional contacts for interlocking the circuit-breaker with the position of the gates, so that the motors cannot be driven in a wrong direction, whether the gates are open or closed.

*Lighting.*—There are nineteen arc-lamps on the bridge and approaches, whilst the six arc-lamps on the protecting platform are of the marine type, with ruby globes and guard-cages. The arc-lamps, arranged in series of five, are of the enclosed long-burning type, in which the automatic cut-out and substitutional resistance is contained in the lamp-case itself.

*Cables.*—The two main cables are brought on poles from the power-house to the Pyrmont end of the bridge, thence along the bottom chord of the side spans to the rest-pier, at which point two lightning-arresters with kicking coils are placed, together with a 300-ampere main switch. From the switch the two armoured submarine main cables pass down the end of the rest-pier and are laid in a trench across the fairway excavated in the bed of the harbour to a depth of 30 feet below low-water mark. The cables are taken thence up the side of the pivot-pier under the track and up through the centre of the hollow pivot, thence to the underside of the footpath, where they enter a wrought-iron box reaching from the curb to the underside of the controlling-house, and they finally pass through hollow cedar pedestals in the inside of the house to their connections with the main bus-bar on the switchboard. Two seven-conductor armoured submarine cables for the two gate-motors, and one for the arc-lighting, laid in a similar manner to the main cables, extend from the controlling-house to each rest-pier; whilst a four-conductor submarine cable is also provided on the Sydney side for the operator's direct telephonic communication with the power house and the City Exchange.

To prevent twisting of the cables (due to the swinging of the bridge) from occurring at the bottom of the pivot, where it would be difficult to effect repairs, the cables are bunched together and are made fast to the top of the pivot; they are then given a complete coil of large diameter, the coil resting on horizontal wooden rollers carried on the radial struts, which permit the coil to wind and unwind with the movement of the swing-span.

As the sluing-motors are worked on the series-parallel system, and as their direction of rotation has to be reversed, the field- and armature-leads of both motors are brought into the controlling-house, which is accomplished by using an eight-conductor cable. The four leads of the end-lift motors are likewise brought into the controlling-house in a four-conductor cable. Although the wiring in the controlling-house is so encased as to be hidden from view, yet it is readily accessible, and all wires are tagged and numbered.

*Switchboards.*—The operating cedar switchboard, provided with porcelain insulators throughout, is placed directly over the controllers and carries a 300-ampere main switch; a 250-ampere switch with a 250-ampere circuit-breaker for the sluing-circuit; a 100-ampere switch with 150-ampere circuit-breaker for the end-lift circuit; and a switch for the four gate-motor circuits, with a circuit-breaker for each gate-circuit. A feature of the last-mentioned is that each is provided with an auxiliary tripping-coil connected with the contacts at the gates, so that when once a gate is started the operator's further attention is not needed, the contact when the gate is in position causing the circuit-breaker to trip: it is then impossible to move the gate or to close the circuit-breaker unless the controller be reversed. Weston ammeters are placed immediately over each controller and a 600 Weston voltmeter is placed at the centre of the board. The cedar switchboard for the arc-lighting is placed at one end of the house, and carries a 100-ampere main switch, a 40-ampere circuit-breaker, five switches for the five arc-lamp circuits, two switches for the ten glow-lamps in the house and machinery-room, and a switch for the pilot-light in the house which is in series with two red glow-lamps on the mast-head used for signalling to shipping.

*Cost of Power.*—The charge made by the Railway Commissioners for the supply of current is 1*d.* per Board-of-Trade unit, the main cables from the power-house having been laid at the cost of the Public Works Department; one complete cycle of operations costs ¾*d.*, which includes the closing and opening of the four gates, the lowering and raising of the ends of the span, and the opening and closing of the swing-span, the whole—including the lighting—being controlled by one man in the controlling-house. The detailed cost of operating the swing-span and lighting the bridge for 4 years is given in Table V, the cost of current for 24,610 openings having been £83 6*s.* 5*d.*

*Protecting Platform and Dolphins.*—A platform built of turpentine piles, 325 feet long and 3 feet 4 inches wider than the over-all width of the swing-span when open, affords protection from passing vessels. Dolphins connected by stout rubbing-strips shield the rest-piers, the platform and dolphins forming two long fairways, which materially facilitate the passage of vessels through the openings.

*Side Spans* (Figs. 5, Plate 3).—The six ironbark trusses in each side span carry transverse floor-beams on which is laid 6-inch by 4-inch longitudinal planking alternately on flat and edge, covered with tarred metal, to form the road-surface; asphalt is laid on the footpaths, whilst the wrought-iron parapet is carried from end to end of the bridge. With the heavy traffic the tarred metal has not been a success, and it is being replaced by wood blocks.

The trusses are of the Howe type, in which redundant members have been omitted. As the success of timber trusses is largely dependent on the strength of the bottom chord-joint, it was decided to test the full-size joint in a machine specially designed for the purpose under the direction of Mr. C. W. Darley, M. Inst. C.E. This machine consisted of a heavy ironbark frame and large hydraulic jack, a steam-pump being used for working the jack, whilst a pipe-connection between the jack and a 50-ton testing-machine enabled the results to be read on the latter. In the three tests, failure occurred by the shearing of the bolts and of the timber between the notches, the recorded results showing an ultimate strength of 151 tons, 160 tons, and 182 tons respectively. In making the joints in the actual work, the notches were carefully cut in the timber, and the plates on either side were then cramped hard up. The joint was placed under a steam-drill, the drill passing through the steel plates and the timber in the one action, twelve turned bolts were then driven through the holes to complete the joint, thus ensuring the bolts bearing on the timber and the two plates. The trusses, weighing 15 tons, were put together on the wharf close to the bridge-site and were hoisted about 30 feet on two pile-driving machines, being then towed to the site and placed on the piers. In finishing the bridge, twelve trusses were lifted from the wharf and placed in position in 7 hours, whilst half a pier and two spans with roadway-gates were completed for traffic in 8 days.

*Approaches.*—The approaches on either side consist of embankments and concrete retaining-walls, the abutments and northern retaining-walls, which are the more exposed to view, being faced with sandstone, whilst a stone parapet extends the whole length of the approaches. The Pyrmont approach is founded on the rock, whilst the Sydney approach is for the greater portion of its length carried on 368 piles driven to the rock.

The work was designed by the Author, then Engineer-in-Charge of Bridge Design under Mr. C. W. Darley, M. Inst. C.E., Engineer-in-Chief for Public Works. The Author also supervised the construction of the work under Mr. Darley until his departure for England, by which time the piers were nearly all in place, and subsequently until its completion under Mr. W. J. Hanna, the Commissioner and Principal Engineer for Roads and Bridges.

Mr. H. H. Dare, Assoc. M. Inst. C.E., and Mr. Lincoln Buswell were the Author's principal assistants in the office and on the works respectively.

The cost of the completed work, including all contingencies and engineering expenses, was £112,500, as detailed in Table VI, the rate of wages paid being given in Table VII, and the cost of materials in Table I.

The Author is indebted to Mr. J. Davis, M. Inst. C.E., Under-Secretary for Public Works, for the plans and photographs illustrating the Paper, and to Mr. O. W. Brain, Electrical Engineer for Railways, for advice in connection with the electric equipment.

The Paper is accompanied by twenty-four drawings, from which the illustrations in Plate 3 have been selected for reproduction, and by numerous Tables; also by an album of photographs.

## APPENDIX—TABLE I.—PROPORTIONS AND COST OF CONCRETE.

| Position in Work. | Description and Gauge of Stone. | How deposited. | Proportions to 374 Lbs. (1 Cask) of Cement. | | Cost per Cubic Yard in Place. |
|---|---|---|---|---|---|
| | | | Stone. | Sand. | |
| | | | Cubic Feet. | Cubic Feet. | £ s. d. |
| Between inner and outer walls of caisson | Basalt to pass through 1¼-inch ring, and be caught on ⅛-inch screen | Laid in the dry | 17 | 9 | 1 15 0 |
| Bottom 5 feet of Sydney rest-pier | Ditto | Through the water | 17 | 9 | 2 10 0 |
| Between sand-bag wall and ring of special concrete under bell-mouth of caisson | Ditto | Ditto | 17 | 9 | 2 2 6 |
| Bag concrete under cutting edge and special concrete under bell-mouth of caisson | Basalt to pass through 5/16-inch ring, and be caught on ⅛-inch screen | Ditto | 11 | 4 | This item was at a lump sum; but on the quantity deposited the cost was 7 8 0 |
| In rest-piers to within 1 foot of low-water mark | Sandstone to pass through 2-inch ring, and be caught on ⅛-inch screen | Ditto | 17 | 9 | 2 2 0 |
| Between inner walls of caisson to a height of 12 feet above cutting edge | Ditto | Laid in the dry | 17 | 9 | 2 0 0 |
| Hearting in rest-piers from 1 foot below low-water mark to top | Ditto | Ditto | 26 | 11 | 1 10 0 |
| Abutments and retaining-walls of approaches | Ditto | Ditto | 26 | 11 | 1 5 0 |
| Hearting in pivot pier from 12 feet above cutting edge to top | As above, with uncoursed blocks of sandstone of not less than 1 foot embedded in the concrete | Ditto | 26 | 11 | 1 5 0 |
| Foundation of Pyrmont abutment | Ditto | Ditto | 26 | 11 | 1 0 0 |
| Under wood blocks on carriage-way and asphalt on footpaths | Coke to pass through 1¼-inch ring, and be caught on ⅜-inch screen | Ditto | 17 | 11<br>Coke grit screened through ¼-inch mesh | 2 0 0 |

*Cost of Materials delivered on the Works.*—Cement, from 9*s.* 6*d.* to 10*s.* per cask; screened Nepean River sand, 4*s.* 10*d.* per cubic yard; basalt and screenings, 7*s.* 9*d.* per cubic yard; sandstone, broken to gauge and screened, 4*s.* 9*d.* per cubic yard; sandstone for masonry quarried ready for working, 1*s.* 3*d.* per cubic foot; turpentine piles, 1*s.* 2*d.* per lineal foot; ironbark foundation-piles, 1*s.* 6*d.* per lineal foot; coke, 16*s.* per ton unbroken; small coke grit (requiring to be broken), 3*s.* 6*d.* per cubic yard; hewn ironbark girders, 1*s.* 10*d.* per cubic foot; sawn ironbark braces, 2*s.* 4*d.* per cubic foot.

TABLE II.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR SLUING SPAN AT DIFFERENT SPEEDS. CALM DAY. NO WIND.

| No. of Run. | Time taken to Slue Span through 83°. | Maximum Effort Exerted by Motors. | Maximum Speed of Armature-Shaft. | Time for which Current was Applied. | Distance Travelled by Span at Time of Cutting off Current. | Distance Coasted by Span between Time of Cutting off Current and bringing Span to Rest with Brake. | Power Consumed by |  |  | Cost of Current for each Run at 1d. per Unit. | Time taken to Slue Span through 83°. | No. of Run. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  | Motors. | Resistances. | Motors and Resistances. |  |  |  |
|  | Seconds. | HP. | Revolutions per Minute. | Seconds. | Degrees. | Degrees. | Watt-Seconds. | Watt-Seconds. | Watt-Hours. | d. | Seconds. |  |
| 6 | 30 | 89 | Not recorded | .. | .. | .. | 967,800 | 316,400 | 357 | 0·357 | 30 | 6 |
| 17 | 47 | 97 | 480 | 14 | 20 | 63 | 575,770 | 259,430 | 232 | 0·232 | 47 | 17 |
| 18 | 47 | 78 | 580 | 18 | 21 | 62 | 561,360 | 302,640 | 240 | 0·240 | 47 | 18 |
| 5 | 47 | 72 | 480 | 24 | 40 | 43 | 666,640 | 154,160 | 228 | 0·228 | 47 | 5 |
| 4 | 47 | 57 | 510 | 26 | 40 | 43 | 598,360 | 168,440 | 213 | 0·213 | 47 | 4 |
| 8 | 48 | 64 | 500 | 18 | 30 | 53 | 576,640 | 269,360 | 235 | 0·235 | 48 | 8 |
| 9 | 49 | 74 | 510 | 17 | 28 | 55 | 605,540 | 258,460 | 240 | 0·240 | 49 | 9 |
| 10 | 51 | 51 | 540 | 30 | 40 | 43 | 555,240 | 298,840 | 237 | 0·237 | 51 | 10 |
| 7 | 53 | 58 | 480 | 16 | 28 | 55 | 437,280 | 318,720 | 210 | 0·210 | 53 | 7 |
| 19 | 53 | 78 | 550 | 18 | 25 | 58 | 569,520 | 265,680 | 232 | 0·232 | 53 | 19 |
| 13 | 54 | 40 | 480 | 26 | 37 | 46 | 524,980 | 238,220 | 212 | 0·212 | 54 | 13 |
| 16 | 55 | 70 | 480 | 12 | 13 | 70 | 356,000 | 335,200 | 192 | 0·192 | 55 | 16 |
| 12 | 55 | 72 | 540 | 14 | 13 | 70 | 470,160 | 264,240 | 204 | 0·204 | 55 | 12 |
| 20 | 55 | 48 | 480 | 22 | 35 | 48 | 479,440 | 179,360 | 183 | 0·183 | 55 | 20 |
| 14 | 55 | 45 | 630 | 25 | 33 | 50 | 525,610 | 219,590 | 207 | 0·207 | 55 | 14 |
| 11 | 60 | 67 | 510 | 10 | 14 | 69 | 352,960 | 316,640 | 186 | 0·186 | 60 | 11 |
| 3 | 64 | 44 | 440 | 25 | 40 | 43 | 542,970 | 240,030 | 217 | 0·217 | 64 | 3 |
| 21 | 64 | 34 | 480 | 32 | 40 | 43 | 507,040 | 252,560 | 211 | 0·211 | 64 | 21 |
| 15 | 68 | 62 | 480 | 11 | 13 | 70 | 319,700 | 285,100 | 168 | 0·168 | 68 | 15 |
| 22 | 69 | 15 | 360 | 45 | 53 | 30 | 408,320 | 387,280 | 221 | 0·221 | 69 | 22 |

Weight of span when swinging 850 tons. Area of floor-space on swing-span 12,000 square feet.
Being slightly on the skew the span is opened only through 83°.

TABLE III.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR RAISING AND LOWERING END LIFTS.

| No. of Run. | Time taken to Revolve Cams through 180°. |  | Maximum Effort Exerted by Motor. | Maximum Speed of Armature-Shaft. | Power Consumed by |  |  | Cost of Current for each Run at 1d. per Unit. | Time taken to Revolve Cams through 180°. |  | No. of Run. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Lowering. | Raising. |  |  | Motors. | Resistances. | Motors and Resistances. |  | Lowering. | Raising. |  |
|  | Seconds. | Seconds. | HP. | Revolutions Per Minute. | Watt-Seconds. | Watt-Seconds. | Watt-Hours. | d. | Seconds. | Seconds. |  |
| 27 | 7 | .. | 26 | 800 | 75,600 | 50,400 | 35 | 0·035 | 7 | .. | 27 |
| 28 | .. | 8 | 29 | 900 | 132,320 | 28,280 | 44 | 0·044 | .. | 8 | 28 |
| 25 | 9½ | .. | 22 | 620 | 87,480 | 74,520 | 45 | 0·045 | 9½ | .. | 25 |
| 26 | .. | 11 | 19 | 620 | 111,960 | 111,240 | 62 | 0·062 | .. | 11 | 26 |
| 23 | 10 | .. | 16 | 700 | 91,100 | 142,900 | 65 | 0·065 | 10 | .. | 23 |
| 24 | .. | 14 | 18 | 480 | 134,320 | 99,680 | 65 | 0·065 | .. | 14 | 24 |

80 tons weight on cams when ends of span are raised full height.

TABLE IV.—SUMMARY OF TESTS MADE 9TH AUGUST, 1903, SHOWING THE POWER REQUIRED AND COST OF CURRENT FOR OPENING OR CLOSING ONE GATE. CALM DAY. NO WIND.

| No. of Run. | Time taken to Open Gate through 90°. | Maximum Effort Exerted by Motor. | Maximum Speed of Armature-Shaft. | Power Consumed by | | | Cost of Current for each Run at 1d. per Unit. | Time taken to Open Gate through 90°. | No. of Run. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Motors. | Resistances. | Motor and Resistances. | | | |
| | Seconds. | HP. | Revolutions per Minute. | Watt-Seconds. | Watt-Seconds. | Watt-Hours. | d. | Seconds. | |
| 9 | 18 | 2·9 | 980 | 22,620 | 27,780 | 14·0 | 0·014 | 18 | 9 |
| 10 | 18 | 2·3 | 980 | 21,210 | 30,990 | 14·5 | 0·0145 | 18 | 10 |
| 5 | 18 | 1·7 | 910 | 15,290 | 40,510 | 15·5 | 0·0155 | 18 | 5 |
| 8 | 20 | 2·0 | .. | 22,460 | 40,820 | 14·8 | 0·0148 | 20 | 8 |
| 1 | 22 | 1·5 | 840 | 20,664 | 36,936 | 16·0 | 0·016 | 22 | 1 |
| 3 | 22 | 1·5 | 840 | 18,760 | 38,120 | 15·8 | 0·0158 | 22 | 3 |
| 4 | 24 | 1·5 | 840 | 20,180 | 39,220 | 16·5 | 0·0165 | 24 | 4 |
| 6 | 24 | 1·4 | 840 | 20,340 | 39,420 | 16·6 | 0·0166 | 24 | 6 |
| 2 | 24 | 1·5 | 840 | 21,770 | 39,430 | 17·0 | 0·017 | 24 | 2 |

TABLE V.—SUMMARY OF CURRENT CONSUMPTION, PYRMONT BRIDGE.

1 July 1902 to 30 June 1906.

| Dates. | Number of Openings. | Consumption. | Cost. | Arc-Lamps. | Consumption. | Cost. | Glow-Lamps. | Consumption. | Cost. | Total for Operating and Lighting. | Cost. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B.T.U. | £ s. d. | Hours. | B.T.U. | £ s. d. | Hours. | B.T.U. | £ s. d. | B.T.U. | £ s. d. |
| 1 July 1902 to 30 June 1903 | 6,152 | 6,855 | 28 11 3 | 76,915 | 44,685 | 186 3 9 | 24,069 | 1,622 | 6 15 2 | 53,162 | 221 10 2 |
| „ 1903 „ „ 1904 | 6,222 | 4,692 | 19 11 0 | 62,795 | 35,537 | 148 1 5 | 22,235 | 1,781 | 7 8 5 | 42,010 | 175 0 10 |
| „ 1904 „ „ 1905 | 6,432 | 4,509 | 18 15 9 | 61,415 | 34,914 | 145 9 6 | 22,805 | 1,822 | 7 11 10 | 41,245 | 171 17 1 |
| „ 1905 „ „ 1906 | 5,804 | 3,941 | 16 8 5 | 66,070 | 36,370 | 151 10 10 | 33,220 | 2,222 | 9 5 2 | 42,533 | 177 4 5 |
| Total . . . | 24,610 | 19,997 | 83 6 5 | 267,195 | 151,506 | 631 5 6 | 102,329 | 7,447 | 31 0 7 | 178,950 | 745 12 6 |

TABLE VI.—SUMMARY OF COST.

| | £ | £ |
|---|---|---|
| Swing-span, pivot-pier, rest-piers, protecting platform and dolphins complete— | | |
| Pivot-pier | 14,320 | |
| Rest-pier | 9,217 | |
| Protecting platform and dolphins | 3,379 | |
| Metal-work in swing span including installation of electric equipment | 18,293 | |
| Asphalting footpath and wood-blocking carriage-way | 1,240 | |
| Controlling-house and painting | 777 | |
| Supply of electric equipment | 1,649 | |
| Removal of portion of old bridge and sundry extras | 352 | |
| | | 49,227 |
| Side spans, including gates and gate-machinery complete | | 33,276 |
| Approaches, including steel overbridge in Sydney approach | | 24,070 |
| Supply and installation of arc-lighting, including lamp-standards | | 484 |
| Engineering expenses and minor works | | 5,443 |
| Grand Total | | £112,500 |

TABLE VII.—RATE OF WAGES.

| | s. | d. | |
|---|---|---|---|
| Divers | 15 | 0 | per day of 6 hours. |
| Foreman boiler-maker | 15 | 0 | " " 8 hours. |
| " carpenter | 13 | 4 | " " " |
| " painter | 10 | 0 | " " " |
| Masons | 11 | 0 | " " " |
| Boiler-makers and riveters outside | 10 | 8 | " " " |
| " " " in shop | 10 | 0 | " " " |
| Blacksmiths | 10 | 0 | " " " |
| Carpenters | 10 | 0 | " " " |
| Fitters | 9 | 0 | " " " |
| Woodpavers, leading hand | 9 | 0 | " " " |
| " ordinary | 7 | 0 | " " " |
| Dogman | 9 | 0 | " " " |
| Engine-drivers | 9 | 0 | " " " |
| Concrete-turners | 8 | 0 | " " " |
| Labourers, special | 8 | 0 | " " " |
| Attendants on divers | 8 | 0 | " " " |
| Masons, labourers | 8 | 0 | " " " |
| Painters | 7 | 0 | " " " |
| Holders up | 7 | 0 | " " " |
| Labourers | 7 | 0 | " " " |
| Boys | 5 | 0 | " " " |

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(*Paper No. 3666.*)

## "Swing-Bridge over the River Avon, at Bristol."

By WILLIAM HENRY BOURCHIER SAVILE, Assoc. M. Inst. C.E.

THE bridge which is the subject of this Paper conveys both a carriage-road and a double line of railway across the River Avon at a point about ¼ mile above the entrance to Cumberland Basin (*Fig. 1*). It forms an important part of a large scheme of extension carried out by the Great Western Railway Company to deal more effectively with the dock-traffic at Bristol. Before its construction, railway-accommodation was provided only to the wharves on the south side of the Floating Harbour, and all the traffic from these wharves had to join the main line at the Bristol Joint Station where the traffic was very congested. Further, vehicles had no means of crossing the river between Bedminster bridge, and the Clifton suspension-bridge, a distance of about 2 miles, and much inconvenience resulted.

The railway-extensions which necessitated the construction of this swing-bridge included the provision of railway-accommodation to the wharves on the north side of the Floating Harbour, the extension of the railways on the south side to the timber-wharves, and the building of a central goods-depot at Canons Marsh, where dock-traffic can now be marshalled. The bridge provides an outlet for the railway at the west end of the Floating Harbour, and forms a junction with the Portishead branch of the Great Western Railway, whence the trains can join the main up or down line without passing through Bristol station.

Negotiations between the Corporation of Bristol and the Great Western Railway Company resulted in the promotion of a joint Bill in Parliament in the Session 1897 for a combined road- and railway-bridge. The consent of Parliament was duly obtained, but the work

## APPENDIX.

### TABLE OF WEIGHTS OF SWING-SPAN.

| | Tons. | Tons. |
|---|---|---|
| Steelwork in main girders | 231 | |
| Steelwork in longitudinal and cross girders, deck plating, etc. | 234 | |
| Steel and cast iron in handrailing | 21 | |
| Steelwork in machinery-tower | 42 | |
| Cast iron and cast steel in curbs to footpaths | 12 | |
| Steelwork in annular girder | 35 | |
| Steel and cast iron in roller-frame | 14 | |
| Cast steel in rollers | 51 | |
| Oak blocks, concrete, asphalt, etc., in footpaths and roadway | 99 | |
| Permanent way | 18 | |
| Turning-machinery, pipes, etc. | 36 | |
| Timberwork, etc., in machinery-house | 12 | |
| Kentledge | 156 | |
| Cast steel in top roller-path | 29 | |
| Total weight of swinging parts | | 990 |
| Cast steel in bottom roller-path | 52½ | |
| Cast iron in centre pivot | 2¾ | |
| Weight of fixed part of turn-table | | 55¼ |
| Total | | 1,045¼ |

### STEELWORK IN APPROACHES.

| | | | |
|---|---|---|---|
| *Fixed Span No. 1:* | Main girders | 9½ | |
| | Trough flooring | 37½ | 47 |
| *Fixed Span No. 2:* | Main girders | 102 | |
| | Cross girders and trough flooring | 102 | 204 |
| *Fixed Span No. 3:* | Main girders | 87 | |
| | Cross girders, floor-plating, etc. | 136 | 223 |
| *South Approach:* | Main girder, cross girders and trough flooring | 116 | 116 |
| | Total steelwork in approaches | | 590 tons. |

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## Discussion.

The PRESIDENT, in proposing a vote of thanks to the Authors, observed that the Papers described in detail the design and construction of what he believed were two of the largest swing-bridges in the world, and contained a great deal of information which would be of value to The Institution. The President.

Mr. C. O. BURGE, who represented Mr. Allan in his absence in Australia, thought there was one point which might be explained before the discussion began. Some members might have been surprised to see that such a structure as the Pyrmont swing-bridge, a substantial work in one of the great cities of the Empire, should be flanked on each side by a row of timber spans, which gave it a temporary and inferior appearance. The design involving the timber spans had been agreed upon in opposition to the opinion of the engineers on the spot. The Engineer-in-Chief had been very anxious to have a bridge entirely of steel, but the decision had rested with the Committee of Public Works, who were Members of Parliament, but none of them engineers. There was, however, something to be said for construction in timber, because New South Wales timber was of a very high quality. The strength of the ironbark used for the timber spans was nearly one-half of that of wrought-iron: it could withstand a tension of 10 tons and a compression of 4½ tons per square inch, and its density was so high that it weighed about 80 lbs. per cubic foot. In the form of piles or girders ironbark had generally a life of 30 to 35 years; and it had been thought that the saving by constructing a large part of the bridge of timber was worth effecting, because at compound interest it would provide more than a sufficient sum after 30 years to renew the bridge in steel. The Railway Construction Department, with which he himself had had to do, had built a large number of viaducts of timber on the basis—arrived at by careful calculation—that if a bridge could be built in timber for less than one-half of the cost of a steel bridge it was better, economically, to build it so; but those bridges were up in the bush and not, like the bridge under consideration, in the heart of Sydney. It seemed to him that it would have been worth while for a rich Government like that of New South Wales to build a steel bridge throughout, even though the latter would have cost a little more. Mr. Burge then exhibited a series of lantern-slides illustrating the Pyrmont bridge and its construction. Mr. Burge.

Mr. Savile. Mr. **Savile** wished to mention a few things which he had not been able to put into the Paper, as the bridge had not been actually opened until 2 or 3 days after the Paper was sent in. From the 4th October, when the bridge was opened, to the 31st January, it was worked on 222 tides and was swung 1,048 times for the passage of 2,411 vessels, the average being 4·72 swingings per tide, and the average interruption of traffic being 6½ minutes. The time of the swinging was given in the Paper as 2¼ minutes, but since the bridge had been working and the driver had become more experienced, the speed had been improved, and in the previous week the time taken had been reduced to 1 minute 45 seconds for the opening and 2 minutes 5 seconds for the closing. One interesting point had cropped up in connection with the automatic locking-bolts, of which there was one at each end. One morning in March of the current year, after a sharp frost at night and a warm sun in the morning, the east girder became warmed while the west girder was still practically frozen, with the result that the bridge bent slightly, and when at 11 o'clock it was desired to open the bridge, it was found impossible to withdraw the locking-bolts without the assistance of a jack, causing a delay of about 20 minutes. That delay might have been serious if a tug had been approaching towing a string of vessels, as tugs often did. One method of getting over the difficulty might have been to enlarge the socket for the bolt. There was a clearance of a bare ⅛ inch in the socket. The objection to enlarging the socket, however, was that, under present circumstances, if the bridge was going at all too fast when it got into position, the bolt, instead of shooting, rode over the hole, and in that way saved the bridge from the severe jar it might suffer if the bolt shot when the bridge was swinging too fast. It had not been considered safe to enlarge the socket, and therefore the tail-end locking-bolt had been withdrawn altogether, and the bridge was worked only with the locking-bolt at the nose end. The tail-end locking-bolt was still kept on the bridge, but it was made so that at the end of the stroke it was not far enough out to get into the socket. The bolt was not removed entirely, because its removal would have necessitated considerable alterations in the electric contracts for indicating and interlocking. He would be interested to hear whether anyone else had had experience of the twisting of a bridge due to the sun. The Bristol bridge was particularly subject to lateral bending, because the upper roadway-deck completely protected one girder from the sun, while the other girder was much exposed, whereas in the ordinary type of bridge the sun was generally on both girders, even if one was partially protected. The amount of water used for one complete opening and shutting of the bridge was 182 gallons, which included the water used in the presses, and in the rams for sliding in the blocks. Since the working of the bridge was started, an indicator had been added in the machinery-tower to show the driver at any time the position of the bridge. As stated in the Paper, there was originally only an indicator showing the driver when he was over a dolphin and when he was in position, so that he did not know where he was until the indicator suddenly showed "open" or "shut." In foggy weather the man might swing the bridge a little too far and get the tail-end of the bridge over the stream and liable to be fouled. The only accident that had occurred to the bridge in working was that one of the rams used for lifting the ends of the girder dropped while the bridge was swinging and came in contact with the cast-iron block on the abutment. Originally, when the man was swinging the bridge the lever which operated the presses was always half-way between pressure and exhaust, but on that occasion there was a little leak, so that the pressure-water got into the cylinder and let the ram down so that it fouled the block on the abutment. That had been prevented from happening in the future by altering the electric contacts of the lever, so that when the lever was not at "pressure" it was at "exhaust," and therefore water could not get into the cylinders during the operation of swinging. Mr. Savile exhibited a series of slides illustrating the Bristol bridge and its construction.

Mr. Savile.

Mr. Burge. Mr. C. O. **Burge** wished to ask a question with regard to the time required for moving the swing-bridge over the River Avon. It appeared from the Paper that it had been reduced to 1 minute 45 seconds, the motive power being hydraulic. In the Paper on the Pyrmont bridge it was stated that the minimum time of moving the bridge was 30 seconds, the motive power in that case being electricity. In the Pyrmont bridge the total weight of the swing-span was 850 tons, and in the other bridge 990 tons. The difference in weight would account for some of the difference; but still, there seemed to be a large difference between the times occupied in moving the two bridges to the full extent. The Pyrmont bridge swung about 80 degrees, and according to Figs. 2, Plate 4, the Bristol bridge appeared to swing through much the same range. It would be interesting to know why there was so considerable a difference, because in a navigable river, especially at Bristol, where the bridge had to be crossed by railway-trains, it was very important that the least possible time should be occupied in the operation.

Mr. Thorpe. Mr. W. H. **Thorpe** observed that the two Papers naturally raised the old question of swing-bridges having equal arms versus swing-bridges having unequal arms. He did not pretend to say that

Mr. Thorpe. in the case of the Bristol bridge any other than unequal arms could have been adopted; but it appeared to him that, wherever practicable, the arrangement of equal arms was better. In the case of a bridge having unequal arms, the turning-moment necessary to rotate the long arm of the bridge was greater than the turning-moment necessary to move the short arm, for the same angular acceleration at starting; and there was a slight tendency for the bridge to move about some centre other than the pivot. It brought side pressure—slight in the present case—on the pivot, which might readily be avoided by adopting equal arms. More important, however, was the question of the effect of wind upon the longer arm, an effect which might considerably increase the amount of power necessary to open the bridge. The cost of a bridge with unequal arms was perhaps a little less; but that depended on the price of the kentledge as against the price of the girder-work. The Bristol bridge had been perhaps cheaper as built; but it was possible that had both arms been made of the length of the longer, by shortening the side-walls and flooring to the road, and cutting out some of the piling, there might have been a slight saving, although it was somewhat doubtful. In one particular case within his knowledge on the Manchester Ship-Canal—the Barton swing-aqueduct—it was originally proposed to make clear-openings of 90 feet and 60 feet respectively; but when the preparation of the working-drawings was gone into it was found that, having regard to the contract price for girder-work and the contract price for kentledge, it was decidedly cheaper to make the arms of equal length, and they were so made; not, however, wholly for that reason. In the case of an aqueduct having a trough carrying 760 tons of water, the bridge, although it might be properly balanced with the trough full, would be very badly out of balance when, by accident or for repair, the water was run off. The long end would be on the point of tilting up. That, of course, had settled the matter at Barton: the arms there had to be of equal length. He noticed that at the Pyrmont bridge there had been some difficulty with the roller-path, and he thought that was not very surprising. The construction and correct fixing of a roller-path and rollers were really matters of rather high art and special experience, and without the resources of large and well-equipped machine-shops, it was not remarkable that there should have been some little trouble.

Mr. Homfray. Mr. S. G. Homfray observed that the Pyrmont bridge was interesting not only as showing what was being done in a very distant part of the Empire, but also because some novelties were introduced in it—apart from the timber spans. The Bristol bridge

also was of great interest, as although there was one other double- Mr. Homfray. decked bridge in England—that over the Stanley Dock entrance at Liverpool—it was not nearly as large as the Bristol bridge, which marked a departure in swing-bridge construction. He believed that in America there was at least one double-decked swing-bridge, but he had not been able to find a reference to it, and the fact did not render the Bristol bridge less interesting. With regard to the Bristol bridge being the heaviest swing-bridge, although bridges of considerably greater swinging weight had been built in England, no bridge had been built in which the weight on the rollers was so great. It might be interesting if he mentioned a few of the heavier bridges in this country, going back first to a bridge which, although rather lighter than the Bristol bridge, was still of great interest for many reasons, namely, that at Goole on the main line of the North Eastern Railway, between Doncaster and Hull. That bridge, built about the year 1868, was the pattern on which practically all live-roller swing-bridges had been built. It was interesting also from the fact that a Past-President of The Institution (then Sir W. G. Armstrong) was largely responsible for the design and carrying out of the work, which was done under his direction.[1] The length of that bridge over-all was 250 feet, and its swinging weight 750 tons. That weight was not exceeded in other bridges of similar design—notably the Naburn bridge on the North Eastern Railway, between Selby and York—until 1876, when the swing-bridge over the River Tyne was completed, the total length of which was 280 feet and the swinging weight 1,400 tons, 870 tons of which was carried upon a centre press forming a hydraulic pivot which relieved the weight on the rollers. Mr. F. N. Thorowgood, M. Inst. C.E., was responsible for the foundations of that bridge. Then, in 1894 eight swing-bridges over the Manchester Ship-Canal were built, four of which were well over 1,000 tons in weight. The Trafford Road swing-bridge had a total length of 212 feet and a swinging weight of 1,600 tons, with a centre relieving-press of 800 tons capacity; and, as far as he knew, it was the heaviest road-bridge that had been built. The Barton Aqueduct swing-bridge had a total length of 234 feet with a swinging weight of 1,600 tons, including the water in the trough. That bridge had also a centre relieving-press of 800 tons capacity. The Latchford and Stockton Heath swing-bridges were similar,

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[1] Sir W. G. Armstrong, "Description of the Hydraulic Swing-Bridge for the North Eastern Railway over the River Ouse, near Goole." Proceedings of the Institution of Mechanical Engineers, 1869, p. 121.

Mr. Homfray. having a total length of 252 feet and a swinging weight of 1,200 tons each, the centre press taking off 600 tons in each case. There were four other bridges on the Ship-Canal ranging between 125 feet and 238 feet in length and weighing about 800 tons. Those were the largest and heaviest bridges that had been built in England, as although the Hawarden bridge had a length of 287 feet its swinging weight was rather under 657 tons. All those bridges, with the exception of the Goole bridge, he knew well, as he had been personally concerned in their erection and control. It would therefore be seen that in no case had a swinging weight of more than 1,000 tons on the rollers been exceeded. That gave, as stated in Mr. Savile's Paper, a load of about 1·2 ton per lineal inch of roller, which was exactly the same as that on the Pyrmont bridge; but whereas in the Bristol bridge the rollers were 2 feet 6 inches in diameter, in the Pyrmont bridge they could not be much more than 15 inches, which might prove rather a serious matter hereafter. All the bridges he had mentioned were worked by hydraulic power, and on the same lines. Whether the hydraulic turning-machinery was placed on the pier, or in a house raised above the bridge, did not affect the question. At the Pyrmont bridge electrical power was used both for the turning and for the end gears. He thought it very necessary that such bridges, some of which were on tidal rivers where it was a serious thing to stop the traffic, should be always ready for work; and one of the best ways of ensuring that was to have the working parts as few and the speeds of the principal parts as low as possible. That conduced to reduction of wear and to long life. The Goole bridge had had very little done to it, and was still as it was originally designed; the Tyne bridge had been at work for 31 years with no renewals whatever, and with a minimum of repairs, and was now doing a great deal more work than it was expected ever to do when it was built—facts which said something for that class of installation. In 1905 the Tyne bridge was opened 4,295 times, an average of nearly six openings per tide. With electrical machinery directly operating the different motions, as in the Pyrmont bridge, there was a high motor-speed, a considerable amount of reduction-gearing, and, in the case of the gear at the ends, long shafts running from end to end with gearing and cams and a certain amount of complication in the way of cam cut-offs, switches, and safety-gears. The question whether that was the best arrangement must be decided for each case according to its particular circumstances. But even where electricity was available, he ventured to think it was worth consideration whether the transmission between the electric motor and the point of application of the power on the bridge, especially the Mr. Homfray. end blocking-gears, should be through shafts and gearing or through the medium of a pump and a hydraulic pipe. He was no specialist for hydraulic machinery, but as it was the older he naturally knew more about it than he knew about electrical machinery. On the Bristol bridge the total reduction between the hydraulic engines turning the bridge and the rack was 203 to 1, whereas on the Pyrmont bridge it was 1,223 to 1, or six times as much; that was to say, there was six times as much gear. It was a question on which side the balance of advantage lay. Mr. Thorpe had referred to the Bristol bridge being unequal-ended, and had asked where the economy of that came in. Mr. Homfray thought it might be taken roughly that the economy ceased when ordinary kentledge had to be abandoned for ballast, and special ballast had to be adopted, particularly if it were lead. The ballast must be near the end. The plating-up necessary for the ballast-box at the tail end gave more wind-surface, and he thought that, if the effect was worked out, in most cases it would be found there was not much difference between the two ends in the matter of wind-pressure. With regard to the difference between the cam-gear at the ends of the Pyrmont bridge and the solid blocks at the end of the Bristol bridge, there was the question of efficient bearing-surface—not only for carrying the weight, but also for wear and tear—and there was also the question of time. As to Mr. Burge's comparison of the time for swinging the two bridges, he thought it was clear from Mr. Allan's Paper that the 30 seconds was the fastest time ever attained for swinging the Pyrmont bridge only, while 1¾ minute for the Bristol bridge was the time of ordinary working, and included lifting and unblocking the ends and getting ready to swing. On the Tyne bridge 30 years ago a speed was obtained which only stopped the traffic over the bridge for 2½ minutes, in which time the bridge was unblocked and swung open, a tug and a vessel were passed, the bridge was closed again, and traffic over it was resumed. That was an exceptional performance, but 3 minutes was a very common time. No doubt the fact that the bridge was equal-ended and that the vessel was closely followed up helped towards this result. It was the slowness of the vessel that prevented the performance of the operation in the minimum time in all cases.

Mr. G. E. W. Cruttwell thought Mr. Allan was to be congratulated Mr. Cruttwell. on having no idle rollers on the roller-path, as it was very difficult to make them exactly true, so as to take their proper share of the load. Even if they were adjusted to take their share of the load when the

Mr. Cruttwell. traffic was passing over the bridge, there was a tendency, when the bridge was swinging, for the deflection of the girders, when they were unsupported at the ends, to alter the adjustment of the upper roller-path to a trifling extent, unless it was extremely rigid. The least displacement of the position of the roller-path would make some of the rollers take more of the load and others less than they did when the bridge was carrying the traffic. That was one reason why, wherever practicable, it was desirable to adopt the central lift instead of the ring of rollers. Neither at Pyrmont nor at Bristol was that possible, because there was no solid foundation for the roller-path at the rear end of the bridge, which was necessary with the central lift, the rear end having a preponderance given to it in order that it might always bear upon the roller-path at the end. With that system the preponderance need be only a few tons, and it was only necessary to have a couple of rollers, one on each side of the rear end, to take that preponderance, as compared with sixty-six rollers in the case of the Pyrmont bridge and thirty-four at the Bristol bridge. Radial rollers were expensive to make and difficult to adjust, and he thought it would be found that a central lift, where it could be adopted, was much simpler and more economical in every way, especially for a swing-bridge over a lock-entrance or passage, where it was possible to place a roller-path at the rear end on the quay-side. He did not understand the object of the 6-inch layer of sand which had been spread over the bottom of the Sydney pier. He thought it would have been much better to lay the concrete of the pier directly on the bottom, whatever it might have been, rather than to interpose the layer of sand. Even if there were a little silt in the trench he thought it would make a better mixture with the concrete than with the sand. With regard to conveying the cables across to the central pier of the Pyrmont bridge the Paper stated that they were laid 30 feet below low-water mark, which he made out would be about 7 feet below the bottom of the harbour. He would like to know whether that was deep enough to guard against any damage from vessels' anchors and to allow for future dredging. In the case of the Bristol bridge, perhaps the Author could say whether the hydraulic pipes which crossed the Avon to the central pier were protected in any way from similar damage. The bitumen sheeting which was laid between the concrete and the pavement of the roadway on the Bristol bridge had also been used at the Tower bridge, but the result had not been satisfactory. Recently some of it had been taken up, and had been found to be quite rotten and porous; in fact, it was owing to its letting water through that it had had to be taken up. It was now being replaced with a composition of pitch. With regard to

Mr. Cruttwell. the jamming of the locking-bolts of the Bristol bridge due to the curvature of the girders, a similar curvature had occurred in the case of the girders of the temporary foot-bridges which were placed on either side of London Bridge whilst it was being widened. The foot-bridges were roofed over, so that the sun could only get to one side at a time, and the girders being quite close to the parapet of the bridge it was very easy to take extremely accurate offsets to them. It was noticed for a long time that the girders deflected sideways, so much so, that it was possible to see their deflection. Measurements showed that every day when the sun was shining in the morning the girders deflected towards the east, and in the afternoon, when the sun was in the west, they deflected towards the west. The deflection took place at the middle of the girders, the ends being fixed. The amount of movement was between 1 inch and 2 inches. It seemed that if the locking-bolts at the Bristol bridge, instead of being made rectangular as described, had been made conical, like the point of a pencil, very likely they would not have got jammed in the same way; but he would like to hear Mr. Savile's opinion on that point.

Mr. Thorowgood. Mr. F. N. Thorowgood observed that as Mr. Homfray had mentioned the sinking of the foundations of the Tyne swing-bridge, with which he too had been connected, he would like to draw attention to the fact that the cylinders which carried the piers of that bridge, which were taken down almost to rock—or at least very hard material—were sunk under compressed air by a system which was not generally used. There were two valves opening downwards. Entrance was through the first valve, which was in the cylinder below the level of high water, and then through the lower valve. At the time, 32 years ago, many engineers said that was a dangerous method. The usual plan was to have the air-lock at the top of the cylinders, but in the case he mentioned the air-lock was like the old shot-flask, one valve closing and the other opening in the cylinder itself. No accidents occurred, but once he was going down with a man, and when the first door was closed, before the balance of pressure could be restored to open the lower door, the man fainted.

Mr. Copperthwaite. Mr. W. C. Copperthwaite asked how it was that, in the Bristol bridge, a departure had been made from the general practice with regard to swing-bridges in England, especially those carried out by the Armstrong firm, in which the live-load rollers were carried on radial axles attached to a ring which went round a pivot in the centre—as in the case of the Goole, Naburn, and Selby bridges. At the Bristol bridge there was an extremely rigid frame with two circular girders at the outside, and the rollers were fitted between

Mr. Copperthwaite.

the girders. He did not see that there was any economy in that construction, and, as one who had to look after that kind of work, he could see that there would be great difficulty in getting at the rollers, and at the work generally, on account of this extra material. He would like to know why that practice, which, as Mr. Homfray had said, had been very successful in the other bridges, had been departed from. Another point he noticed was that the screen put round to keep the roller-path dry at high spring-tides was of wrought iron. At the Selby swing-bridge a similar sheath was fitted which was of cast iron, it having been considered that if a vessel struck the screen it would probably break one or two panels of cast metal which could be replaced by reserve panels before the next high tide. If, however, a boat struck a wrought-iron fender, that fender would crumple up: it might or might not foul the working-gear; but at any rate it was not a matter that could be put right on a single tide. Many days would pass before the bent plates could be cut out and replaced. Another matter on which information was required was in regard to the 1·2 ton per inch of width of rollers. In English practice it was generally 1 ton per inch. American practice, however, worked out at 1·7 ton per inch on a 30-inch roller, and the Bristol bridge was well inside that limit. He had been carrying out for the Chief Engineer to the London County Council a small swing-bridge, of which he had put a plan on the wall, called the Old Gravel Lane bridge. The Chief Engineer had suggested that as the bridge was, so to speak, of a manageable size, an endeavour should be made to ascertain what the real drawbar-pull was for a bridge of that kind. By drawbar-pull he did not mean the pull necessary at the particular place where the rack happened to be fixed, but the actual pull if taken at the centre of the roller-path itself. Many experiments had been carried out. First an attempt was made to find what the coefficient would be of a roller-path without the weight of the bridge upon it—with nothing but the rollers, the upper roller-path, and the circular plate which was used to join it together, the total weight of which was about 29 tons. When the bridge was erected the pull was taken at the nose, at the point marked B (*Fig. 1*), and again just outside the roller-path; and adjusting the calculations, allowing for leverage and so on, figures were obtained which were fairly close together for the different trials. With an unloaded roller-path the pull was practically 1·16 per cent. of the weight, that was, the coefficient would be 0·012. The unloaded-path coefficient was obtained with a velocity of about 19 feet per second, which was considerably in excess of what the actual working-velocity would be.

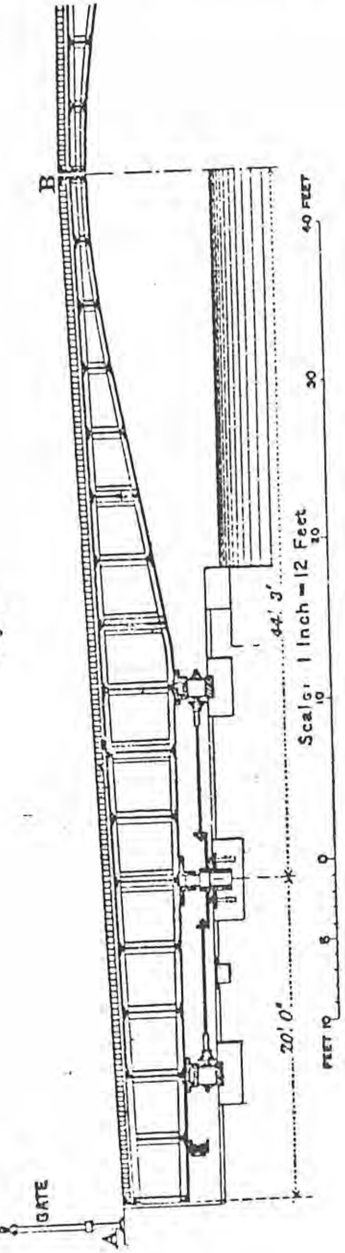


*Fig. 1.*

Old Gravel Lane Bridge.

Mr. Copperthwaite.

When the bridge was constructed, with everything complete, it was found that the pull varied between 1·8 per cent. and 2·2 per cent. or a coefficient of 0·02. When the roller-path was moving at 3 feet per minute the nose was moving between 11 and 12 feet per minute, which was rather less than half the speed of ordinary working. It practically came to the fact that the force required for swinging an ordinary bridge of that character was obtained by multiplying the weight of the moving portion by a coefficient of about 0·02. The starting-pull was practically 100 per cent. more. It varied a good deal in the experiments, as the work was done with a hand-winch, and the dynamometer, inserted in the wire rope, had a limit of about 10 tons, so that it was rather difficult to get the exact starting-load.

The Presid

The President asked what was the condition of the rollers and the roller-path.

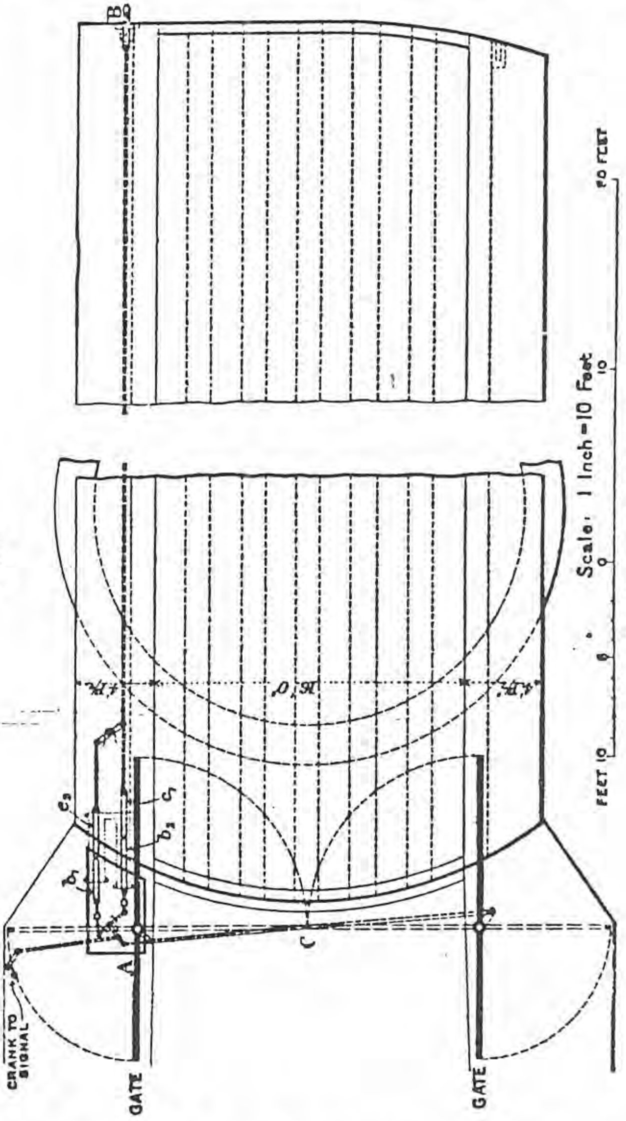
Mr. Coppe thwaite.

Mr. Copperthwaite said they were not treated at all: the dust was swept off the lower roller-path, and the rollers were quite dry. The other point to which he wished to draw attention was an arrangement, not very novel, but simple for the conditions under which it had

Mr Copperthwaite.

to work. A bridge built by the London County Council had to stand a large amount of criticism, and great care had to

Fig. 2.



OLD GRAVEL LANE BRIDGE.

be taken for the safety of the public. *Fig. 2* showed the general outline of the scheme, though it did not show how carefully the contractors had worked out the details. The operator's cabin was 30 feet away from the road, and the first condition was that he should not be able to move the bridge until the gates were shut. That was arranged by having a contact underground at C. The gates were made with centre pivots, so that the movement of one gate shut not merely half the road, but one foot-path as well, and on the other side of the road there was a similar gate connected with the first by cranks, as in level-crossing gates. When the gate was shut, a bolt was dropped on each leaf, and those two bolts made the contact at C. Until the gates were shut, the man in the cabin could not move the bridge at all. The interlocking was worked in the following manner. There was a crank at A, connected with a short bolt $b_1$ and a longer bolt $b_2$. When the bridge was open, and the gate was in position, these bolts held the bridge. On the bridge itself there was a crank with a long bolt $c_1$ and a short bolt $c_2$; and the bolt $c_1$ went through into the other half of the bridge at B. When the gate was swung round the crank caused one pair of bolts to advance and the other pair to recede, so that when the gates were completely shut the adjacent ends of each pair of bolts were quite free. The operator in his cabin was thus able to open the bridge. When he closed it again, exactly the reverse happened. He swung the bridge into position while the gates were shut, and as the gates were opened for the public to go through, the lock was put in again. Precautions were taken against the gates being swung too soon by putting in a back lock, so arranged that the bolt could not be shot home until the other leaf of the bridge had come forward, and, by means of a little lever, had lifted the back lock which held that bolt. It was therefore impossible for anybody to get on the bridge while it was being opened.

Mr. Brereton.

Mr. C. A. BRERETON, having had an opportunity of seeing the Bristol swing-bridge during its construction and after its completion, wished to bear testimony to the fact that it certainly had been one of the successful works of swing-bridge construction. It gave an impression of ample strength and stability, and of being well suited for the work it had to perform. No doubt, as Mr. Homfray had said, it was of the utmost importance that there should be no failure either in the bridge itself or in its working, because it was not only dealing with the railway- and road-traffic over it, but also the river-traffic under it, and that could not be kept waiting when once the signals had been given for the bridge to open. It was therefore of the utmost importance in all swing-bridges of that kind that there should be no possible hitch in opening or closing. The construction of the foundations

Mr. Brereton. in this instance had not been so difficult as in some other cases, and therefore the coffer-dam system adopted appeared to have answered in a very satisfactory manner. Of course in the Avon at low tide there was very little depth of water to contend with, and therefore the caulking of timber coffer-dams could be readily carried out. The advantage was that inside a coffer-dam the pier could be built exactly where it was wanted, whereas sometimes in sinking caissons or large monoliths through a great depth of mud or silt there was a tendency for them to drift out of the true position. With regard to the question of supporting the weight upon rollers, as Mr. Cruttwell had remarked, there was apt to be a difference between the weights that came upon the rollers when the bridge was actually working and when the bridge was in position and carrying traffic, and therefore some allowance had to be made to provide a margin for the rollers that were not actually in play when the bridge was turning. A centre pivot no doubt relieved the weight, and also it had an advantage where tail rollers could be used to guide the bridge and steady it in its turning; but in many cases where that was impossible, it was desirable to make the diameter of the roller-ring and also that of the rollers as large as possible. The question of interlocking was an important one, especially where a bridge had to carry both trains and road-traffic. In most of the swing-bridges he had been concerned with, it was done by shooting bolts, working alternately, putting one in and the other out—in fact, an arrangement somewhat similar to that explained by Mr. Copperthwaite. The adjustment of those bolts had to be done with a great deal of care. If the ends of the bolts were made somewhat in the shape of the ordinary bolt on a locking-bar of a switch, it added very much to the facility with which the bolts could be inserted and withdrawn. The Bristol bridge was a thoroughly practical example of what a swing-bridge of the kind ought to be.

Mr. Douglass. Mr. W. T. Douglass observed that Mr. Savile stated that in carrying out the foundations of the central pier of the Bristol bridge, a coffer-dam was erected, the piles being driven about 2 feet into the marl. He would like to know what arrangements had been made for filling the holes which the piles occupied, after the piles were removed. It appeared to him that it would never do to leave the bed of the river in that condition. Again, further on in the Paper Mr. Savile stated that the live load on the roadways was assumed to be 1·5 cwt. per square foot. Mr. Douglass imagined that would be excessive for a bridge of the kind, and he desired to know whether any experiments had been made before arriving at that figure.

Mr. Wilson. Mr. J. S. Wilson, having seen the construction of the Pyrmont bridge at the bridge-yard, thought he might be able to add a few details that would be of interest. The swing-span of the Pyrmont bridge and the caisson were constructed in Belgium by the Société Anonyme des Ateliers de Construction de Hal, near Brussels, and he carried out the inspection of the work there on behalf of the Engineer to the New South Wales Government. The specification required that the swing-span should be completely erected at the girder-yard and turned on its pivot before leaving. That of course necessitated not only that special foundations should be prepared, but that the work should be erected in a position where the necessary space was available. It was also necessary that all the joints should be made in a suitable manner to support the weight of the bridge. When swung at the bridge-builder's works, it must have weighed about 500 tons. The foundations under the roller-path were put in to a depth of about 1·28 metre. Reference was made in the Paper to the difficulty experienced with regard to machining, and the impossibility of turning the cast-iron ring and roller-paths. This part of the work was carried out as follows:—The cast-iron segments were planed parallel top and bottom in an ordinary planing-machine; the ends were then machined and the whole of the segments bolted up into a ring. The ring was laid down and carefully levelled with a surveyor's level, and the pivot to be used for the bridge was mounted in the centre. A special carriage was constructed with two rollers running on the top of the ring and constrained to move round the centre pivot by a radius beam. A tool in a tool-box fixed on the carriage could be brought to bear on the vertical edges of the cast-iron ring, and the carriage was pulled round by a horse (which had been trained to work a roundabout) harnessed to a projecting arm. The vertical edges were satisfactorily turned in that manner. The conical-faced treads had to be secured to the drum on which the whole weight of the bridge rested, without intervening packing of any sort, and the manufacturers anticipated that without very special care it would be difficult to make a good job of the arrangement. While the cast-iron ring was perfectly level the drum with its flange angles loosely bolted on was put to rest on the top of it; the angles were then clamped down on to the ring, and while in that position the holes were rimered through and the rivets were closed. With regard to the accuracy with which this part of the work was fitted together, he tried all the rollers while they were supporting the whole weight to see how many were bearing. He found that he could only get a No. 6 feeler (0·006 inch) between one roller and the upper tread, and

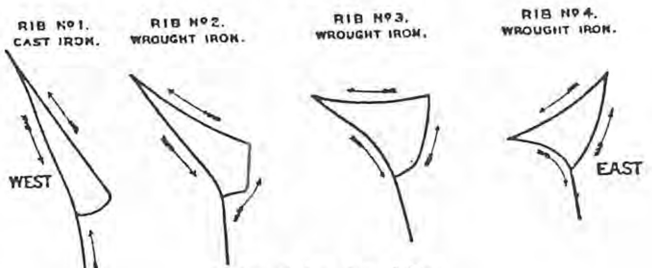
Mr. Wilson. considered the adjustment was good. With regard to the temporary erection of the main girders, these were to have no initial camber, and they were packed up till the top booms were quite horizontal and the holes through the ties and struts were rimered through with pneumatic tools. The joints were made with turned bolts and parallel drifts, and the deflection was about 1 inch under the girder's own weight. He wished to ask Mr. Allan one question with reference to the camber of the bridge. To work the end-lifting mechanism, a shaft ran the whole length of the girders, and on account of the camber varying, the bearings of the shaft must get out of line. From the figures given in the Paper there appeared to be a good deal of friction, and he would like to know whether the Author recommended that system in similar cases, or whether he would consider it advisable to work the end-lifting mechanism by a separate motor at each end of the bridge. He thought the Author was to be congratulated not only on having designed a bridge so fine in appearance, but on having carried out the erection so successfully, and on the very satisfactory manner in which the bridge could be operated.

Mr. Homfray. Mr. S. G. Homfray wished to answer one or two questions that had been asked. Mr. Copperthwaite had spoken of the roller-ring as being different from what it was in the Goole bridge. He had not closely inspected the plan of the roller-ring for the Goole bridge lately, and had not got it very clearly in his mind, but he thought the difference was rather more apparent than real. The axles were attached to a ring, and revolved with it around the centre pivot. In the case of the Bristol bridge and of many bridges that came before it—certainly in the Tyne bridge—a structure was built which used to be called a cobweb, and to that the roller-shafts were attached. It really shortened the roller-shafts and transferred the ring from the pivot to some distance out. The ring outside the rollers was not a very stiff one, and adjustment could be given easily and satisfactorily. He thought Mr. Copperthwaite had fallen into an error in regard to the weight per lineal inch. Mr. Homfray had a list giving particulars of some of the older and some of the newer bridges, and he found that in the Goole bridge the rollers were twenty-six in number, 3 feet in diameter, and 15 inches wide, and the swinging weight was 750 tons. That gave a load, per lineal inch of roller, of 1·93 ton. In the case of that bridge the roller-paths were made of cast iron with forged steel faces and the rollers of cast iron with steel hoops. Some little difficulty was experienced owing to the rolling out of the steel hoops, and they had to be rehooped. The bridge thus worked until as recently as 2 years ago, when some of the rollers were replaced by cast-steel rollers without interfering with the traffic. In later bridges the load had been reduced considerably per lineal inch, and the steel faces had been given up. The Tyne bridge had cast-iron paths and cast-iron rollers, hooped with steel. In the case of the Bristol bridge there were cast-steel paths and cast-steel rollers, and therefore it was thought there was justification for putting rather more work on them than would have been the case with cast iron, especially when it was remembered that the bridge at Goole was still not exactly a nightmare to those who had to look after it. With regard to the tail-end bridges referred to by Mr. Cruttwell, there could be no question that where it was possible to get in a centre-press bridge with a tail-end roller-path, that was the best and cheapest. That that was recognized in Bristol was apparent from the fact that there were a considerable number of tail-end bridges there, the bridge under discussion being really the only live-roller bridge. Bristol was an old port, and, as was often the case in the West of England, possessed many things that were being reintroduced at the present day. With regard to the tail-end bridges, he had spoken of 1,000 tons as being practically the limit, so far, of the load on a live-roller ring for a bridge, but, curiously enough, that was also the heaviest load that had ever been put upon a centre-press bridge. There were bridges of 950 tons in existence, one of them, the heaviest bridge made, being at the Royal Albert Docks. Beyond that weight, the centre-press became unwieldy, unless the hydraulic pressure was very high, and then it was necessary to provide for great strength to resist bursting. Hitherto, no bridge of more than 1,000 tons had been made of the tail-end pattern. With regard to the locking-bolts, it was necessary on a railway-bridge, if the locking-bolts were to be of real value, that the parts engaging in the socket should be parallel, so as to ensure the rails coming to the same point. If the bolts were tapered they would not so satisfactorily ensure the bridge coming into line, and he did not think a railway-engineer would be prepared to accept them. It was possible to have a locking-bolt with a tapered end for entering, as in the bridge which Mr. Cruttwell and he had had the pleasure of dealing with in years past, but that again would not do in the case of a swing-bridge where the locking-bolts acted to pull it up as it swung past. There would be a danger of the bolt flying in and something being carried away. If the fit of the bolt in the socket was made sufficiently fine, then, if the bridge was swinging too quickly, the bolt simply jumped past and did not engage. The question of camber brought him to the point that

Mr. Homfray. while in the Pyrmont bridge only a comparatively small portion of the camber was taken out, in the Bristol bridge practically the whole of the camber was taken out by the hydraulic end gear, and sliding blocks were put in, leaving the bridge at practically the level at which it was built, and so reducing it to the condition of a fixed girder-bridge. As to the tail-end centre-press bridge, another great advantage over and above the simplicity and cheapness was, that when it was across the entrance it was resting upon six bearing-blocks of its own, and was in exactly the same position as a fixed girder without machinery. It rested on solid bearings which had no mechanical supports at all.

Mr. Elliott-Cooper. Mr. R. Elliott-Cooper observed that Mr. Savile had referred to the difficulty of being unable to shoot the bolts when the bridge was closed on account of a certain amount of twist caused by the effect of the sun, and Mr. Cruttwell had referred to an instance of the same effect in connection with the widening of London Bridge. A good many years ago he built in Yorkshire a road-bridge consisting of two arches with spans of 166 feet each, and 60 feet wide. When one-half of the bridge was finished, he decided that, before taking away the staging, he would get a series of self-registered diagrams, showing what was the effect of the changes of temperature in 24 hours upon the structure, in order to ascertain the rise and fall of the centres of the arches, and also to see to what extent the rest of the structure would be affected by the rising and lateral movement of the outside ribs. It seemed to him that strains of considerable magnitude must occur in bridges and other structures of iron and steel from the effects of changes in temperature, particularly in a bridge, where the outer ribs or girders might be exposed to the sun's rays while the inner ones were in the shade. *Figs. 3* illustrated the curious movements of the bridge he referred to. The diagrams

*Figs. 3.*



Scale: Twice Actual Size

were started late at night, and showed that early in the morning before sun-rise the four ribs rose fairly together. When the sun rose, the eastern rib took an upward and easterly direction, but as the other ribs were not exposed to the sun's rays they were pulled over horizontally. The westernmost rib, which was cast iron—all the others being wrought iron—was pulled over horizontally about $\frac{3}{4}$ inch. When that rib reached a point when the sun left the east side and came across to the west, the eastern rib was beginning to get cool and was dropping, but it was pulled over in a westerly direction by reason of the rising of the westernmost rib. The other ribs were pulled over horizontally in the same way. Just as the two inner ribs had been pulled over horizontally to the eastward in the morning, so they were pulled over to the westward in the afternoon. That gave an idea, roughly, of the strains there seemed to be on a structure of this description. One part of the bridge having less natural movement of its own, through expansion and contraction of the metal, was dragged over by the cross bracings and floor-plates by reason of the greater movement of the outer ribs. There must be many cases where the strains were much severer; in such a climate as that of Africa, for instance, where the range of temperature in 24 hours at some parts of the year was often as much as 100°.

The President. The President asked the nature of the "ribs."

Mr. Elliott-Cooper. Mr. Elliott-Cooper said the outer rib was a cast-iron arch with ornamental cast-iron spandrels, but the inner ribs were solid plate-girders with lattice spandrels.

Mr. Carew-Gibson. Mr. J. G. Carew-Gibson remarked that having been at one time connected with the Public Works Department in New South Wales, he knew the original Pyrmont bridge, and was familiar more or less with the site of the present structure. It had been remarked already that European engineers would probably be most struck by the use of so much timber in the side spans in an important structure in one of the principal cities of the Empire; but that was due to the fact that while steel was not made in Australia—or at any rate was not made when he was there some years ago—there was some magnificent timber, and there was a strong feeling—with which he concurred—that where public money was being spent it was quite right that local materials, and as far as possible local labour, which had made the country, should have a preference. That was probably one of the main reasons why timber had been used in this case. But, apart from considerations of that nature, he was willing to believe, from what he knew of the circumstances, that timber was actually the more economical. Of course, there was the inconvenience of

Mr Carew-Gibson. constant repairs and renewals, but possibly the political consideration had led to that being subordinated. He had had to do with the construction and maintenance of a good many timber bridges while he was in New South Wales, in different parts of the colony, and his experience was that the useful life of those structures averaged, for the important parts of them, about 25 years. Most of the bridges in the colony outside the big towns had timber decks, and the decking being subject to the wear and tear of the traffic, its life would be about 12½ years, so that a bridge wore out two decks. At the expiration of that time, as a rule, it was not economical to go on repairing and renewing, but was truer economy to replace the structure with a new one. The bridges, as a rule, were built from the nearest suitable timber at the site of the bridge, no particular attention being paid to cutting timber at the proper time of year. He did not know whether it was such an important matter with Australian timbers as with timbers in other parts of the world, but he imagined it would have a considerable effect upon the life of the timber if it were always cut when least full of sap. He thought it very probable that if the timber for the bridges were selected a little more carefully, and felled at the proper season of the year, the life would average perhaps a few years more, but he doubted whether there would be much economy, as the cost would be considerable under the prevailing conditions. He regretted the Paper did not contain more details of the timber portion of the Pyrmont bridge, but judging from the information given, he thought Mr. Allan had improved on the designs formerly in use in New South Wales. He seemed to be using small scantlings, which was an important thing with Australian timber. The weak point in that timber was the heart, which was very often decaying before the tree had reached maturity. It was the first part of the timber to fail. It was quite a common thing to find beautiful sticks of timber absolutely hollow, sound at both ends but hollow farther along, so that Australian timber was very deceptive timber to deal with. By using small scantlings it was possible by avoiding the heart to get better timber, and he had no doubt the life of the timber in this bridge, therefore, would be more than the average. The deck upon the swing-span was said to be laid with tallow-wood blocks, and it would be interesting if the Author would say whether this was because tallow-wood was found to be the most suitable timber for wood-paving, or because it was a local timber, whereas jarrah, which seems to be about the only Australian timber used for the purpose in England, came from Western Australia. When wood paving was being laid in London, he had often looked at stacks of what were said to be jarrah blocks, and wondered whether those responsible for their purchase could tell the difference between jarrah, karri, "red gum," "cabbage gum," and sundry other Australian timbers when in the form of blocks, many of them being extremely alike in appearance and yet very different in quality. The Paper did not go very much into details of the design, and hence criticism was not invited. But as a low first cost seemed to have been a primary consideration, it was perhaps a little surprising that a monolithic pivot-pier had been adopted. Whilst the design of this pier was quite sound, from an engineering point of view, and where the ground was at all doubtful was no doubt to be preferred, yet, in the present case, with an absolutely sound rock-bottom, a group of cylinders would have been equally effective, as there would be no danger of unequal settlement; and such a pier would probably have been cheaper, and would have taken a shorter time to construct. Perhaps the Author would say whether this question had been considered, and what had been the reasons influencing the design. No doubt the large pier, faced with handsome Pyrmont stone masonry, had a good appearance. He thought Mr. Allen was to be congratulated upon having designed and constructed a bridge which would bear comparison with similar structures in other parts of the world, and which, as a sound and practical piece of engineering, reflected credit not alone upon himself and the Public Works Department of New South Wales, but upon Australian engineering generally.

Mr. Savile. Mr. **Savile**, in reply, explained that the hydraulic mains of the Bristol bridge were laid about 6 feet below the present bed of the stream. The idea was at some future period to dredge the river about 2 feet deeper there, so that there would always be a depth of 4 feet over the pipes. Further, in order to protect them, heavy iron cables had been laid across the river at a distance of about 50 yards up and down stream, so that any vessel dragging its anchor would probably catch it in the cables. There was also a rule of the river that no vessel was allowed to anchor within ¼ mile on either side of the bridge. He thought the mains ought to be fairly safe. With regard to bitumen sheeting under the wood paving, it was not nearly so good as asphalt, but it had been put down in order to reduce the weight of the swing-span as much as possible. It was a fairly easy thing to renew, but he was afraid it would not last as long as the wood paving; if it did, the bitumen sheeting could be renewed when the wood paving was renewed. With regard to the length of the axles, he thought one great advantage of keeping the axles short was that if an axle went wrong in any way it could be taken out, whereas if it was long the water-tight casing round the pier would prevent that from being

Mr. Savile. done. The chief reason why steel had been adopted for the material of the casing in place of cast iron was because steel was much cheaper, and as good strong timber fenders were provided, he thought that there would be no trouble. He could quite understand that, if a ship did run into the pier, cast iron might possess an advantage. With regard to Mr. Douglass's question about the pile-points below the concrete of the piers, no steps had been taken to fill up the holes, but the piles had not been universally driven below the excavation. Some piles stopped slightly above the bottom of the foundation and other piles which were fairly deep were cut off, so that he thought there was quite enough marl and piles against the concrete to obviate any risk of the piers sliding bodily, which apparently was the danger Mr. Douglass had in mind. With regard to the live load, it was quite possible 1½ cwt. per square foot was excessive, but he thought that in designing the bridge there had been a desire to provide for future loads. It had been found that all bridges designed within the last 40 or 50 years had had their loads increased very much, and bridges soon became out of date; and as it was hoped that the Avon bridge would last longer than its builders, a large —perhaps impossible—increase in the loads had been provided for. Mr. Homfray having replied to the question about the time taken to swing the bridge, he would only add that the process of putting in or taking out the blocks occupied about 40 seconds, so that the actual time of swinging the bridge was about 1 minute. Mr. Thorpe had raised a question about the possible strain on the centre-pivot due to the turning-moment being unequal on the two arms. Mr. Savile did not think that was of much importance, because a greater strain was liable to come on the centre pivot due to wind, and that would be the case in a bridge with either equal or unequal arms. As the pivot had to be made strong enough to withstand that strain, he thought it was quite safe from any other slight strain that might occur. No saving in cost could have been effected if the bridge had been made with equal arms, because the swing-span would have been more expensive, and no appreciable economy could have been obtained on the south abutment, because the length of this was regulated by the length required to bend away the road to the eastward, and that could not be shortened much without making a very awkward corner.

Mr. Burge. Mr. C. O. **Burge** did not think there was anything he could very well say on Mr. Allan's behalf, except with regard to the question of the time. The 30 seconds he had mentioned as being the time occupied in swinging of the bridge was, as he had subsequently discovered, only the time taken in swinging, and 8 seconds were occupied in lifting, so that really the comparison was between 38 seconds and 1 minute 45 seconds. In such cases engineers were governed by circumstances, quite apart from questions of time and cost, but still he thought it would be interesting to have further information on the subject of the relative advantages of hydraulic and electric working.

Mr. Allan. Mr. **Allan**, in reply, thanked the members for the consideration given to his Paper, and expressed his indebtedness to Mr. Burge for explaining the adoption of timber side spans in lieu of steel. In view of the heavy loads to be carried the span had been somewhat more difficult to design than it would have been had the more permanent material been decided upon. With regard to the wind-pressure on swing-spans with unequal arms, even with equal arms unbalanced wind-pressure had to be anticipated, and in the calculations for the sluing-machinery of the Pyrmont bridge a velocity of 30 miles per hour acting on one arm had been allowed for, the exposed surface being taken as the area of the hand-rail plus twice the area of the main girder as seen in elevation: this necessitated providing an estimated force of 15,475 lbs., applied at the pitch-circle of the rack, in the motive power. The Author agreed with Mr. Thorpe as to the importance of good workmanship in the manufacture and fixing of roller-paths, and, holding this opinion, he had spared no expense in stipulating for the best class of work. In the fixing of the path, however, no difficulty had been met with except the small matter of rubbing down a $\frac{5}{16}$-inch "pig in the track" due to working the masonry bed from one, instead of sixteen level points in the circle. Mr. Homfray had instanced a number of notable hydraulic swing-bridges in which the weight on the rollers was relieved by a centre press; but in a wide-decked high-speed swing-span with an easy-running turn-table, the friction to be overcome by the power applied at the pitch-circle of the rack was so small, compared with the constant accelerating force required to overcome inertia plus unbalanced wind-pressure (calculated at 7,752 lbs. as against 38,544 lbs. in the case of Pyrmont bridge) as to render a centre relieving-press unnecessary for economy in sluing, whilst the 18-inch diameter of the rollers and a weight of 1·2 ton per lineal inch on them, had not caused any appreciable wear after 30,800 openings in 5 years, and was within the bounds of good practice as indicated by the examples on p. 68. He could not follow Mr. Homfray's argument that six times as much gear had been provided at the Pyrmont bridge, the pinion on the armature-shaft meshing with the spur-wheel alone taking the place of the connecting-rod and crank at the Bristol bridge; from that point the train of gears was similar, the greater reduction at the Pyrmont

Mr. Allan.

| Bridge. | Motive Power. | Rollers. | | Pressure per Lineal Inch. |
|---|---|---|---|---|
| | | Diameter. | Face. | |
| | | Inches. | Inches. | Ton. |
| Harlem River four-track railway . . . | Steam | Outer 24<br>Inner 20½ | Outer 10½<br>Inner 10½ | 1·65 |
| " " 3rd Avenue tram and road | " | 24 | 12 | 1·47 |
| Rock Island railway and road . . . . | Electric | 18 | 10 | 1·83 |
| Thames River, U.S.A. . . . . . | Steam | 20 | 11½ | 1·96 |
| Cardiff Bridge, England . . . . . | Hand | 18 | 9 | 1·21 |
| Pyrmont Bridge, N.S.W., Australia . . | Electric | 18 | 10 | 1·21 |

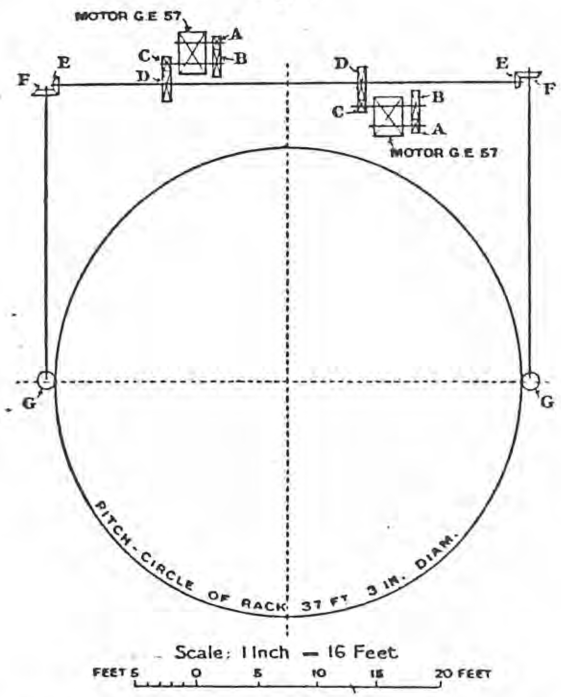
bridge being obtained by adopting a smaller pitch with consequent lighter gearing, finishing with a rack of $3\frac{21}{32}$-inch pitch, as against 6 inches at the Bristol bridge. The general arrangement of the machinery at the Pyrmont bridge was the following (*Fig. 4*):—

| | |
|---|---|
| First motion, armature-shaft, carrying pinion A with 19 teeth.<br>Second motion, axle-shaft, carrying spur B with 66 teeth . . | 3·473 to 1 |
| " " " " " pinion C with 14 teeth .<br>Third motion, main driving shaft, carrying spur D with 74 teeth | 5·29 " 1 |
| " " " " " bevel pinion E with 15 teeth . . . . . . . . . . .<br>Fourth motion vertical shaft, carrying spur E with 39 teeth . | 2·60 " 1 |
| " " " " rack pinion G with 15 teeth<br>Rack with 364 teeth . . . . . . . . . . . . . | 25·60 " 1 |

The foregoing gave 47·767 revolutions of the armature-shaft to 1 of the rack pinion, or 1,222·83 revolutions of the armature-shaft to 1 of the swing-span. With a large reduction, the effort to be exerted by the motive power was diminished, and the starting was made so smooth as to render the movement of a heavy swing-span difficult to detect. He concurred with Mr. Cruttwell as to the desirability of a stiff upper roller-path with equal distribution of weight in rim-bearing swing-spans, and considered these features to be essential in designing such structures. The whole weight of the superstructure of the Pyrmont swing-span was distributed at sixteen equidistant points on the circumference of the drum, as shown in *Fig. 5* (p. 70). The facts of the conical tread being connected direct to the bottom flange of the drum, and of the drum being so deep, gave a particularly stiff path, the absence of which had caused the crushing of rollers and paths of some hand-power swing-bridges in New South Wales. In designing the section of the drum it had been treated as a straight girder, with a length equal to one-eighth of its circumference, supported at the ends, and carrying a centre weight of 68 tons, the maximum stress in the flanges as adopted being 3·9 tons per square inch, and in the web 1·1 ton per square inch. By taking only 1¼ inch out of the deflections at the ends the dead load on the rollers was varied between 800 and 710 tons, and as this difference of 90 tons was transmitted through the distributing girders and stiff drum to the rollers, the difficulties in regard to altered adjustment of rollers referred to by Mr. Cruttwell had not been met with. The object of placing a thin layer of sand on the bottom of the Sydney rest-pier had been to fill the voids along each pile, caused by the four flitches on the follower being driven below the clay bottom, and also to precipitate any possible remaining film of silt. It was considered that the richer concrete in the bottom batches would take up the sand and would set better than if it were deposited directly on the bottom, which, in view of the care taken in pumping out the silt, was an unnecessary refinement that had been omitted by the Author in constructing similar piers elsewhere. Regarding

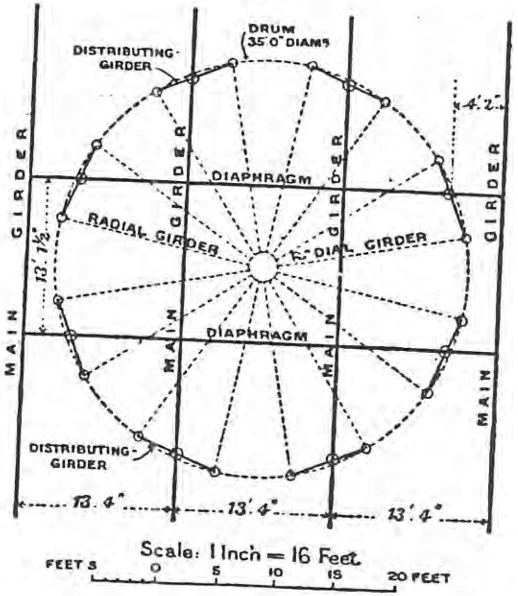
Mr. Allan.

*Fig. 4.*



Mr. Allan. the possible danger to cables from ships' anchors, it might be pointed out that there was no anchorage above or within reasonable distance below the bridge, the larger vessels being berthed at the different wharves with the aid of tugs. The only contingency was the somewhat remote one of an anchor carrying away by accident whilst a vessel was passing through the fairway, when a 4-foot cover would be available over and above the probable maximum 26 feet depth of future dredging. Mr. Wilson's description of the methods adopted in machining the track, and the steps taken during manufacture to ensure the bottom angle-bars of the drum being truly horizontal for receipt of the upper conical tread, indicated the care exercised by the manufacturers under Mr. Wilson's inspection, which had helped very much to facilitate erection; for with track and pivot once bedded, everything had gone together without trouble, a result which, the Author considered, amply justified the expense incurred in stipulating for the swing-span being erected and worked in the manufacturer's yard before shipment. Of the total deflection of 4¼ inches at the ends of the span only 1¼ inch was taken out by the end lifts, whilst the total spring in the longitudinal shaft was also 1¼ inch in a length of about 100 feet, the shaft being placed in such a position as to spring ¼ inch above and 1 inch below a horizontal line, and ensure horizontality of the shaft at the moment when maximum effort had to be exerted by the motor, the work to be done then quickly dropping either way. The worm-gearing, although having the known advantage of acting as a "stop" when power was cut off, was responsible for the major portion of the friction alluded to by Mr. Wilson, and when designing the work, although the calculations by the usual formulas showed 8 HP. only as being required, the Author decided upon a 35-HP. motor, his experience being that with worm-gearing the usual calculations for friction were quite fallacious. In the tests the maximum effort required from the motor had been 29 HP. Except in longer-armed swing-spans, or where the ends were raised to full height, the Author preferred the longitudinal centrally-driven shaft, as being the more direct and certain method of actuating the end-lifts, and of securing more readily single control, the lifting of the ends to exactly the same height, certainty of stopping the cams in the correct position with a simple strap brake, and mechanical connection between the lifting-gear and dial in the controlling-house. Mr. Carew-Gibson's experience of the average life of New South Wales timber structures agreed closely with the Author's.[1] The felling of timber when the sap was "down" had been advocated in New South Wales for many years, but, owing to commercial considerations, without result; to ensure as much seasoning as practicable, however, it was generally stipulated, in regard to the more important bridges of New South Wales, that the sawn truss-timbers had to be delivered at the site before an advance on the contract would be made. The trusses in the side spans were 80 feet between the centres of triangulations, giving 82 feet 5 inches between the centres of the piers. The top and bottom chords each consisted of two sawn and planed flitches, 14 inches by 7 inches and 13 inches by 6 inches respectively, cut free of heart and sap-wood; each brace also consisted of two flitches bowed and stiffened with distance-pieces, the flitches varying from 13 inches by 6 inches in the end diagonals to 8 inches by 4 inches in the central bays, the vertical rods in pairs at each apex varying from 1⅞ inch diameter at end intersections to 1⅛ inch for central bays, and all rods being upset at the ends. The floor-beams were spaced 2 feet 8 inches apart, sawn 14 inches by 6 inches and 14 inches by 5 inches over apexes and intermediate points respectively, and were adzed down 2 inches at curbs to obtain part of the camber in the

*Fig. 5.*



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[1] See P. R. Allan, "Timber Bridge Construction in New South Wales." Royal Society of N.S.W., 1895.

Mr. Allan. carriage-way. Tallow-wood, as the best timber for the purpose in New South Wales, was used for wood blocks, it being peculiar in its absence from gum-veins. It was delivered in flitches to facilitate inspection for class, and gauging to a width of 3 inches with a strict margin of $\frac{1}{16}$ inch or less, the object sought being to reduce spaces and secure a water-tight pavement. A group of cylinders would have been cheaper than the pier adopted, but difficulty had been anticipated in securing sufficient stiffness in the circular girder to give an absolutely unyielding path, which was perhaps the feature of the design. Apart from this, however, it had been deemed desirable that a solid pier should be adopted, in view of the heavy shipping which would use the fairways, and the unfortunate experience at Parramatta River bridge close by, where in collision a steamer lifted the braced group of cylinders bodily out of plumb.

## Correspondence.

Mr. Brain. Mr. O. W. Brain, of Sydney, observed that the question of the motive power to be adopted for swinging the bridge appeared to have been a matter of utilization of local advantages rather than selection of the superior method for the work, both at Bristol and at Pyrmont. In the former case the Docks Committee's hydraulic power was at hand, while at Pyrmont the State had available its own electric supply, of such a character that reliability of service was ensured. No doubt serviceable operation of either bridge could have been obtained with either of the secondary powers under consideration. Mr. Allan's Paper showed that the results of working at Pyrmont over a period of 4 years had been entirely satisfactory, and doubtless it was safe to assume, from the absence of any statement in the Paper to the contrary, that Mr. Savile wished it to be understood that the equipment he described discharged in all respects the functions for which it was designed. At the same time, Mr. Brain would like to have seen a statement of the cost of power consumed in the operation of the Bristol bridge, which might have been compared with Mr. Allan's very complete figures. In connection with the latter, it might be mentioned that the charge of 1*d.* per kilowatt-hour made by the Railway Commissioners was for the power at the bus-bars of their power-house. The cost of the cables was a charge against the bridge, and the losses in the cables were included in the annual charge for power-

supply. Hence the low charge of 1*d.* per kilowatt-hour. Power Mr. Brain. might be obtained at the bridge at a flat rate of 1½*d.* from the City Council, who incurred all costs of transmission. In view of the cheap available electric power, the only commercially feasible methods of operation open to Mr. Allan had been direct electric working, and hydraulic working by means of electrically-driven pumps. There would not seem to be any excuse for the latter except habit, as a similar arrangement was even now occasionally installed for elevators, where the ordinary directly-operated electric elevators would be satisfactory and do the work at less cost. There might perhaps be an inclination to prefer a smaller gear-reduction than 1,223 revolutions of the armature to 1 of the swing-span. There would, in fact, have been no difficulty in dividing the former figure by six; but no object, except possibly an æsthetic one, would have been served. The motors would have had to be proportionately larger, heavier, and more costly. There might have been more difficulty in accommodating them on the swing-span, and repairs, if any, would have been more difficult and costly on account of the larger parts. This was pre-eminently a place which justified a small motor, so long as the loading was not carried to a point at which the reliability of the motor would be affected. The swing-motors, in fact, made a little over 3½ million revolutions per annum, or less than one-twentieth of what the same class of motors ordinarily did in traction service. The annual power-output also bore approximately the same relation. The damage resulting from the reversing of the motors, as a method of bringing the swing-span to rest, was only what might have been anticipated. This course was permitted in traction service only when everything else had failed; as, with a well-loaded car, high speed, and good adhesion on the rail, the reversing of the motors and application of current was very likely to be attended with serious damage. As a rule, the car-wheels slipped, but the bridge-gearing providing no such safety device, the probability of injury was much greater. This consideration did, however, suggest another method which was entitled to adoption for this class of work, particularly where the cost of current was of importance. He referred to the Raworth regenerative system, and he did so with confidence, as the results which had been obtained with the tramcar-equipment imported by the Railway Commissioners had been such that he would now have no hesitation in recommending Mr. Allan to install the system for bridge-work. The speed of sluing might be increased with a decreased consumption of power and without increased strain upon any part of the gear. In fact, the retardation was under better control and could be applied more

Mr. Brain. regularly than by any method of mechanical braking. It would hardly be necessary to explain that the principle involved merely the return to the line of the energy stored in the swing-span, which would otherwise be dissipated in heat at the brake-shoes. There would be nothing experimental in the adoption of the system in connection with the swinging of a bridge, as the whole of the requirements under such conditions had been met in tramway service. The latter work, in fact, was of a much more exacting nature and involved requirements considerably beyond those for the operation of a swing-bridge.

Mr. Buswell. Mr. LINCOLN BUSWELL, of Sydney, remarked that in the 5 years which had elapsed since the Pyrmont bridge was opened for traffic, the working of the swing-span had disclosed one or two slight weaknesses. The pins supporting the top or movable foot-blocks of the end lifts had shown signs of bending, making the pins eccentric, with the consequence of the blocks sticking and thus being thrown at an angle, which, if allowed to remain, would have resulted at some time in serious accident. The difficulty had been overcome by easing the pins by $\frac{1}{32}$ inch, which allowed the weight of the ends of the span to be thrown on the outside of the boss in which the pins worked. No difficulty was now experienced. Again, on account of the high speed of the gate-motors, and their sudden stoppage when the attachment on the slotted bars came in contact with the circuit-breaker, a severe strain was thrown upon the levers and extended to the pinion-shaft on the motors, due to the momentum of the gate; and the pinion-shaft had on two or three occasions been broken, throwing the gate out of gear. This difficulty had been overcome by lengthening the levers connecting the solenoid brake and strap on the brake-wheel, and attaching thereto a dash-pot or air-cushion. Thus the motor was allowed to travel a few revolutions after the current was cut out, while the air was escaping from the dash-pot through a small valve, which when exhausted brought the strap hard on to the wheel at the same time as the gate was brought to rest. One dash-pot was fitted to each gate-motor, and had been found to work admirably. The coil given to the cables had been found to work fairly satisfactorily, but on account of the cables being fixed so tightly in the 7-inch opening at the top of the pivot, they had been found to be cutting, and thus in danger of a complete breakdown. An important alteration had therefore been made by inserting a series of flexible couplings; each cable was cut at the top of the pivot and distributed over a double-terminal granite slab, one on the permanent pivot and the other on the movable girders with suitable attachments; the two terminal boards were

coupled up by means of flexible couplings, and the cables were then carried to a junction-box and thence to the various controllers and the switchboard in the controlling-house. The division of the cables at various points afforded facilities for isolating a fault in a very short time. In connection with Glebe Island bridge, a work designed and constructed by the Author on similar lines to the Pyrmont bridge, and situated about 1½ mile away, a break actually occurred a short time ago, when a fault was definitely located in 7 minutes in a distance of about 5 miles. The cost of the flexible coupling was a little under £100. The whole arrangement now worked very satisfactorily. The coke-concrete foundation over the buckled plates for the wood blocks on this span had always appeared to him to be too thin, and he had been of opinion that the excessive pounding on the blocks by the heavy traffic over it, and the constant lifting and lowering of the span at the ends, would eventually crack it. Such had proved to be the case, the area on this portion of the bridge having been the most expensive for repairs. He thought that a better roadway would have been obtained by making the blocks 4 inches deep, the 2-inch space being made up by laying longitudinal planking on top of the concrete, and a groove being left for tramway-rails, the laying of which was now contemplated. The thickness as now laid had been adopted for lightness, it being impossible to increase the concrete. The wood-blocking on the side spans had answered admirably, though a little more camber in the roadway would have been an advantage. No expense for repairs had been occasioned since the blocks were laid, about 4 years ago. Mr. Buswell.

Mr. T. B. COOPER stated that the blows which occurred during the excavation for the centre pier of the Bristol bridge had been caused by the presence of large stones which lay in the gravel bed below the river-mud. These stones had interfered with the regularity and closeness of the piles of the dam. It had frequently been found that although a pile above the mud-level was apparently in true line the lower portion had been deflected several inches, leaving an opening between the piles which could not be got at for caulking. The water of the river had very free communication through the shingle at that level, and this underground channel, as it might be termed, had rendered the leaks difficult to attack, with the very considerable head of water which prevailed at high tides. The north pier had been more fortunate in this respect than the centre pier, as at the north side of the river the large stones were not so numerous as on the south. If he had similar works to do again, where such a large rise of tide had to be dealt with, he felt confident he would ask to be Mr. Cooper.

Mr. Cooper. allowed to adopt monoliths. It would be remembered that the works of the Bristol bridge were begun about 8 years ago, before it was generally recognized that the monolith system could be handled as easily and expeditiously as had since proved to be the case. By adopting that method, much of the excavation might have been grabbed out wet; and although pumping might have been needed occasionally if a large stone or other obstacle was encountered, the cost of this would not have been comparable with that of the dams used. This would be understood when he stated that the average pile of the dams was 52 feet long by 12 inches square. Again, once the monolith shoe had got into the red clay and the top was above high water of neap-tides, operations could have proceeded absolutely in the dry for several days, and the interior concrete hearting could have been put in with practically no attendant cost of pumping or washing down. It was interesting also to recall that, nearly at the bottom of the excavation for one of the two pits behind the tow-path pier (Fig. 2, Plate 4), human remains and a skull, this last practically unbroken, were discovered. It would be noticed that the strata here formed a hollow, and there seemed no doubt that the River Avon at one time took this course.

Mr. Dare. Mr. H. H. **Dare** contributed the following account of how the power required for turning the Pyrmont bridge had been calculated, and how the calculations agreed with the actual results. The total weight of the span when swinging was 797·6 tons, the radius of the rack-circle was 18 feet 7½ inches, and the radius of the drum was 17 feet 6 inches. It was assumed that the bridge would be opened or closed in 60 seconds, of which 24 seconds would be occupied in uniformly accelerating the speed, 12 seconds in turning the bridge at the maximum speed so produced, and 24 seconds in running with the current cut off, the speed diminishing evenly from the maximum to nothing. The calculations were based upon opening the span through 90°, but it was subsequently settled that 83° should be the maximum opening. The resistances to be overcome were:—

1. Rolling-friction.
2. Sliding-friction between the disks of the pivot under the radial girders.
3. Collar-friction of the rollers.
4. Inertia.
5. Unbalanced wind-pressure.

As the tests were made on a calm day, wind-pressure for purposes of comparison was omitted from the following calculations. It

formed, however, a considerable item when unevenly distributed over the span, and it was estimated that in the extreme case of an unbalanced wind-pressure of 30 miles per hour covering the whole of one arm only, the time required to open or close the bridge would be very nearly double that taken on a calm day, with the motors exerting the same power. Mr. Dare.

1. The rolling-friction, taking a coefficient of 0·003, was 5,036 lbs.
2. The sliding-friction between the disks of the pivot, taking a coefficient of 0·10, was 110 lbs.
3. The force at the rack to overcome the collar-friction of the rollers was estimated at 2,606 lbs. The design of the rollers was subsequently somewhat modified.
4. The inertia, which was by far the greatest resistance to be overcome, was determined by dividing the span into its component parts, and the resistance due to the inertia of the whole moving mass was found to be 23,069 lbs.

Therefore the power required at the rack-circle on a calm day, for sluing the bridge in 60 seconds, as originally calculated, was—

| | Lbs. |
|---|---|
| 1. Rolling-friction . . . . . . . . . | 5,036 |
| 2. Sliding-friction at pivot . . . . . | 110 |
| 3. Collar-friction of rollers . . . . . | 2,606 |
| 4. Inertia . . . . . . . . . . | 23,069 |
| Total . . . . | 30,821 |

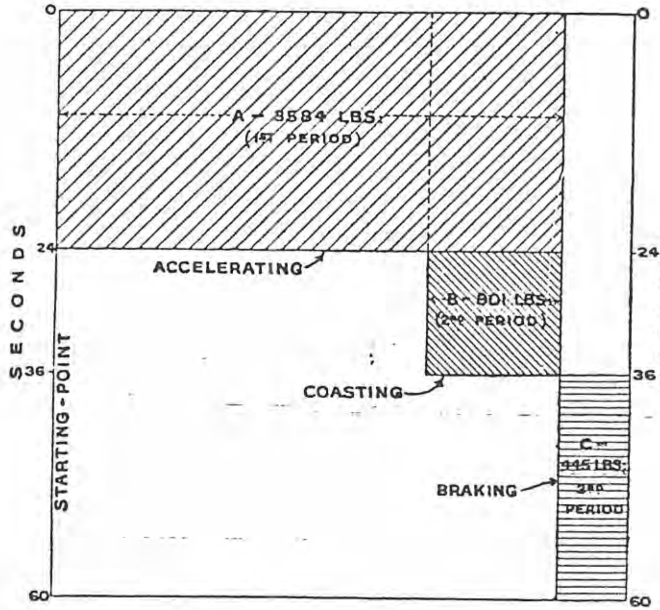
47·767 revolutions of the pinion on the armature-shaft = 1 revolution of the rack-pinion. The circumference of the pinion on the armature-shaft was 1·658 foot and that of the rack-pinion 4·570 feet. Allowing 100 per cent. for friction of shafting and gearing, the power required at the pitch-circle of the pinion on the armature-shaft was:—

$$\frac{30{,}821 \times 2 \times 4{\cdot}57}{47{\cdot}77 \times 1{\cdot}658} = 3{,}584 \text{ lbs.}$$

This represented the power required to accelerate speed and overcome friction during the first period of 24 seconds from rest (*Fig. 6*) on a calm day. The 5,384 lbs. given as the guaranteed starting-effort of the motors included also a provision for overcoming unbalanced wind-pressure. During the ensuing 12 seconds the resistance due to inertia disappeared, and the only power

Mr. Dare. required was that to overcome friction, namely, 901 lbs. During the final 24 seconds a retarding force must be applied, calculated upon the force required to overcome inertia, but deducting the retarding effect of friction in the moving parts. This was estimated at 445 lbs. The friction allowance for shafting and gearing was calculated to be 60 per cent. on the foregoing, but in order to ensure ample power this was increased to 100 per cent. when finally determining the capacity to be provided in the motors. The following calculations of the power actually developed had been made,

*Fig. 6.*



*A = force required at pitch-line of pinion on armature-shaft to overcome total resistance and accelerate speed so that after 24 seconds the maximum motor-speed of 509 revolutions per minute, or 0·81 foot per second at the pitch-line of the rack-pinion, will be attained. This corresponds to 91 HP. with 100 per cent., or 72·8 HP. with 60 per cent., allowance for friction of gearing.*

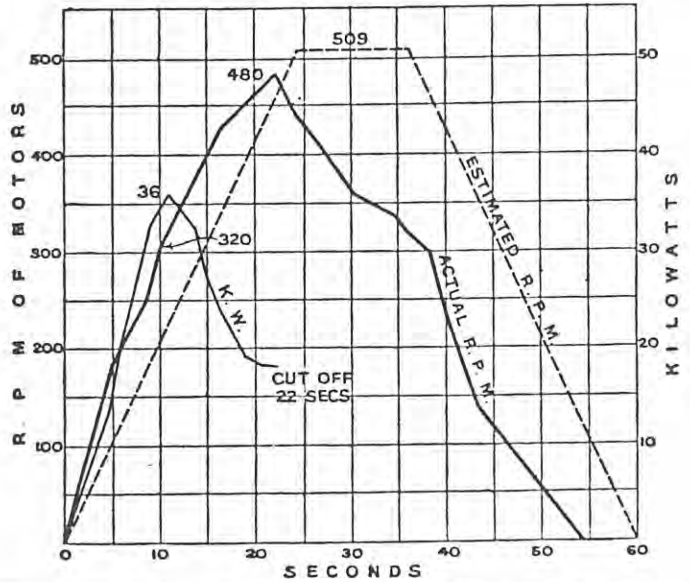
*B = force required at pitch-line of pinion on armature-shaft to overcome rolling-, sliding-, and collar-friction, and maintain a speed of 509 revolutions per minute.*

*C = retarding-force required to bring span to rest.*

based upon diagrams of trials of the swing-span supplied by the Author:— Mr. Dare.

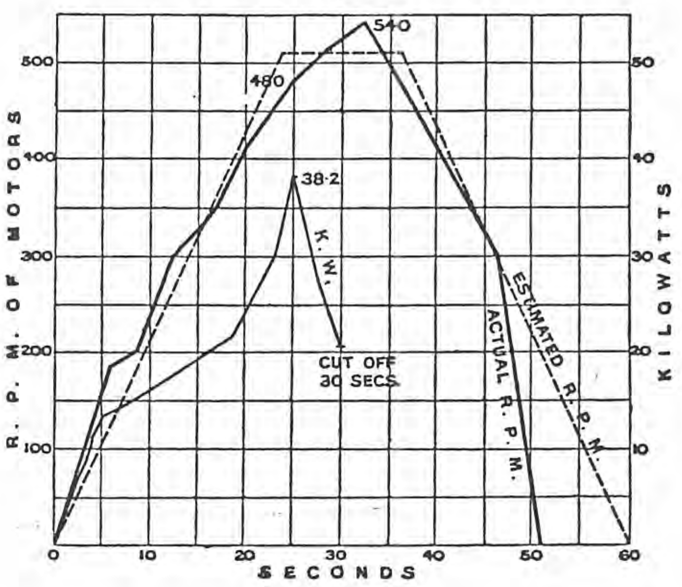
*Run No. 20.*—This was referred to by the Author as the most economical run, and was illustrated in *Fig. 7*. Current was applied uniformly for 11 seconds, when the power required was 36 kilowatts, or 48 HP., and the revolutions of the motors 320 per minute. From the maximum of 36 kilowatts the power diminished to 18 kilowatts in 11 further seconds, during which the span gathered speed up to 480 revolutions per minute of the motors. At the end of 22 seconds power was cut off, and the span was brought to rest in 55 seconds. The main point to be considered was the uniform accelerating force required to overcome inertia, and the calculations in this and other cases were based upon the peak in the kilowatt-diagram, up to which the acceleration was fairly constant. The power required, neglecting the friction of the gearing, was 36·6 HP. The actual maximum power developed was 48 HP. The difference, 11·4 HP. or 31 per cent., on the assumption that 39,443 lbs. was, as calculated, the total force required at the rack, would represent the additional power required to overcome the friction of shafting and gearing.

*Fig. 7.*



Mr. Dare. *Run No. 10.*—In this run the acceleration-period was 25 seconds, and the total time for swinging 50 seconds. This case had been taken because the acceleration-period and the maximum number of revolutions of the motors were more nearly similar than in other runs to those in the original calculations, though the power-curve (*Fig. 8*) was not so even as in most of the other cases given in the following Table. Current was applied for 25 seconds, increasing in a fairly uniform manner to 38·2 kilowatts, or 51 HP., when the speed of the motors was 480 revolutions per minute. Reduced power was used for 5 seconds longer, the revolutions increasing to 540 per minute; and the current was then cut off, and the spans were brought to rest in 51 seconds. The results of this run, and also of other runs recorded in Table II, which gave diagrams from which the accelerating force could be calculated, were given in the following Table. It should be noted that in runs Nos. 12, 8, and 18 the maximum actual horse-power did not agree with that given in Table II, because the diagrams for these runs gave more than one peak in the kilowatt-curve, indicating a reduction in power

*Fig. 8.*



after reaching a certain stage, followed by a subsequent increase to the maximum horse-power. The first peak in the kilowatt curve, or the termination of the period of uniform acceleration, had been taken in these cases. Runs with similar acceleration-periods had been grouped together. Mr. Dare.

The average percentage of difference was 53 per cent. This agreed very fairly with the 60 per cent. estimated for the friction of shafting and gearing, which had been obtained by calculating in detail the friction of each set of gear. The tabulated results appeared to indicate that, though the actual periods of acceleration and cut-off did not coincide with those allowed in the original calculations, the method employed in estimating the power required was reasonably correct. The deflections of the ends of the span, with the bridge swinging, had been calculated to be 3·89 inches for the outer and 4·03 inches for the inner main girders. The actual deflection was $4\frac{1}{4}$ inches.

PYRMONT BRIDGE. TABLE SHOWING HORSE-POWER AS ESTIMATED BY THE FOREGOING METHOD COMPARED WITH THE ACTUAL HORSE-POWER DEVELOPED IN SLUING THE BRIDGE.

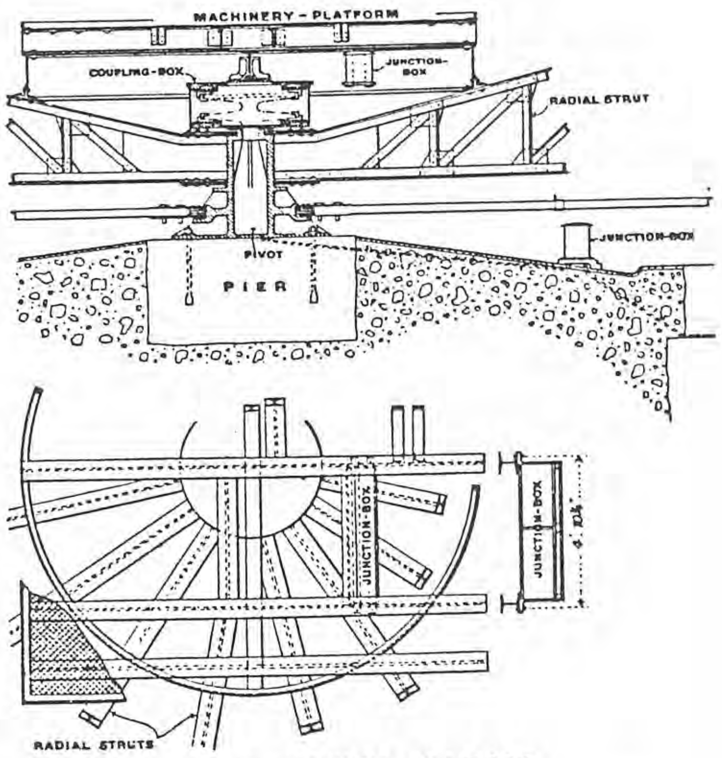
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Period of Uniform Acceleration. | Number of Run. | Speed of Motors at End of Acceleration Period. | Power, calculated from diagrams, required in Sluing, *ex* Friction of Shafting and Gearing. | Actual power developed by the Motors. | Difference between cols. 5 and 4. | Percentage of Difference, representing Friction of Shafting and Gearing. |
| Seconds. | | Revs. p. Min. | HP. | HP. | HP. | Per Cent. |
| 5 | 12 | 250 | 45·4 | 67 | 21·6 | 48 |
| 7 | 11 | 300 | 47·6 | 67 | 19·4 | 41 |
| 7 | 8 | 250 | 34·0 | 55 | 21·0 | 62 |
| 7 | 9 | 275 | 40·6 | 74 | 33·4 | 82 |
| 9 | 4 | 290 | 40·1 | 57 | 16·9 | 42 |
| 9 | 7 | 275 | 32·9 | 58 | 25·1 | 76 |
| 9 | 5 | 335 | 46·3 | 72 | 25·7 | 55 |
| 10 | 18 | 320 | 39·5 | 70 | 30·5 | 77 |
| 11 | 20 | 320 | 36·6 | 48 | 11·4 | 31 |
| 17 | 14 | 360 | 31·8 | 45 | 13·2 | 41 |
| 25 | 10 | 480 | 39·4 | 51 | 11·6 | 29 |

Mr. Hanna.

Mr. W. J. HANNA observed that when he took over the Pyrmont bridge immediately before Mr. C. W. Darley left for England, the caisson was, in consequence of the "blow," being sunk in the wet, and at that time it was thought possible to bed the cutting edge for more than half its periphery on the solid rock, at about 3 feet 9 inches above contract depth, and for the remaining distance to make good the space between the rock and the cutting edge with bags of concrete placed by divers after undercutting the clay. On reaching this less depth, however, it was found that the caisson was bearing on such a small portion of the ring that it was deemed desirable, in order to avoid risk, to carry the caisson to its original contract depth. It was doubtful whether the water could have been pumped out, and such a satisfactory foundation obtained, without adopting this course. The blow referred to in the Paper was probably due to the stiff clay not following the quick cant of 11 inches which occurred when pumping out the water, thus leaving a space along the outer wall of the caisson down which water found its way, ultimately bursting under the cutting edge. Had the caisson been pumped out a few feet before the cutting edge touched the high side of the rock, the canting might possibly have been diminished; but, with an unyielding stratum on one side, unequal settlement was to be anticipated, which the Author endeavoured to meet by leaving a large bed of clay on the low side. With the large diameter of the coil of cables at the top of the pivot, the opening and closing of the Pyrmont swing-span occasioned such a small amount of movement as to cause no trouble; but at the sister bridge at Glebe Island, where only a limited amount of cable was available and a much smaller diameter of coil had consequently to be adopted, failure had ensued in two of the leads in cables after about 12,000 openings, necessitating the introduction of a flexible connection between the standing and the moving parts of the cable at the top of the pivot, which it had been thought desirable to adopt also at Pyrmont. This device had proved eminently satisfactory in the past, and no trouble was anticipated in the future. In the hope, therefore, that it might be of some assistance to those interested in the design and construction of swing-bridges, the following description of the mechanism was given, illustrated by *Figs. 9* and *10*. The whole of the electrical apparatus in connection with the bridge was controlled from the cabin on the swing-span. This necessitated the provision of forty-eight conductors connecting the stationary equipment with the controlling-gear on the bridge. In order to gain flexibility, the two mains were furnished with two conductors, each in the coupling-box at the pivot, bringing the total number of connectors in the box to fifty. The connectors included, besides the mains from the power-house referred to above, the leads for the gate-motors and lighting, and the telephone-service. The coupling arrangement consisted of two horizontally-placed circular rings

Mr. Hanna.

*Figs. 9.*



PLAN OF MACHINERY-PLATFORM

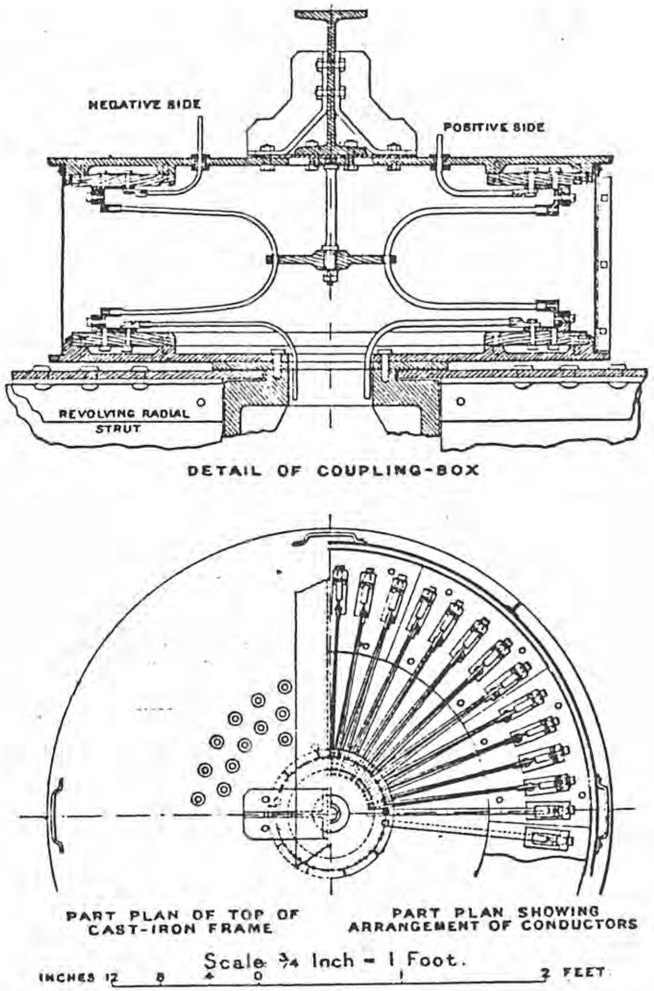
Scale 1 Inch – 6 Feet.

FEET 5 4 3 2 1 0 5 10 FEET

of terminals, each 3 feet $6\frac{3}{4}$ inches in diameter. Both were concentric with the pivot, one being secured to the bridge at a height of 12 inches above the other, which was mounted on the pivot. Each ring consisted of fifty terminals, which were fixed on a number of easily replaceable marble slabs. Each terminal of the upper ring was connected by flexible cable to the terminal of the lower ring which

Mr. Hanna. was immediately below it when the bridge was closed. The length of each flexible cable was 30 inches, which permitted the bridge to

*Figs. 10.*



turn through an angle of more than 90° in either direction from the closed position. To the ends of each flexible connection were sweated shaped connectors, which were held by set-screws in recessed

terminals on the cabin and pivoted conductors on the marble slabs. Mr. Hanna. In each ring there were ten slabs of marble on which were mounted five terminals, facing outwards for accessibility. This arrangement allowed of a terminal or a slab of five terminals being quickly replaced in case of a short-circuit or broken connection. The positive and negative main connections each consisted of two cables in parallel, made of one hundred and five wires, No. 26 S.W.G., with vulcanized rubber insulation and braided covering; and each of the remaining connections consisted of twenty-five wires of No. 26 gauge similarly protected. The flexible connections looked inwards from the terminals and were held by a wooden guide which kept them uniform and allowed them to move only in a predetermined path. The special features of the design were ease and quickness of repairs and accessibility of the whole of the parts for cleaning or inspection without taking to pieces. The conductors on the swing-span and the pivot passed through junction-boxes to facilitate testing and changing over in case of trouble. The coupling-box was made dust- and water-proof by a detachable cylindrical sheet-iron cover which could be quickly moved when inspection was necessary. Seeing that this high-speed swing-span had now been opened and closed 30,800 times, involving 246,400 individual gate-movements without accident or any expenditure on repairs, where the traffic was particularly heavy, consisting approximately of 6,000 vehicles and 12,500 pedestrians per diem, it left little to be desired in the matter of design.

Prof. Ker Professor W. C. Kernot observed that the questions about the Pyrmont bridge which suggested themselves to him were the following:—(1) The comparative merits of the solid centre pier as compared with one consisting of six or eight cylinders, as used at several other swing-bridges in Victoria and South Australia. The latter construction would certainly have saved some costly work in levelling the rock, for the separate cylinders need not have been taken down to the same level; it would also have reduced greatly the volume of concrete needed. Further, cast-iron cylinders as used in the Victorian and South Australian bridges would have been much more durable, especially in the salt water, possibly made more corrosive by impurities from the shipping and the surface drainage of a densely-populated manufacturing district. (2) The comparative merits of girders above or below the deck. In the Australian bridges referred to above, the girders were above the deck, and acted either as the ultimate handrail or as a barrier between the carriageway and footway. They allowed of the maximum headway underneath, thereby

Prof. Kernot. obviating the necessity of opening the bridge for small vessels. On the other hand, the arrangement at Pyrmont required much lighter cross girders and distributed the weight better on the rollers. (3) Would it not have simplified construction somewhat to have had the bottom members straight instead of curved? In view of the importance of the bridge and its proximity to the centre of a large city, the timber approach-spans seemed hardly appropriate, intervening as they did between an elaborate and magnificently equipped swing-span, and an approach-viaduct of great architectural pretensions, the parapet alone of which abounded in massive and costly enrichments. No doubt ironbark was a fine and durable timber; but surely the extra expense of steel would have been justified, even if the architectural adornments had been somewhat reduced in cost to help meet it. The approach-gradients, not given in the Paper, were undesirably steep, and that on the eastern or city side presented an ugly and unnecessary break that was an impediment to heavy traffic.

With reference to Mr. Savile's belief that the Bristol bridge was "the only double-decked swing-bridge of anything like its size in existence," a double-decked railway and road swing-bridge of much larger dimensions was erected nearly 30 years ago at Albany, America. That swing-span was 397 feet long. The foundation of the towpath pier seemed questionable. Surely it would have been better to carry it down symmetrically to the gravel. A composite foundation as shown suggested possibilities of unequal settlement and loss of verticality. The arch in the centre pier was unusual, and its purpose not obvious. In cross section DD (Figs. 2, Plate 4) there appeared to be an excessive thickness and weight of concrete under the oak blocks and asphalt.

Mr. Robertson. Mr. F. E. Robertson suggested that the girders of the Pyrmont bridge were much too shallow, and the panels too short for an economical and rigid design: the reason for this was not clear, as there seemed to be plenty of room between high-water mark and the roller-path. Two girders of a reasonable depth would probably have been better than the four shallow ones actually used. The Paper did not say where the girders were built, and it might be remarked that the troubles with the turning-gear were entirely due to poor work. There was no difficulty in making rollers strictly interchangeable.

There were several points in the design of the girders of the Bristol bridge which seemed open to criticism. It was presumed that the reduction of $\frac{1}{2}$ ton in the unit-stresses of the swing-span was an implicit recognition of the heavy reversals of stress which occurred

in it; but it would be preferable to allow definitely for these reversals by figuring them on the stress-diagram and adding, say, half the area required for the minor stress to that required for the major. Mr. Robertson By the method adopted, members having no reversals got an allowance which they did not want, while others which had heavy reversals received an insufficient allowance. The statement that a string of heavy goods-locomotives was equal to 1·66 ton per lineal foot was rather misleading, as the equivalent uniform load depended upon the length loaded. For the stringers it would be just about double. If the web-members, then, had been proportioned on the data given, they would all be much too weak. The object of the "point of contraflexure" in *Fig. 4* was not clear. There were an infinite number of such points in a beam with a rolling load, and certainly no such point could occur as shown in the diagram, in the midst of a panel of a truss. The section of the chord shown in Fig. 5, Plate 4, though quite common, was essentially bad. From the figures given, the area of the sides appeared to be 40 square inches, and of the bottom plates 105 square inches: it would be very much better if these proportions were reversed, the bulk of the metal being put into the sides, and thus receiving stress directly from the braces and gussets. As it was, five-sevenths of the total stress had to be transmitted through the edges of the trough-plates to the bundle of bottom plates, which it reached by the inefficient means of $\frac{7}{8}$-inch rivets $4\frac{1}{8}$ inches long. He suggested that as hydraulic power was used, rams hauling direct on a pitch-chain would have been a simpler gear than that adopted.

Mr. Smith Mr. Walter A. Smith mentioned that the maintenance of the Pyrmont bridge had come under his charge as Metropolitan Engineer after its completion in 1902, and from that time forward the whole structure had been an unqualified success, as regarded both road- and harbour-traffic. The former comprised nearly 6,000 vehicles per day, while during the year the average number of vessels passing through the opening span per day was thirty-two. In the 4 years during which this structure had been under his control, the openings of the swing-span numbered very nearly 25,000, and in not one opening had serious delay been caused to vehicular traffic, nor had any hitch or breakdown occurred with any part of the machinery. The coke concrete used on the swing-span was not strong enough to withstand the enormous traffic together with the repeated flexure of the girders and roadway of this span whilst opening and closing. This concrete had had to be partly replaced by stronger material, and a covering of "malthoid" had been placed over the concrete and under the wood blocks to prevent leakage of water from the roadway to the machinery below.

Prof. Warren. Professor W. H. **Warren** observed that the distinctive features of the Pyrmont bridge were the arrangements for sluing the swing-span, for lifting its ends, and for working the roadway-gates on the side spans by means of electric motors supplied from the tramway power-house. He considered these arrangements to be entirely successful; the opening and closing of the bridge was effected in a rapid and at the same time economical and satisfactory manner. The details of the design of the main trusses and of the floor-system of the swing-span, and the method employed for distributing the load upon the rim-bearing turn-table, by means of short distributing girders, had all been carefully worked out, and appeared to him to be satisfactory. In regard to the design of the Howe trusses in the side spans, wherein ironbark timber was used throughout—except for the vertical tension members, which were of steel—a large number of bridges had been constructed in this manner in New South Wales. Where a strong, durable, and thoroughly satisfactory timber such as ironbark was available at a moderate cost, the method adopted was entirely successful; but in other countries, and generally, it would be found in his opinion to be more economical in the long run to substitute steel Pratt trusses for the Howe timber trusses. The chief difficulty in the design of the Howe truss occurred at the joints in the bottom-chord, the efficiency of which, no matter how well they were proportioned, was dependent upon the shearing-strength of the timber. In ironbark timber the shearing-resistance along the fibre was about 2,000 lbs. per square inch, and bolts did not work loose in it.

In the swing-bridge over the River Avon, there appeared to have been no attempt to distribute the load uniformly over the rollers. Again, the main trusses appeared to him to be inferior in design to those of many modern swing-bridges built in America—such as the bridge over the Harlem Canal by Professor Burr, the Harlem River bridges by Mr. Katte, and also bridges by Mr. Theodore Cooper and others—in regard to economical strength and stiffness.

Mr. Allan. Mr. **Allan**, in reply, observed that Mr. Brain's advice had been so amply borne out in the practical results obtained at the Pyrmont bridge, that, if he were designing another electric swing-span, he would seriously consider the introduction of the Raworth regenerative system in lieu of a mechanical brake. The suggested improvement, however, would affect only the cost of sluing the swing-span, which if eliminated would mean but a saving of £12 per annum, less the interest on the difference in cost between the improved apparatus and a mechanical brake; so that, from a commercial point of view, there was not—with the cheap power avail- Mr. Allan. able—much margin for obtaining a more economical result. As to the difficulty with the coke-concrete referred to by Mr. Buswell, he had purposely limited the thickness of this concrete foundation, the cost of occasional renewal with cheap local material being less than the interest on the cost of steelwork to carry any additional dead load; moreover, with more attention to the surface dressing of the wood paving, water was now prevented from finding its way to the coke-concrete, and the life of the latter was consequently lengthened. Had data similar to those now given by Mr. Dare been available, they would have saved Mr. Allan a considerable amount of anxious thought as to the sluing-power to be provided. The figures showed how closely the 60 per cent. total friction-losses calculated for each set of gears agreed with the results obtained in actual working. Mr. Allan considered it desirable, however, in swing-spans of a similar character, to allow 100 per cent. for friction-losses in gearing and overhauling of the shafting between motors and rack, as adopted in the Pyrmont design, the additional cost being small and in the nature of an insurance against possible errors in manufacture and erection. Whilst it was possible that, as suggested by Mr. Hanna, had the water been pumped out of the caisson before reaching the rock, the "blow" might not have occurred, yet the contract had so bristled with the possibilities of heavy claims for extras as to make it desirable to adhere to the specification, a decision which, in spite of the blow, financial results had justified. The introduction of a flexible cable-connection between the fixed and the moving parts of the swing-span, described in detail by Mr. Hanna, had removed a weak spot in the design. In adopting a deck bridge, Mr. Allan had been influenced by the fact that in such a design the whole width of roadway right up to the curbs was made use of, whereas, when girders rose above the deck—as mentioned by Professor Kernot—the traffic pulled away from the girders, leaving a practically unused deck-space of 2 or 3 feet long at each curb-line. Again, the width of the boom had to be added to the length of the girders in order to obtain the same effective waterway. Whilst it would have simplified construction if the bottom members had been made straight, yet it was considered that the improvement in appearance had justified the small additional cost. He had been limited to the adoption of timber side-spans, but had considered it desirable to provide stone parapets on the approaches in keeping with the iron hand-railing extending from abutment to abutment, the whole presenting—from the deck—the same appearance as if a steel substructure had been

Mr. Allan. adopted. He regretted the break of gradient in the approach, which was due to a departure from the original design in order to minimize land-resumption, and a subsequent effort to recover lost opportunities. If two girders had been adopted as suggested by Mr. Robertson, it would have meant an entirely different design with accompanying heavy cross girders, and a difficulty, as pointed out by Professor Kernot, in obtaining a satisfactory distribution of the weight on the rollers. The 15 feet depth—where four girders were provided—was economically proportioned, as shown by the weight of material in the web as compared with the booms; whilst the short panels adopted were an important factor in increasing the stiffness, the rigidity of the span when swinging at high speeds being perhaps one of the most noticeable results obtained. In view of the heavy road- and shipping-traffic, it reflected credit on Mr. Smith's administration that the span had been for such a long period operated without hitch or complaint from the divergent interests involved. He was pleased that the electric equipment and the method of distribution of the load of the swing-span, as well as the general design of the trusses for the side-spans, were in accord with the views of Professor Warren, who had designed some of the larger bridges in New South Wales, and was well acquainted with the durability and other characteristics of Australian hardwoods.

Mr. Savile. Mr. Savile, in reply to Mr. Brain's question as to the cost of the hydraulic power for swinging the bridge, stated that the quantity of water used for the complete process of opening and closing was 182 gallons, and, basing the cost on the assumption that the pressure-water cost 2*s.* per thousand gallons (the price charged by the Docks Committee to outside consumers), the cost of each swinging amounted to 4·37*d.* The bridge had been working now for more than 10 months since the date of opening, and had been swung on an average about 270 times per month, the working of the machinery being entirely satisfactory. Referring to Professor Kernot's remarks, the reason for the towpath pier being founded partly on piles and partly on the gravel was that the design of the north approach was altered after this pier had been built, and as the alteration considerably increased the load which the pier had to carry, the concrete columns were added, and all the weight of the girders was carried on them. The arch in the centre pier had the advantage of reducing the obstruction to the flow of the river somewhat, and it also saved a considerable amount of concrete, while still leaving the pier quite strong enough to carry its load. Mr. Robertson was correct in assuming that the reduced working-stresses in the main girders of the swing-span had been adopted on account of the reversals of stress which occurred under different conditions of loading. With regard to his criticism of the statement in Mr. Savile's Paper that a string of heavy goods-locomotives was equal to 1·66 ton per lineal foot, he appeared to have overlooked the fact that the Author went on to say, "with a load of 18 tons on an axle." This load per lineal foot was quite correct for any span exceeding 40 feet and had been adopted for the main girders; but in designing the cross girders and rail-bearers the heaviest axle-load had of course been allowed for. As to the point of contraflexure in *Fig. 4*, Mr. Savile was quite aware that this point was movable under the various conditions of loading, but the diagram professed to show only the stresses for one particular distribution of the load, and it gave the theoretical position of the point under this condition. As, however, very heavy flange-stresses occurred in this neighbourhood when the bridge was swinging, the booms were designed to take these stresses, and so had a very large margin of safety for the stresses which might occur under the live load. With reference to Professor Warren's remarks as to the distribution of the load over the rollers, it appeared to Mr. Savile that the annular girder, with the help of the stiff cross girders over it, was sufficient for distributing the load. At any rate, as far as could be seen, all the rollers did their work, as no idle rollers had been detected since the bridge was opened.

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23 April, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

It was resolved—That Messrs. E. R. Dolby, F. Hudleston, E. W. Monkhouse, R. J. G. Read, A. W. Szlumper, T. Frame Thomson, and J. J. Webster be appointed to act as Scrutineers of the Ballot, in accordance with the By-laws, for the election of the Council for the year 1907–1908.

The Council reported that they had recently transferred to the class of

*Members.*

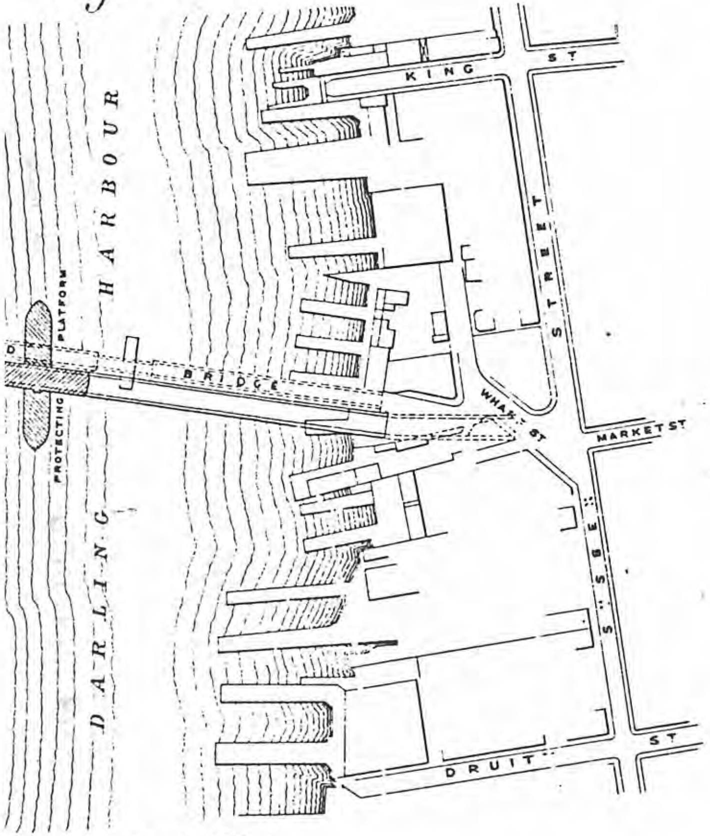
William Corin.
William Liston Douglass.
John May.
Stephen Westropp Stacpoole.

And had admitted as

*Students.*

Hermann Charles Bender.
John Hyslop Gardner, B.Sc. (*Glas.*)
Cyril Thomas, B.Sc. (*Durham.*)
Sydney Upton.
James Douglas Whittall, B.Sc. (*Manchester.*)

Fig: 1.



PLAN OF SITE.

Fig: 3.

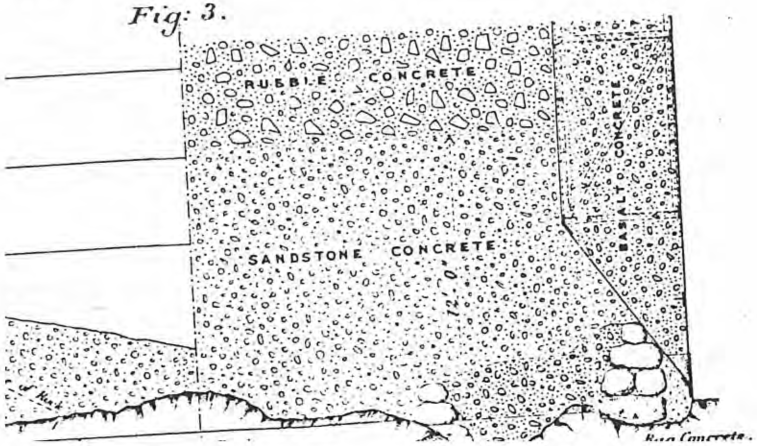
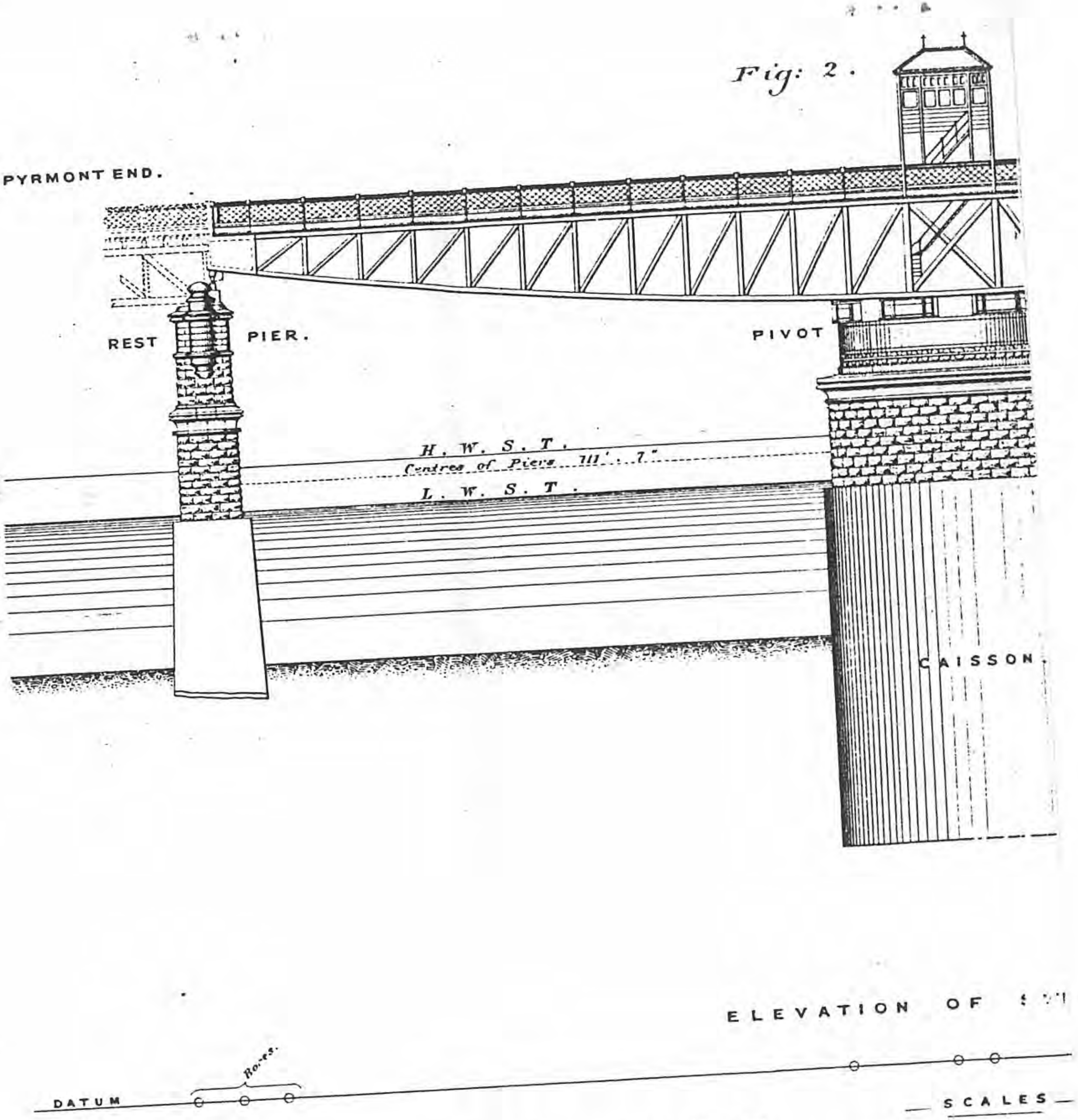


Fig: 2.



ELEVATION OF

— SCALES —

Fig: 1 ...... 1 Inch = 400 Feet.

Feet 100 50 0 100 200 300 400 500 1000 Feet.

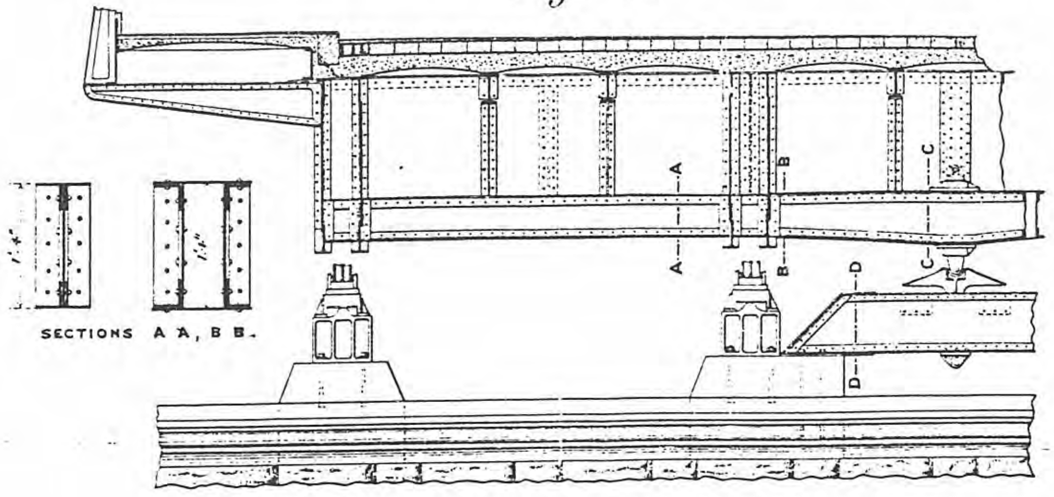
Fig: 2 ..... 1 Inch = 24 Feet.

Feet 10 5 0 10 20 30 40 50 Feet.

Minutes

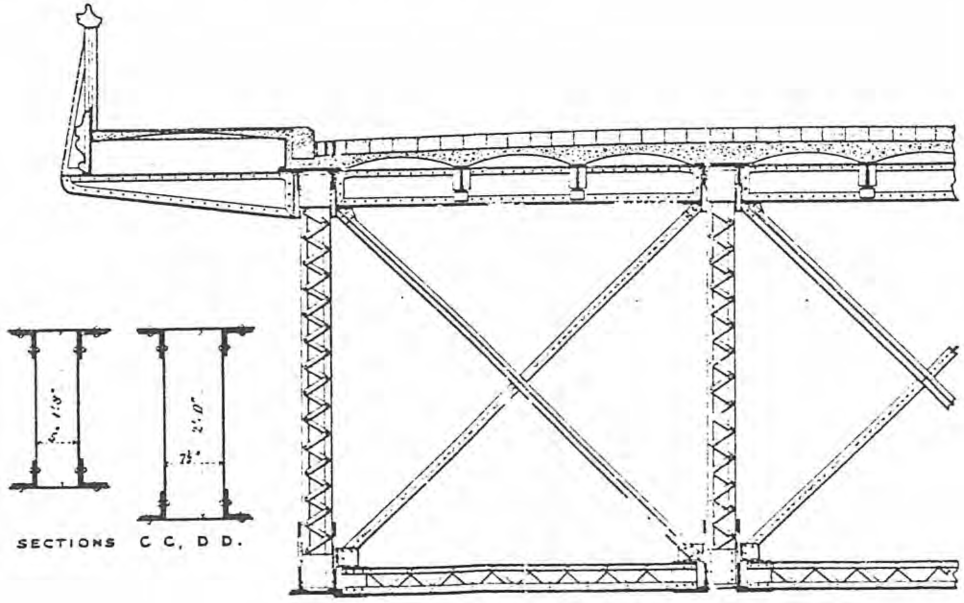
PLATE 3.

Figs 4.



SECTIONS A A, B B.

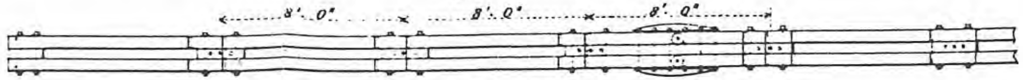
CROSS SECTION AT END OF SWING SPAN.



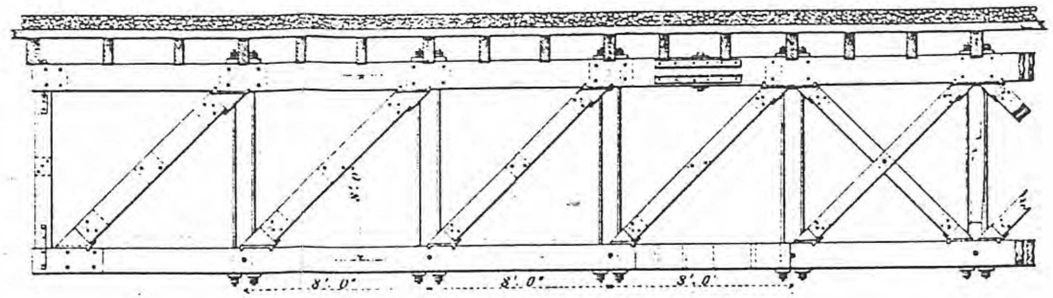
SECTIONS C C, D D.

CROSS SECTION OF BRIDGE.

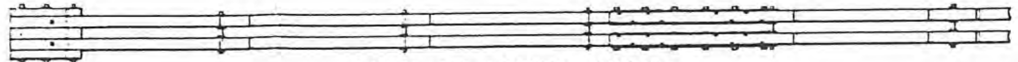
Figs 5.



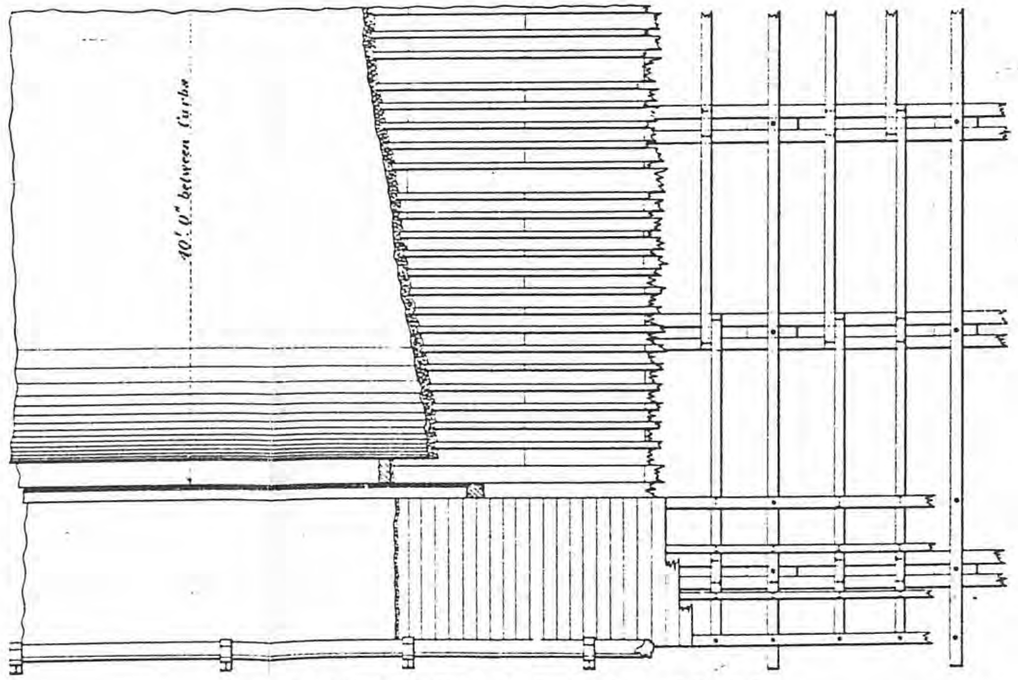
INVERTED PLAN OF TOP CHORD.



SECTION AT CENTRE.



PLAN AT LOWER CHORD.



DETAILS OF TIMBER SIDE SPANS.

THOˢ KELL & SON LITH. 40 KING Sᵀ COVENT GARDEN.

# PYRMONT ELECTRIC SWING BRIDGE

**FROM THE ENGINEER, JAN-FEB 1919**
**reduced copy**

three other vessels of the same class are to be included in next year's programme, and the remaining three in that of the following year. In view of the insistent demand of the navy for more scouts, it is probable that several further cruisers of this type will be added to the ten already authorised.

During the current year twenty destroyers are to be laid down, representing the first batch of the fifty provided for in the Naval Act of 1916. These vessels, it is officially stated, will be of uniform type. They are known for the time being as Nos. 75 to 94, and will be named after officers who distinguished themselves in past naval operations. The displacement is to be 1185 tons, the speed 35 knots, and the armament four 4in. and two anti-aircraft guns, with twelve tubes on triple mountings. The complement will be 95. The destroyers of the 1914 programme, known as the "Allen" class, which are now passing into commission, are in many respects the most powerful torpedo vessels in the world. One of them, the Sampson, was visited by the writer at New York last December, shortly after her completion. The keel was laid at the Fore River yard on April 21st, 1915, the launch took place in the March following, and trials began in November. These dates, which are not exceptional, indicate the growing celerity with which vessels of war are now constructed across the Atlantic. The Sampson is 315ft. in length overall, 29ft. 10in. in beam, and draws 9¼ft., the normal displacement being 1111 tons, increased to 1225 at full load. Her machinery consists of Curtis geared cruising turbines, driving twin screws, and designed to develop 17,000 shaft horse-power, equivalent to a speed of 29½ knots. This speed was improved upon at the trials, but the exact figures are not available. Steam is supplied by four Yarrow boilers, burning oil, with a total heating surface of 21,500 square feet. The total weight of the machinery is estimated at 397 tons. About 300 tons of oil are carried, which gives the class a very extended radius of action. There are two electrical generating sets, each of 25 kilowatts and 125 volts. The armament comprises four 4in. 50-calibre Q.F., two 1-pdr. automatic anti-aircraft guns, and twelve torpedo tubes. In appearance the Sampson differs but little from the "Cushing" and "Aylwin" class. She has the usual high forecastle, recessed to give end-on fire to the 4in. guns on the deck below. There are four thin funnels in pairs, and two lofty masts. Owing to the numerous guns and tubes there is little free space on deck, and in anything like a seaway it must be very difficult to move about. One 4in. gun is mounted on the forecastle, with a high angle 1-pdr. a few feet behind it. The chart-house is surmounted by an open navigating bridge, above which rises a searchlight platform. A second projector is carried on a skeleton platform abaft the main mast. The triple tubes are disposed two on each beam, *en echelon*, allowing a discharge of six torpedoes on either broadside. These mountings, which must be of considerable weight, take up a lot of room, and certainly look very cumbersome, but they have been retained in all the latest destroyers. A 4in. gun is mounted on each side at the break of the forecastle. The fourth gun of this calibre, and a second 1-pdr. anti-aircraft weapon, are placed at the stern. Circumstances did not permit of more than a cursory inspection of this interesting vessel, but one could not escape the impression that rather too much had been attempted on the displacement in the direction of armament. The accumulation of so much top weight can hardly tend to improve the sea-going qualities, while it would seem that the crowded condition of the deck must inevitably hamper the effective handling of the armament in action. Germany's practice has always been to give her destroyers a powerful torpedo armament at the expense of gun power, while in this country an opposite policy has been followed. American constructors, on the other hand, have sought to combine torpedo and gun power in the highest degree, with results not altogether fortunate. Like most over-armed vessels of war, the actual fighting power of the Sampson and her sister craft is probably less than their details would imply. It should be added that measures are now in contemplation to reduce the entire flotilla of sea-going destroyers to an oil-burning basis. This will be done by dropping from the Navy Register the Smith, Reid, Lamson, Flusser, and Preston, all of which, it is reported, may be sold to a South American Republic. At first it was intended to convert these five vessels into oil-burners, but the work involved was considered too costly to be worth while. They are all of 700 tons, and have a designed speed of 28 knots, and were launched in 1909.

Of the new coastal submarines, twenty-seven in number, for which contracts were placed a few weeks ago, very little is known. The displacement varies from 475 to 550 tons, according to design, and they are not expected to differ essentially from the more recent numbers of the "L" class. There was some opposition in naval circles to this heavy appropriation for a class of vessel which many critics consider to be of indifferent value, but the Navy Department was influenced in its decision by reports from Europe which spoke highly of the war services rendered by many of the comparatively small submarines attached to the belligerent fleets. The new American coastal boats are mainly intended as substitutes for the shore batteries, which are now considered more or less obsolete, and incapable of keeping a hostile fleet at a respectful distance from the great commercial and naval ports. Altogether 58 are to be constructed in the next three years. Nine boats of a much larger type, known as "fleet submarines," have also been authorised, contracts for the first two having been placed with the Electric Boat Company and the Lake Torpedo Boat Co. respectively. They will displace about 850 tons, and a surface speed of 20 knots is expected. So far as is known, the largest submarine under construction for the United States Navy is the Schley, of 1300 tons. Originally she was intended to travel at 25 knots on the surface, but as no bids were received on this basis it was found necessary to reduce the required speed to 20 knots. She is not due for completion before the spring of 1918. As very full details of this boat have already been published, it would be superfluous to repeat them here. At present the United States submarine flotilla numbers 75 units, completed or building, to which must be added the 27 coastal and two "fleet" boats shortly to be laid down. In spite of these imposing numbers, however, the writer found a marked lack of enthusiasm in naval circles for the submarine. For a number of reasons, into which space forbids us to enter, misfortune has dogged this branch of the American Navy from its inception. Serious disasters have been rare, but a long succession of minor accidents and breakdowns appear to have undermined the American naval officer's confidence in the practical value of the submersible boat. The writer was told last December on high American authority that there were scarcely a dozen boats of all those in service which were capable of immediate and effective action under the conditions of war. Whether this was a true statement of the case he does not venture to say, but the frequent exposures of submarine defects published by the American newspapers suggest that there is an undoubted basis for the pessimism that prevails in the service itself.

In his annual report for the year just closed, Mr. Josephus Daniels, the Secretary of the Navy, gives the following estimate of the strength of the fleet in 1921: Dreadnought battleships of the first line, 27; battle-cruisers, 6; battleships of the second line, 25*; scout cruisers, 13; destroyers, 108; fleet submarines, 12; coastal submarines, 130. The report adds that, while there is no possibility of predicting what rank among the Naval Powers the country will then take, the authorisation of such a programme has been accepted as an assurance that the United States has definitely embarked on a policy of building an adequate navy. The great expenditure involved by this new policy is shown by the following analysis of the building programme for 1918, for which Congress has been asked to make the necessary appropriations.

| | |
|---|---|
| Construction and machinery (three battleships, one battle-cruiser, three scout cruisers, fifteen destroyers, one submarine tender, and one destroyer tender).. .. .. .. .. | £10,220,000 |
| Hulls and outfits of four fleet submarines and fourteen coast submarines .. .. .. .. | 3,160,000 |
| Armour and armament of above vessels | 4,330,000 |
| Ammunition for above vessels.. .. | 1,682,440 |
| Total .. | £19,392,440 |

For the continuation of work on vessels already authorised, several of which are under construction, and others are about to be laid down, the following appropriations are asked:

| | |
|---|---|
| Construction and machinery .. .. | £14,727,980 |
| Submarines .. .. .. .. | 3,363,222 |
| Armour and armament .. .. | 5,000,000 |
| Ammunition .. .. .. .. | 698,028 |
| Total .. | £23,789,230 |

In addition to these two sums, aggregating £43,181,670, for new construction and for vessels already in hand, there are other items to the amount of £32,648,670, bringing the Naval Budget for 1918 to a grand total of £75,830,340. This represents an increase of £13,290,230 over the naval expenditure for the current year. Impressive as these figures are, especially when contrasted with the comparatively modest sums devoted to the navy in former years, Mr. Daniels warns the country that it cannot afford to rest on its oars. Complacent retrospection is the father of dry-rot. "We have made a magnificent beginning, but it must not be forgotten by the public that the same intelligent appreciation of our needs, the same willingness to provide for those needs, must be shown this year and every succeeding year, if we are to finish what we have commenced." He concludes his report by expressing a hope that the time is not far distant when armaments will be limited by international agreement, and that the nations of the earth will have the statesmanship to devise means of preserving peace without constantly building larger vessels of war at ever-increasing cost. "Until that hour arrives the United States cannot safely adopt any policy other than that of steadily increasing its naval strength."

## PYRMONT ELECTRIC SWING BRIDGE.

No. I.

THE Pyrmont Bridge which crosses Darling Harbour, an arm of Port Jackson extending into the heart of the city of Sydney, New South Wales, and various views of which are given herewith and on pages 77 and 84, was opened for regular traffic on June 28th, 1902. At that time this bridge was said to be provided with the fastest and most up-to-date swing span in the world, the ends of the span attaining a maximum speed of over four miles per hour, whilst all the operations, including the working of the roadway gates, were performed electrically. When, however, in 1907 a paper on this bridge was read before the Institution of Civil Engineers, a doubt was expressed in the ensuing discussion as to the reliability of electrical operation, it being pointed out how serious a stoppage of traffic would be, and that bridges in such important positions should always be ready to work, many hydraulic swing bridges being cited as fully meeting the required conditions.

In view of this, and of the fact that the Pyrmont swing span, which weighs when swinging 800 tons, having been in constant operation for over fourteen years without a single hitch, some particulars of the bridge, with details of the power costs of operating the swing span, and other data, are of interest.

In the thirteen years ended June 30th, 1915, the swing span was opened 86,471 times for the passage of 142,994 vessels, which involved 711,768 individual movements of the four roadway gates on the side spans in a busy traffic. This traffic totals in the twenty-four hours of an ordinary day 8928 rolling stock; 11,918 pedestrians, and 10,300 live stock. With current obtained from the Railway Commissioners Power House at Ultimo, at 1d. per unit, the total cost of power for operating the swing span for the thirteen years was £247 7s. 8d., which sum covered the opening and closing of the swing span 86,471 times, the opening and closing of the four gates and the lowering and raising of the ends of the span. Table No. 1., which gives the details of expenditure, also shows that the cost of performing one complete cycle of operations was reduced from 1.12d. in the first year's working to 0.64d. in the last year's record. This was due to the smoother working of the machinery, and to the operators becoming more experienced in the time of cutting off of current, and the allowance to be made for "coasting." The table also gives the cost of lighting the bridge for eleven years.

All the controllers, switches, ammeters, &c., are labelled and numbered to agree with a set of printed regulations which are framed and placed in the controlling house. In order to ensure uniform working and direct responsibility in case of an accident, each operator is provided with a copy of these regulations, for which a receipt is taken.

Ordinarily speaking the bridge is worked electrically, and we believe there has not been a single exception during the whole of the period that it has been in service, though there is provision for working it by hand should the electrical current fail for any reason. The regulations just alluded to are most detailed, and too long to reproduce in detail. It may be said, however, that first of all, before opening the span by electricity, there are certain preliminaries to be gone through. These include the switching on of lights on the platform, and the making sure that the danger lights on the gates closing the approaches are alight, if the operation is being performed by night; the seeing that all switches, &c., are in their proper positions, and the warning by whistle of the policemen or other watchmen at either end of the bridge that the span is about to be opened. Then one half of one of the gates on one approach is closed. These gates are electrically worked, and are controlled from the machinery cabin which is in the centre of the moving span. Shortly afterwards the other half of the gate is closed, and when the swing span is clear of vehicular traffic the two gates on the other approach are nearly closed, leaving a few feet open for the passage of foot passengers. When these, too, have passed through the gates are fully closed. The next operation is the lowering of the ends of the swing span so as to free it, and finally current is turned on to the motor which slews the span itself. There is a dial in the control cabin, and the instructions are that current shall be cut off when this dial indicates from 55 to 60 deg., when, under ordinary conditions, the span will "coast" or continue to revolve until its final position, as indicated by 83 deg. on the dial, is reached. When in this position the span is exactly over the centre line of the protection platform, and will give the maximum space for vessels to pass. Instructions are given as to how to bring the span to rest, and how to bring it back to its proper position should it have overrun the stipulated 83 deg. Stress is naturally laid on the fact that, under no circumstances, are the motors to be reversed whilst the span is in motion. For closing the span similar instructions are given, but in the reverse order.

The following are the normal working currents of the various motors, with from 550 to 600 volts:

*Slewing Motor.*—Current required for starting 60 to 70 ampères, gradually dropping down to 25 ampères.

*End Lift Motor.*—Current required at starting to lower ends 70 ampères, dropping to 20 ampères. Current required at starting to raise ends 30 ampères,

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* This total includes the Michigan and South Carolina, which, although "Dreadnoughts," have been reduced to the second line owing to their inferior speed.

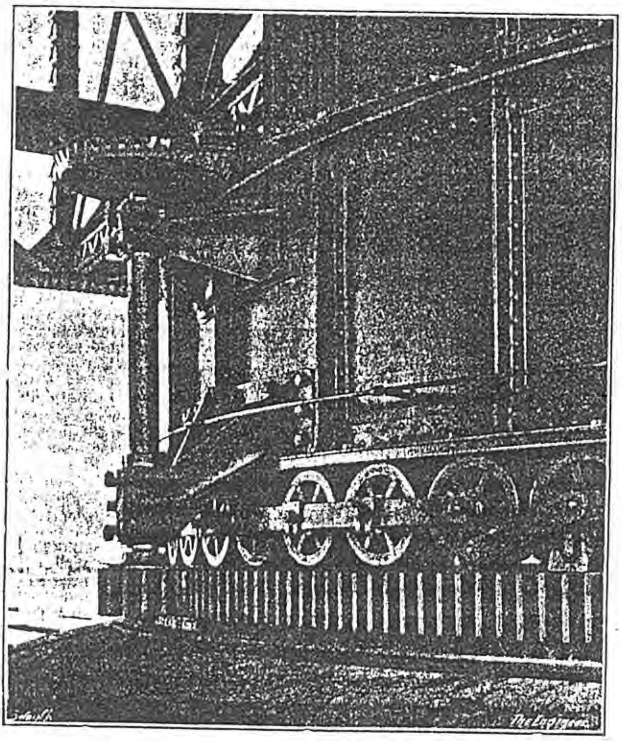

Fig. 1—SLEWING GEAR

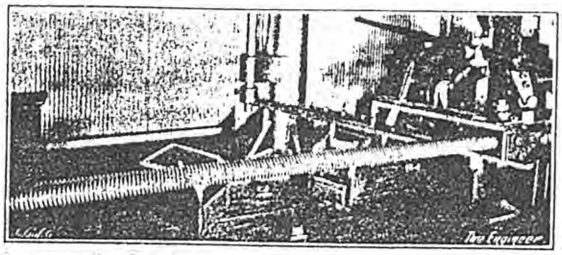

Fig. 2—GATE OPERATING GEAR

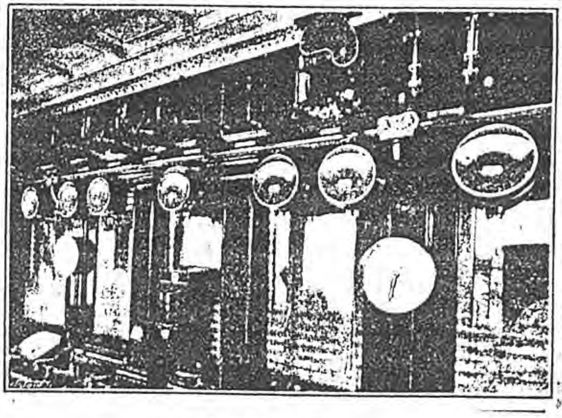

Fig. 3—SWITCHBOARD

dropping to 20 ampères, and then rising to 50 ampères.

*Gate Motors.*—Current required for starting on 1st step 7 ampères; current required for starting on 2nd step, 10 ampères; current required when running on first step, 4½ to 5 ampères.

The average ampèrage used for the lights is 28 at 550 volts. The arc lights should take from 5 to 6 ampères each; the cabin lights ½ an ampère; the machinery room lights, ½ an ampère; and the shipping lights, ½ an ampère. The attendants are enjoined to make themselves familiar with the average current taken by every motor, and in every circuit, and to notify any change from the normal which may be observed.

The hand operation of the span is brought about by means of capstans, and the instructions include the working of these and the disengagement of the mechanisms worked by the electric motors. The operations for each twenty-four hours are booked up by the respective operators of each shift. The bookings for one day given in Table II. show the time the road traffic was delayed at each opening. This is a useful record in meeting complaints of delay, which, however, have been remarkably few during the long period the swing span has been in work.

TABLE I.—*Summary of Current Consumption—Pyrmont Bridge.*

For a period of thirteen years dated from July 1st, 1902, to July 1st, 1915.

| Dates. | Operating swing span. | | | | | Lighting Bridge. | | | | | | | | Totals for operating and lighting. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of openings | Number of vessels. | B.T.U. consumption. | Cost. | Average. | Arc lamp hours. | B.T.U. consumption. | Cost. | Average. | Incandescent lamp hours. | B.T.U. consumption. | Cost. | Average. | B.T.U. consumption. | Cost |
| | | | | £ s. d. | | | | £ s. d. | | | | £ s. d. | | | £ s. d. |
| July 1st, 1902, to July 1st, 1903 ... ... ... ... ... | 6,152 | 11,690 | 6,855 | 28 11 3 | 1·12 | 76,916 | 44,685 | 186 3 9 | ·57 | 24,069 | 1,622 | 6 15 2 | ·07 | 53,162 | 221 10 2 |
| July 1st, 1903, to July 1st, 1904 ... ... ... ... ... | 6,222 | 10,467 | 4,692 | 19 11 0 | ·74 | 62,795 | 35,537 | 148 1 5 | ·57 | 22,235 | 1,781 | 7 8 5 | ·07 | 42,015 | 175 0 10 |
| July 1st, 1904, to July 1st, 1905 ... ... ... ... ... | 6,432 | 11,053 | 4,509 | 18 15 9 | ·71 | 61,415 | 34,914 | 145 9 6 | ·57 | 22,805 | 1,822 | 7 11 10 | ·07 | 41,245 | 171 17 1 |
| July 1st, 1905, to July 1st, 1906 ... ... ... ... ... | 6,304 | 8,996 | 3,941 | 16 8 5 | ·68 | 66,070 | 36,370 | 151 10 10 | ·55 | 33,220 | 2,222 | 9 5 2 | ·07 | 42,533 | 177 4 5 |
| July 1st, 1906, to July 1st, 1907 ... ... ... ... ... | 6,598 | 10,538 | 4,310 | 17 19 2 | ·66 | 67,147 | 36,493 | 152 1 1 | ·55 | 32,523 | 2,174 | 9 1 2 | ·07 | 42,977 | 179 1 5 |
| July 1st, 1907, to July 1st, 1908 ... ... ... ... ... | 7,610 | 12,721 | 5,043 | 21 0 3 | ·67 | 68,500 | 35,910 | 149 12 6 | ·53 | 33,348 | 2,220 | 9 5 0 | ·07 | 43,173 | 179 17 9 |
| July 1st, 1908, to July 1st, 1909 ... ... ... ... ... | 7,518 | 12,457 | 4,902 | 20 8 6 | ·65 | 71,515 | 34,912 | 145 9 4 | ·48 | 31,800 | 2,122 | 8 16 10 | ·07 | 41,936 | 171 14 8 |
| July 1st, 1909, to July 1st, 1910 ... ... ... ... ... | 6,579 | 10,305 | 4,358 | 18 3 2 | ·66 | 76,705 | 36,792 | 153 6 0 | ·47 | 30,936 | 2,061 | 8 11 9 | ·07 | 43,211 | 180 0 11 |
| July 1st, 1910, to July 1st, 1911 ... ... ... ... ... | 7,461 | 12,072 | 4,866 | 20 5 6 | ·63 | 76,770 | 38,649 | 161 0 9 | ·50 | 32,268 | 2,150 | 8 19 2 | ·07 | 45,665 | 190 5 5 |
| July 1st, 1911, to July 1st, 1912 ... ... ... ... ... | 7,610 | 12,247 | 4,462 | 18 11 10 | ·58 | 78,525 | 36,693 | 152 17 9 | ·46 | 33,270 | 2,221 | 9 5 1 | ·07 | 43,376 | 180 11 8 |
| July 1st, 1912, to July 1st, 1913 ... ... ... ... ... | 6,926 | 11,776 | 4,118 | 17 3 2 | ·59 | 78,360 | 37,536 | 156 12 2 | ·47 | 32,712 | 2,180 | 9 1 8 | ·07 | 43,834 | 182 17 0 |
| July 1st, 1913, to July 1st, 1914 ... ... ... ... ... | 6,200 | 9,586 | 3,849 | 16 0 9 | ·62 | 78,395 | 39,614 | 165 1 2 | ·50 | 31,580 | 2,140 | 8 15 4 | ·07 | 45,567 | 189 17 3 |
| July 1st, 1914, to July 1st, 1915 ... ... ... ... ... | 5,359 | 8,536 | 3,467 | 14 8 11 | ·64 | 78,285 | 40,294 | 167 17 10 | ·51 | 31,662 | 2,109 | 8 15 9 | ·07 | 45,870 | 191 2 6 |
| Grand total ... ... ... ... ... | 87,471 | 142,994 | 59,372 | 247 7 8 | ·69 | 941,397 | 488,399 | 2035 4 1 | ·49 | 392,438 | 26,824 | 111 12 4 | ·07 | 574,611 | 2391 4 1 |

*Controlling Apparatus.*—The whole of the operations for working the swing span, which involves the opening and closing of the gates, the drawing and lowering of the latches—by hand—the raising and lowering of the end lifts and the slewing of the swing span are performed by one man from a controlling house over the southern footpath of the central swing span. A view of this house is given in Fig. 11, page 84.

The controllers for the slewing motor are of the standard "G.E.K. 11" series parallel type, whilst the controller for the end lift, and the four controllers for the gate motors, are of the usual rheostatic type, a separate reversing barrel being provided in the gate controllers, on each of which is placed the additional contacts for interlocking the circuit breaker with the position of the gate, which prevents the motor being driven in a wrong direction, irrespective of the gate being opened or closed. The switchboard, which is clearly seen in Fig. 3, carries a main switch, a switch with circuit breaker for the slewing circuit, a switch with circuit breaker for the end lift circuit, and a switch for the four gate motor circuits, with a circuit breaker for each gate circuit. Each gate circuit breaker is provided with an auxiliary tripping coil connected with the contacts at the gate, so that once a gate is started no further attention is needed, the contact, when the gate is in position, causing the circuit breaker to trip. It is then impossible to move the gate or close the circuit breaker unless the controller be reversed. Western ammeters are arranged above each controller, and a 600 Western voltmeter is fixed at the centre of the switchboard.

*Slewing Machinery.*—The two 50 horse-power series wound motors—see Fig. 4, page 77—for slewing are of the standard G.E. 57 type, and are fixed to the machinery platform and drive through cut steel gearing, a main horizontal shaft carrying at each end a bevel pinion meshing with bevel gears keyed to the tops of the two vertical shafts on the outside of the drum. The vertical shafts—see Fig. 1—carry pinions on their lower ends, which mesh with a rack fixed to the cast iron track running right round the pivot pier. The gear reduction is 1223 revolutions of the armature to one complete revolution of the swing span.

*Latches and Catches.*—To stop the span in its correct position without jarring, a latch and catch is provided for each rest pier. The latch—see Fig. 5, page 77—carrying on its end a small wheel is free to move vertically upwards in brackets secured to the swing span, and is adjusted by a counterweight so as to drop into the catch—see Fig. 6, page 77—with the required velocity. The catch is pivoted, and secured at its lower end to a girder on the rest pier, whilst near the upper end of the catch are placed two heavy coil springs. In closing the span the latch wheel rolls up the inclined plane on the catch and drops into the recess, the momentum of the span bringing into play the coil springs, which either bring the ends of the span back to correct position or move sufficiently to allow the latches to release themselves, when by reversing the controller the latches are again brought into engagement.

*End Lift Machinery.*—The 35 horse-power series wound motor for working the end lifts is of the standard G.E. 1000 type, and is arranged at the centre of the span. The motor drives through a cut pinion and spur wheel, a longitudinal shaft running the whole length of the span—see Figs. 7, 8 and 9, page 77. This longitudinal shaft actuates at each end of the span, by means of right and left-handed worm gear, two transverse shafts, each provided with four cams having 1⅝in. throw, which raise or lower the ends of the spans 1¼in., and leave the foot blocks 1⅜in. clear of the pedestals on the rest pier. The gear reduction is 117 revolutions of the armature shaft to one complete revolution of the cam shaft.

*Gate Machinery.*—The hinges of each footpath gate are keyed to the spindle of the roadway gate, the spindle being extended to the machinery platform underneath the deck of the said span. For each gate

## THE PYRMONT SWING BRIDGE, SYDNEY, NEW SOUTH WALES

*(For description see page 75)*

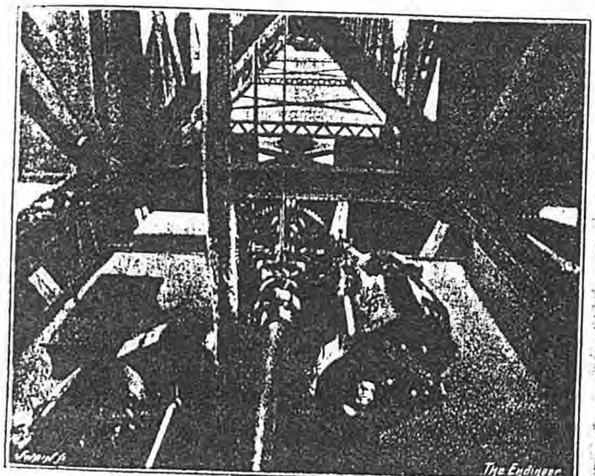

Fig. 4—SLEWING MOTORS

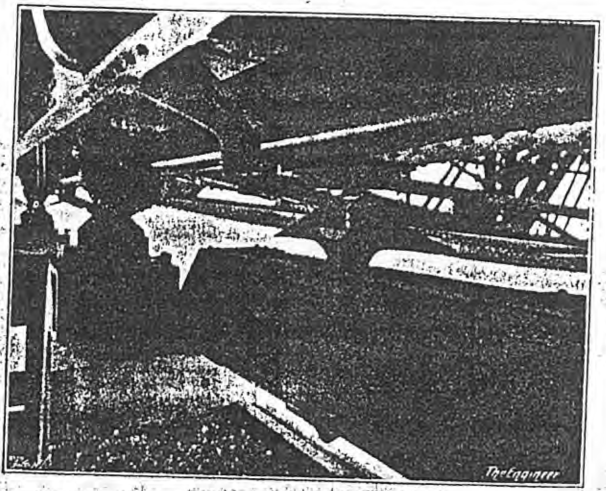

Fig. 5—LATCH—OPEN

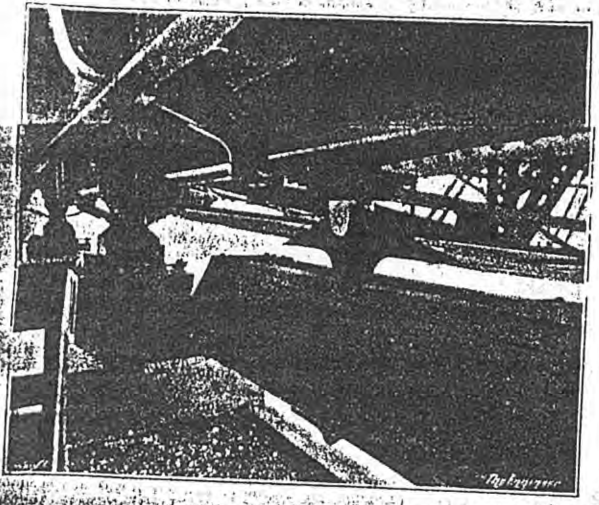

Fig. 6—LATCH—CLOSED

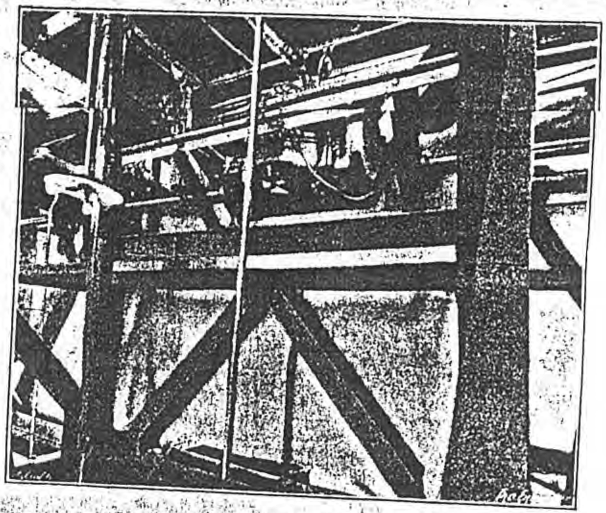

Fig. 7—END LIFT MOTOR

Fig. 8—FOOT BLOCK RESTING

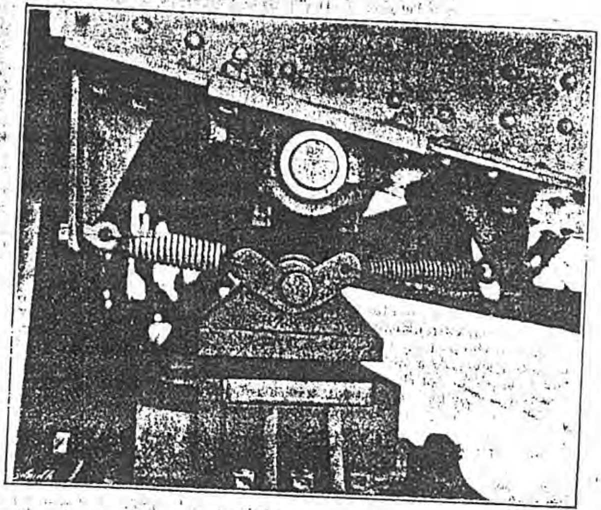

Fig. 9—FOOT BLOCK RAISED

a 5 horse-power series wound motor of G.E. type drives through a bevel pinion and gear a longitudinal threaded shaft carrying a gun-metal travelling nut, having projecting pins at top and bottom. The motor, gearing, screwed shaft, travelling nut, levers, and electrical contacts for operating the gears are shown in Fig. 2. These pins pass through and work in long slotted holes in two wrought iron bars, the lower one being extended and keyed to the gate spindle, thus forming the lever for moving the gates. Attached to the underside of the lever is a copper loop which, in the opened and closed position of the gates, engages with, and short-circuits, two adjustable brass springs, thereby energising the auxiliary tripping coil on the circuit breaker, and cutting off the current from the motor. A solenoid brake being provided, the cutting off of the current causes a weighted lever to drop and stop the motor. A dashpot is attached to the weighted lever to avoid too sudden stoppage of the motor, and allow of the strap brake to engage the brake wheel gradually. This is achieved by allowing the air to escape from the dashpot through a small valve. A view of the bridge on the resumption of traffic, after it has been opened, is shown in Fig. 12, page 88.

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LAST month the 720ft. span of the Paducah and Illinois Railway bridge over the river Ohio was successfully erected. This is claimed to be the longest simple truss in the world.

TABLE II.—*Pyrmont Bridge Swing Span—Record taken on Monday, the 9th day of December, 1913.*

| Name of operator and hours of duty. | Openings. | | | | Time. | | |
|---|---|---|---|---|---|---|---|
| | Name of Tug. | Name of Vessel. | Description. | Direction. | Closing First Gate. | Opening First Gate. | Elapsed Time. |
| C. W. Pitt 12.1 a.m.–7 a.m. | | Erina ... ... ... | Steamer | South | 6.45 a.m. | 6.50 a.m. | 5 |
| | | Kiltobranks ... | ,, | North | 7.4 ,, | 7.12 ,, | 8 |
| J. Hugill 7 a.m.–3 p.m. | Magic ... ... | and hulk ... ... | | N | 7.4 ,, | 7.12 ,, | 8 |
| | | Seagull II. ... | ,, | N | 7.21 ,, | 7.27 ,, | 6 |
| | | Eden ... ... ... | ,, | S | 7.36 ,, | 7.42 ,, | 6 |
| | | Erina ... ... ... | ,, | N | 7.36 ,, | 7.42 ,, | 6 |
| | Nelson ... ... | and punt ... ... | | S | 7.56 ,, | 8.2 ,, | 6 |
| | | Foonbar ... ... | ,, | S | 7.56 ,, | 8.2 ,, | 6 |
| | Magic ... ... | and hulk ... ... | | S | 9.38 ,, | 9.43 ,, | 5 |
| | | Hastings ... ... | ,, | S | 10.5 ,, | 10.11 ,, | 6 |
| | | Macquarie ... ... | ,, | N | 10.5 ,, | 10.11 ,, | 6 |
| | | Beagle ... ... ... | ,, | N | 10.21 ,, | 10.27 ,, | 6 |
| | | Hastings ... ... | ,, | N | 10.57 ,, | 11.2 ,, | 5 |
| | Esther ... ... | and lighter ... ... | | S | 11.25 ,, | 11.31 ,, | 6 |
| | | Augusta ... ... | Steam lighter | N | 11.25 ,, | 11.31 ,, | 6 |
| | Nelson ... ... | and punt ... ... | | N | 11.48 ,, | 11.53 ,, | 5 |
| | | Eden ... ... | Steamer | N | 12.37 p.m. | 12.44 p.m. | 7 |
| | | Helen Nicoll ... | ,, | N | 12.37 ,, | 12.44 ,, | 7 |
| | | Yugilbar ... ... | ,, | S | 12.37 ,, | 12.41 ,, | 7 |
| | | Hastings ... ... | ,, | S | 1.19 ,, | 1.25 ,, | 6 |
| | | Stormbird ... | ,, | N | 1.36 ,, | 1.41 ,, | 5 |
| | | Wee Clyde ... | ,, | N | 2.22 ,, | 2.28 ,, | 6 |
| | | Corra Lynn ... | ,, | N | 2.22 ,, | 2.28 ,, | 6 |
| W. Kelly 3 p.m.–11 p.m. | | Tuncurry ... | ,, | S | 3.20 ,, | 3.30 ,, | 10 |
| | | Macquarie ... | ,, | S | 3.20 ,, | 3.30 ,, | 10 |
| | | Jap ... ... ... | ,, | S | 3.20 ,, | 3.30 ,, | 10 |
| | Marion ... ... | and lighter ... | | S | 3.20 ,, | 3.30 ,, | 10 |
| | | Fitzroy ... ... | ,, | N | 4.5 ,, | 4.11 ,, | 6 |
| | | Jap ... ... ... | ,, | N | 4.5 ,, | 4.11 ,, | 6 |
| | | Hastings ... ... | ,, | N | 4.5 ,, | 4.11 ,, | 6 |
| | Bill Reid ... ... | Curlew ... ... | Lighter | S | 4.5 ,, | 4.11 ,, | 6 |
| | | Corra Lynn ... | Steamer | S | 4.23 ,, | 4.29 ,, | 6 |
| | Delilah ... | and punt... ... | | N | 4.45 ,, | 4.51 ,, | 6 |
| | | Wee Clyde ... | ,, | S | 5.3 ,, | 5.9 ,, | 6 |
| | | Tuncurry ... | ,, | N | 5.3 ,, | 5.9 ,, | 6 |
| | | Illaroo ... ... | ,, | N | 6.20 ,, | 6.26 ,, | 6 |
| | | Sphene ... ... | ,, | S | 6.20 ,, | 6.26 ,, | 6 |
| | | Corra Lynn ... | ,, | N | 6.30 ,, | 6.36 ,, | 6 |
| | | Kallawatta ... | ,, | S | 9.5 ,, | 9.10 ,, | 5 |
| C. W. Pitt 11 p.m.–12 p.m. | | Erringhi ... ... | ,, | S | 9.30 ,, | 9.35 ,, | 5 |
| | | Lubra ... ... ... | ,, | S | 10.20 ,, | 10.26 ,, | 6 |

*Lighting.*

| Circuits. | Cut in. | Cut out. | Time alight. |
|---|---|---|---|
| | | | H. M. |
| Pyrmont ... ... ... ... ... | 12 a.m. | 1 a.m. | 8 30 |
| | 7.30 p.m. | 12 p.m. | |
| | 12 a.m. | 1 a.m. | |
| North Sydney ... ... ... ... | 7.30 p.m. | 12 p.m. | 8 30 |
| | 12 a.m. | 1 a.m. | |
| South Sydney ... ... ... ... | 7.30 p.m. | 12 p.m. | 8 30 |
| | 12 a.m. | 1 a.m. | |
| Span ... ... ... ... ... | 7.30 p.m. | 12 p.m. | 4 30 |
| Platform ... ... ... ... ... | — | — | 0 15 |
| | 12 a.m. | 1 a.m. | |
| House... ... ... ... ... ... | 7.30 p.m. | 12 p.m. | 8 20 |
| Machinery Room ... ... ... | 10.30 p.m. | 11.30 p.m. | 1 0 |
| Shipping ... ... ... ... | — | — | 0 10 |
| Heater ... ... ... ... | — | — | — |

*Meter Record.*

| Time of reading. | Meter Reading | Value in B.T.U.'s. |
|---|---|---|
| 12.1 a.m. ... ... ... ... ... ... | 7620·5 | 747,562·50 |
| Last lamp cut out ... ... ... ... ... | 7627.5 | 747,590.00 |
| First lamp cut in ... ... ... ... ... | 7628·0 | 747,603·75 |
| 12 p.m. ... ... ... ... ... ... | 7630·1 | 747,661·50 |

SUMMARIES.

*Openings.*

| | Number of Openings. | B.T.U.'s Consumed. |
|---|---|---|
| Brought forward ... ... ... ... ... | 112 | 58·22 |
| For day ... ... ... ... ... ... | 25 | 15·5 |
| Total ... ... ... ... ... ... ... | 137 | 73·72 |

*Arc Lamps.*

| | Number of Hours. | B.T.U.'s Consumed. |
|---|---|---|
| Brought forward ... ... ... ... ... | 239·20 | 698·18 |
| For day ... ... ... ... ... ... | 30·15 | 79·6 |
| Total ... ... ... ... ... ... ... | 269·35 | 777·78 |

*Incandescent Lamps.*

| | Number of Hours. | B.T.U.'s Consumed. |
|---|---|---|
| Brought forward ... ... ... ... | 61·50 | 24·6 |
| For day ... ... ... ... ... | 9·40 | 3·9 |
| Total ... ... ... ... ... ... | 71·30 | 28·5 |

*Total B.T.U. Consumption for Operating and Lighting.*

| | |
|---|---|
| Brought forward ... ... ... ... ... | 781 |
| For day ... ... ... ... ... ... | 99 |
| Total ... ... ... ... ... ... | 880 |

## INSTITUTION OF MECHANICAL ENGINEERS.

AT the meeting of the Institution of Mechanical Engineers, on Friday, January 19th, a paper on "The Manufacture of Gauges at the L.C.C. Paddington Technical Institute," by Messrs. A. G. Cooke, W. J. Gow, and W. G. Tunnicliffe, was read.

Mr. Cooke, who introduced the paper, said it had suffered a little owing to the necessary reticence concerning the constructive work that is being carried out at the Paddington and other technical institutes in London. For reasons that would be well understood he was unable to show any of that work, or to explain the organisation upon which it was based. The reasons for this would be well understood, although he had been able to mention the organisation of the London County Council and its various departments which had controlled this work, and the value of the work done by friendly rivals, such as the Northampton Institute and the Goldsmiths' Institute. Mention might also be made of the more important authority which had largely directed much of the work, viz., the National Physical Laboratory, and, as some members of that staff were present, they would no doubt be able to add to the information given in the paper. The real reason why he was reading the paper was to endeavour to obtain a real recognition of technical education, which he was representing. The work described had been done entirely by a staff of workers drawn from teachers of handicrafts in the elementary schools. Eighty per cent had made woodwork their qualification and had learned metal work in the institute, being assisted by pupils. Similarly, the machinery, with one or two exceptions, had been worked by the students during some ten or twelve years of day and evening classes, and it was, of course, not equivalent to precision lathes. Yet the work had been highly satisfactory. He then gave a *résumé* of the paper which we reprint in full on page 95.

The discussion was opened by Mr. E. M. Eden, of the National Physical Laboratory, who showed a large number of slides of machines that are used at the laboratory for gauge-making purposes. The method adopted at Paddington, of altering the change wheels in the lathes to correct a very small error in the pitch of the lead screw, he did not think anyone else was using. With regard to the work of the National Physical Laboratory, the policy of the gauge measuring staff in measuring these large quantities of gauges was to put those that were right on one side, and those that were wrong on the other. When, however, it became necessary to inform the makers of the extent of the error, the large amount of work involved quickly led to the introduction of very rapid methods of measuring, many of which were of value to the manufacturers themselves as well as to the Laboratory. In addition to pointing out the extent of the errors in gauges to the manufacturers, it was the custom to welcome manufacturers to the Laboratory to have things explained, and in this way the Laboratory had been of particular use to manufacturers in the early days in assisting them to get their lead screws correct, the general method being that the manufacturer made a trial screw on his lathe and sent it up. A report was written on its accuracy, and methods suggested for improving it. The two curves—Figs. 2 and 3, page 96—were examples of what had been done in that way, these curves being taken from the National Physical Laboratory's report of November, 1915, on a screw from Paddington, which had the errors shown in the first diagram, whilst the second diagram was taken from a report of April 4th, the great improvement between the two being noteworthy, and being obtained by methods of altering the ball thrust bearing which the Laboratory recommended. Fig. 4 of the paper illustrated an arrangement introduced in the autumn of 1915 for measuring the core and effective diameter of screws. The ordinary method previously employed for measuring core diameter was by means of three little vees, but in practice it was found difficult to manipulate.

Mr. Eden then showed a number of slides of various measuring machines. In several of them the micrometer was shown fixed, and provided with an indicator to enable more accurate measurements to be made, on the lines of Fig. 4 in the paper. In one such instrument a little mirror is caused to tip by the action of a plunger, and the spot of light from a pocket lamp sends its image on to the screen with a magnification of 1000 to 1. Since the introduction of this machine, however, it had been found, said Mr. Eden, that observers were so expert in the sense of touch with an ordinary micrometer that it was not thought worth while to use it.

Coming to the question of the projection of screw prints by optical means, Mr. Eden said the projection method was introduced at the laboratory about a year ago, and had been used ever since. Many people considered it difficult, if not impossible, to project the image of a screw on to a screen with any accuracy, on account of the distortion, but that was not the case. The image of the screw was not projected on to a screen but on to a previously drawn diagram. It was then adjusted to the diagram and the errors observed. To do that, however, the magnification of the whole arrangement had to be fixed at some definite ratio, and a standard magnification of 50 meant that one thousandth of an inch was $\frac{1}{20}$in., and the loss could be measured to half a thousandth or less. In starting on this projection problem there were many difficulties, because it was not known what sort of lenses were required, there being no lens designed specially for the purpose. Fortunately, the distortion problem was not very great, but he had not been able to do any good with cheap lenses. A lens like the Dallmeyer, however, $\frac{1}{2}$in. diameter, would give with a parallel beam a picture on the wall about 2ft. 1in. diameter. That, in general, would show distortion, but if it were a good lens there was a central portion which was free from distortion, and, by taking a small enough area, the distortion could be got rid of.

At this point the President asked Mr. Eden to complete his remarks in writing.

Mr. W. H. Booth commented on the manner in which men, who had nothing to do with gauge making, had risen to the occasion during the past two years. The technical institutions had done exceedingly well in this connection. No one could make a gauge accurately unless he had an accurate lead screw, and at the National Physical Laboratory there was a large lead screw made specially for the purpose. Every manufacturer should have an accurate lead screw, and he would like to hear in the near future that the National Physical Laboratory could undertake to provide such screws for manufacturers. The cost need not be very great, and the manufacturer, by selling with a Kew certificate, would soon

# THE PYRMONT SWING BRIDGE, SYDNEY, NEW SOUTH WALES

(*For description see page 75*)

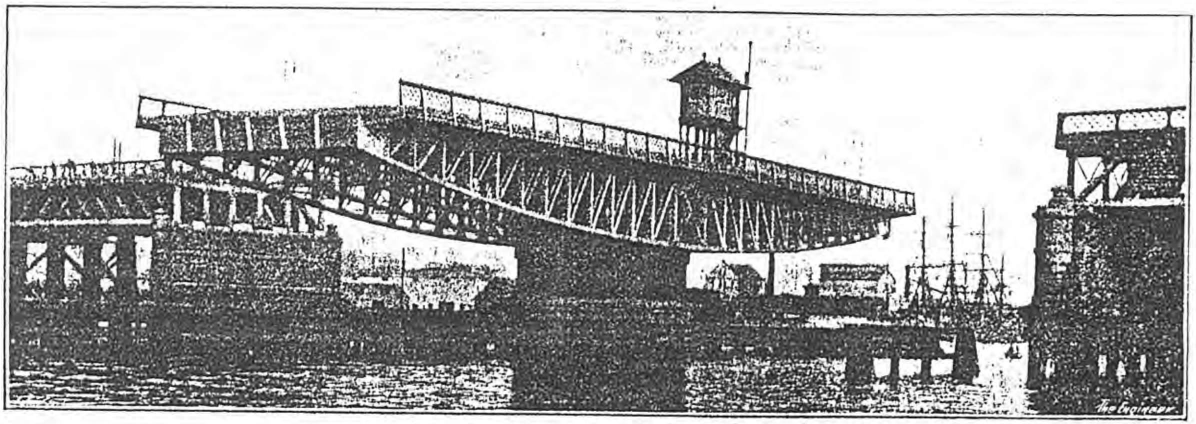

Fig. 10—THE SPAN OPEN

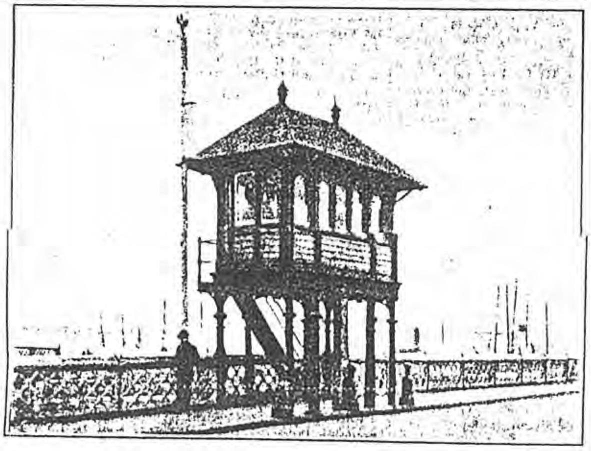

Fig. 11—OPERATING CABIN

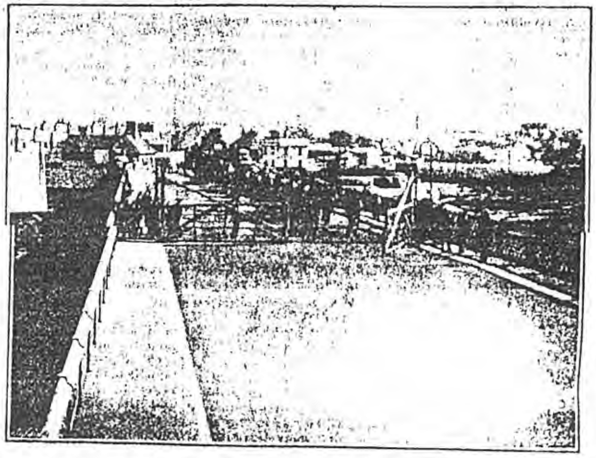

Fig. 12—THE ROADWAY

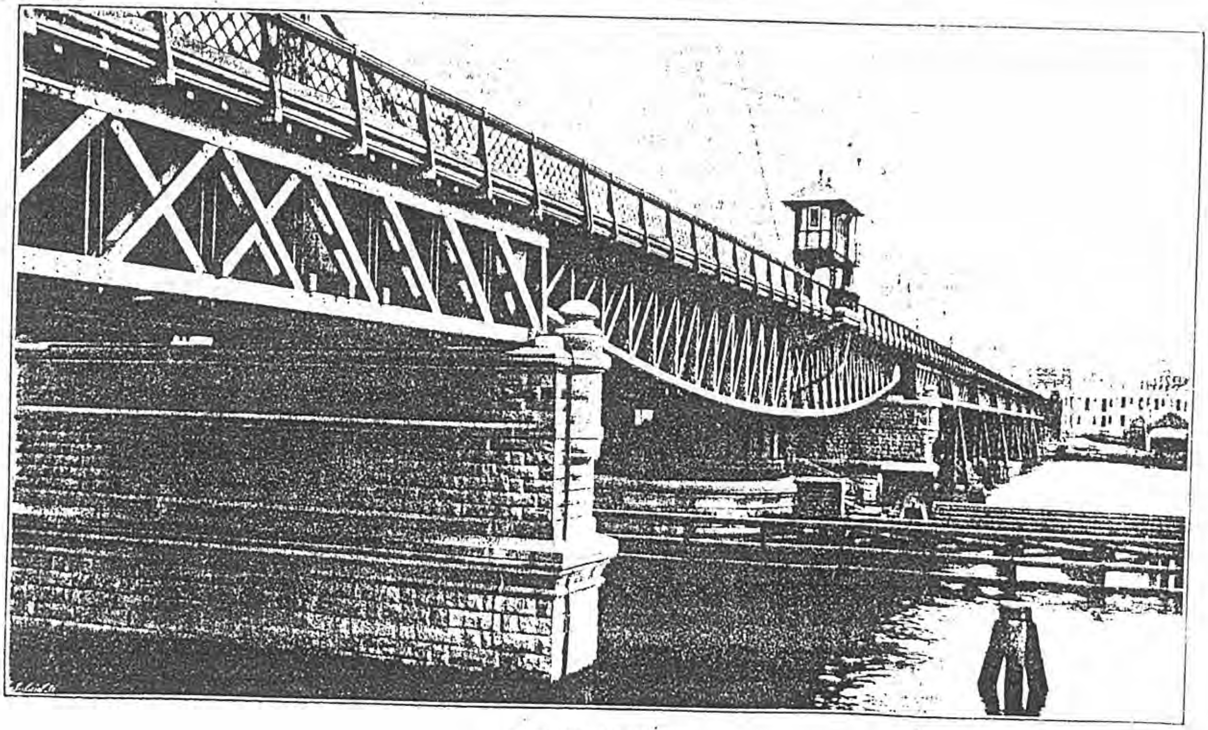

Fig. 13—THE SPAN CLOSED

temperature fractions. The lighter fractions are purified by washing with sulphuric acid, alkali and water; while sulphur, when it occurs, in objectionable quantity, must be removed by means of copper oxide. Among the higher fractions lubricating oil is purified by filtration through animal charcoal.

The lightest fraction, cymogene, which requires special cooling and pressure for its condensation, is used in ice-making machines. Other fractions obtained are rhigolene, the illuminant used in the pentane standard lamp, and as a local anæsthetic in surgery; gasolene, employed for the carburation of water gas for illuminating purposes, for making "air gas," and as a solvent; ligroin, also a solvent; benzine or petrol, which supplies us with motor spirit; and kerosene or lamp oil. Among other products may be mentioned paraffin wax, which, with an admixture of stearic acid, is used for the manufacture of candles, solar oils, various grades of lubricants, and vaseline. The quantity of lighter fractions can be increased if desired by the "cracking" of the more complex bodies.

Astatki, the residue from the distillation of Russian petroleum, yields, on distillation, an excellent illuminating gas, besides quantities of benzol, toluol, naphthalene, anthracene, and pitch.

The shale oil industry, founded by James Young, of Kelly, in 1851, which produces valuable quantities of illuminating and lubricating oils, ammonia, and paraffin wax, depends in a similar manner on scientific operations.

We claim less for science in the extraction of animal and vegetable oils, which has been practised since time immemorial, but must place to the credit side of the account the responsibility for the differentiation and classification of such oils, the selection of their most useful applications, with methods of purification and of analysis and valuation.

Vegetable oils, such as linseed oil—a so-called drying oil—and turpentine are used as vehicles in the manufacture of paints and oil varnishes. The paint industry has derived great benefit from science in the discovery and application of new pigments, and in the improvement of the older methods of making pigments. Turpentine is the starting material for the manufacture of artificial camphor, a synthesis that is a credit to organic chemistry, and although the artificial product cannot as yet be made to compete with the natural substance, it renders good service in keeping down the price of natural camphor, of which the production is practically monopolised by the Japanese. Other vegetable oils, such as olive oil, rape oil, maize oil, and castor oil, are employed as lubricants, whilst some are good illuminating oils.

The essential oils, of which oil of turpentine is an example, are vegetable oils used in many cases as perfumes. There are three methods of winning the and coumarin, New Mown Hay and Jockey Club; whilst in the second class we have such substances as ionone and nitrobenzene substitutes for essence of violets and oil of bitter almonds respectively.

### SOAP AND CANDLES.

The soap and candle industries must now be regarded as offshoots of the oil industries. Their origin is remote, but it was not until 1813, when Chevreul published his remarkable researches on the composition of oils and fats, that anything was known of the true nature of the processes involved in their manufacture. Nowadays the chemist should be in paramount control of their production. The recovery of glycerine, which at one time flowed into our rivers and streams as a waste product, was a scientific achievement of far-reaching importance, as we have indicated in our remarks on explosives, while its use in medicine is considerable. Incidentally we may mention also that glycerine, mixed with water, prevents evaporation and freezing, and this property finds application in the mechanism of gas meters.

Both animal and vegetable oils are used in the manufacture of soap and candles. When fats and oils—such as tallow, palm oil, olive oil—are boiled in large cast iron pans with caustic alkali, they become decomposed and yield an alkaline salt of the fatty acid—soap and glycerine. The excess of alkali and the glycerine are separated by the addition of a solution of common salt; the soap, being insoluble in the brine, rises to the top, and is ladled out as a granular curdy mass, run off into frames—boxes—to cool and solidify. Hard soaps, such as curd and yellow soap, are compounds with soda, consisting of about 26 per cent. of water, 7 per cent. of soda, and 66 per cent. of fatty acids, with, in the case of yellow soap, a small percentage of resin. Soft soaps are compounds with potash, or potash and soda, with fatty acids derived from drying oils, such as whale and seal oils, linseed, &c. With regard to the water content of hard soap it has been rumoured that, since soaps containing as much as 90 per cent. of water have been encountered, it appears to be the aim of some soap makers to cause water to stand upright.

### CANDLES.

The old tallow dips, prepared by dipping a wick repeatedly into melted tallow, gave rise, on burning, to a pungent substance called acrolein, produced by the decomposition of the glycerine combined in the tallow. Modern candles are without this disadvantage, as they contain no glycerine, the free fatty acids from which they are made being liberated from the fat either by the hydrolytic action of sulphuric acid, or by precipitation of the lime salt and its subsequent decomposition with sulphuric acid. The fatty acid—purposes in yarn mills is recovered by precipitating the soap from waste liquids with lime, and pressing the precipitate into briquettes, from which sufficient gas can be obtained by distillation to light the mills. Efforts are at the present time being made to recover fat from sewage, mainly for the sake of the glycerine content.

### EDIBLE FATS.

The invention of butter substitutes, now popularised by prevailing conditions, and the need for the exercise of economy, is due to the chemist. These substances are commonly made by mixing intimately a solid animal fat, such as stearin, with some vegetable oil, such as cotton seed or cocoanut oil, and milk. The use of solid animal oil for this purpose absorbs some of the raw material formerly available to the soap maker, but the deficiency has been made good by the conversion of the plentiful supply of vegetable oils, such as olive oil, into solid fats by hydrogenation in the presence of finely divided nickel, to which we referred in dealing with that metal.

## PYRMONT ELECTRIC SWING BRIDGE.

No. II.*

FIG. 15 shows the general position occupied by the bridge, and Fig. 14 an elevation of the swing span, which consists of four steel continuous N-framed girders, each 228ft. long, over T-bars spaced 13ft. 4in. apart centre to centre. The girders are 15ft. and 5ft. deep at centre and ends respectively, the arrangement of part of an inner girder being shown in Fig. 16. The curved bottom booms of the four main girders are connected with horizontal transverse struts and diagonal ties, the details of which are shown in Fig. 17, whilst the top and bottom booms are connected at intervals with diagonal T bars. The cross section of deck, shown in Fig. 18, provides a 40ft. wood-blocked carriage way and two 7ft. asphalt footpaths; the coke concrete with cement rendered surface under the carriage-way and footpaths is carried on a steel buckled plate deck.

By means of eight small steel built girders the whole weight of the superstructure of the swing span is equally distributed at 16 equi-distant points on the circumference of the drum. The drum, 5ft. deep, is of heavy section, and is centred to pivot by 16 radial struts. The drum carries on its lower flange a rolled steel machine tread, which bears on a live ring of 66 cast steel rollers, the general arrangement being shown in Fig. 19, page 105. The bottom tread is of rolled steel machined on all surfaces, and is secured to a cast iron track bolted to the masonry of the pivot pier.

steel plate angle or bar to be heated to a low cherry red, and cooled in water of 82 deg. Fah. must, when cooled, stand bending double round a curve, of which the radius is not more than 1½ times the thickness of the sample, without showing any signs of injury or fracture. Rivet steel to have an ultimate strength of not less than 22 tons or more than 26 tons, with a minimum elongation of 25 per cent., and must also bend cold through 180 deg. flat on itself, without sign of fracture on the convex side. All hand-driven rivets, whether shop or field, to be of iron. The wrought iron, except rivet iron, when tested in samples of the dimensions specified for rivet steel, to have an ultimate tensile strength with the grain of 22 tons, with a minimum elongation of 10 per cent., and a minimum contraction area of 12 per cent., and samples must, when cold, stand bending through an angle of 50 deg. round a curve of ½in radius. The rivet iron to have an ultimate tensile strength of not less than 22 tons, with a minimum elongation of 16 per cent., and must also bend cold through 180 deg. flat on itself, without showing signs of fracture on the convex side. The cast steel, when tested in samples 8in. long, with a uniform sectional area of not less than half square inch, to have an ultimate strength after annealing of not less than 29 tons, with a minimum elongation of 15 per cent.

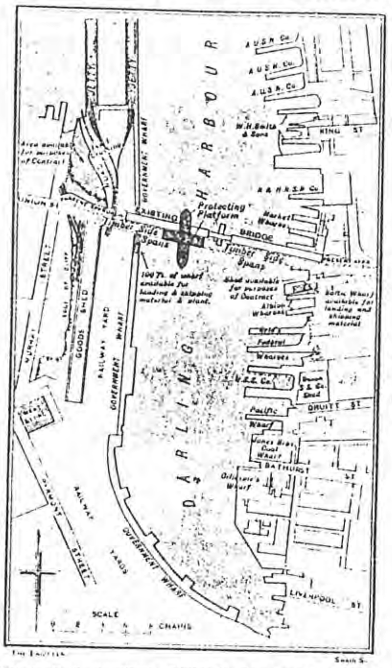

Fig. 15—MAP SHOWING POSITION OF SWING BRIDGE

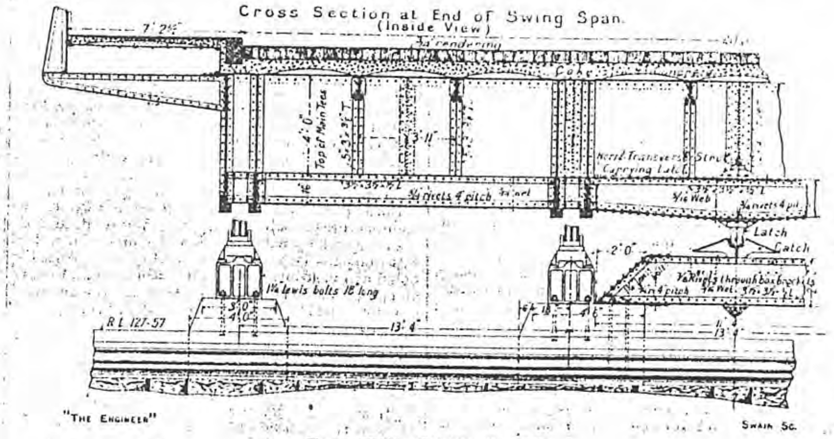

Fig. 18—CROSS SECTION OF DECK

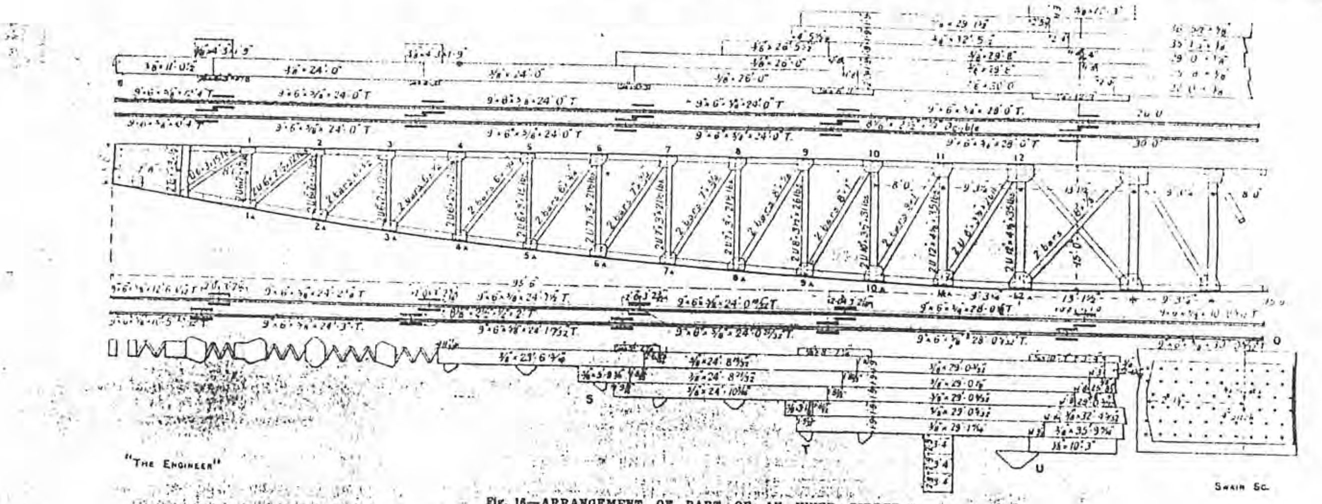

Fig. 16—ARRANGEMENT OF PART OF AN INNER GIRDER

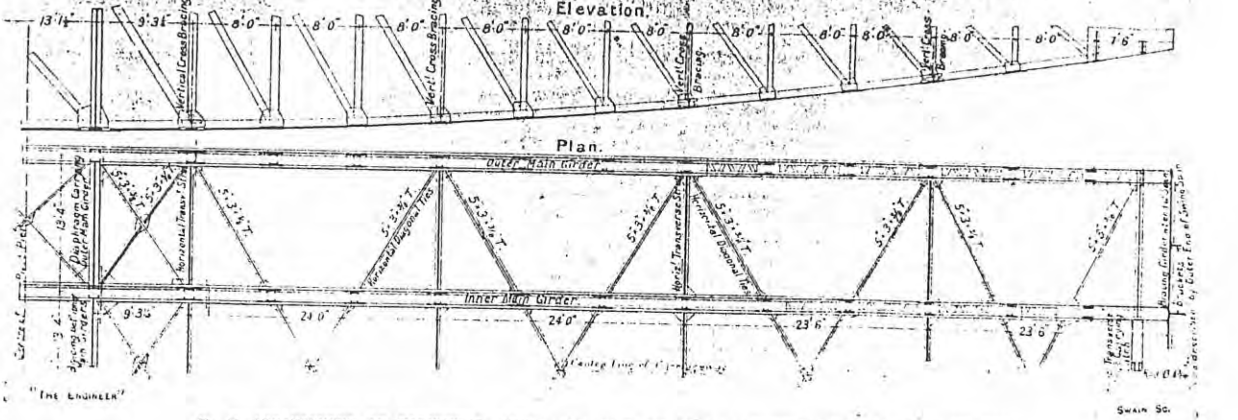

Fig. 17—ARRANGEMENT OF HORIZONTAL STRUTS AND DIAGONAL TIES IN BOTTOM BOOMS OF MAIN GIRDERS

The wrought iron caisson for the pivot pier is 32ft. and 42ft. internal and external diameter respectively, the inner skin at bottom being bell mouthed to meet the outer skin to form a cutting edge. The caisson was sunk by open dredging, and weighting with concrete between the shells. The caisson finished 1ft. below low water. A temporary caisson from this point reached to 2ft above high water mark; this having been used for building the masonry work between tides. The concrete was deposited through the water in single rope self-tripping iron boxes, designed with a view to reducing the disturbance to a minimum, and was carried on continuously until completion of each section of the work, 1850 yards in the bases of the two rest piers being finished in 19 days. The composition of the concrete used in the construction was as follows:—Between inner and outer walls of caisson (laid in the dry); between sand bag wall and ring of special concrete under the bell-

## PYRMONT SWING BRIDGE, SYDNEY, NEW SOUTH WALES

(For description see page [illegible])

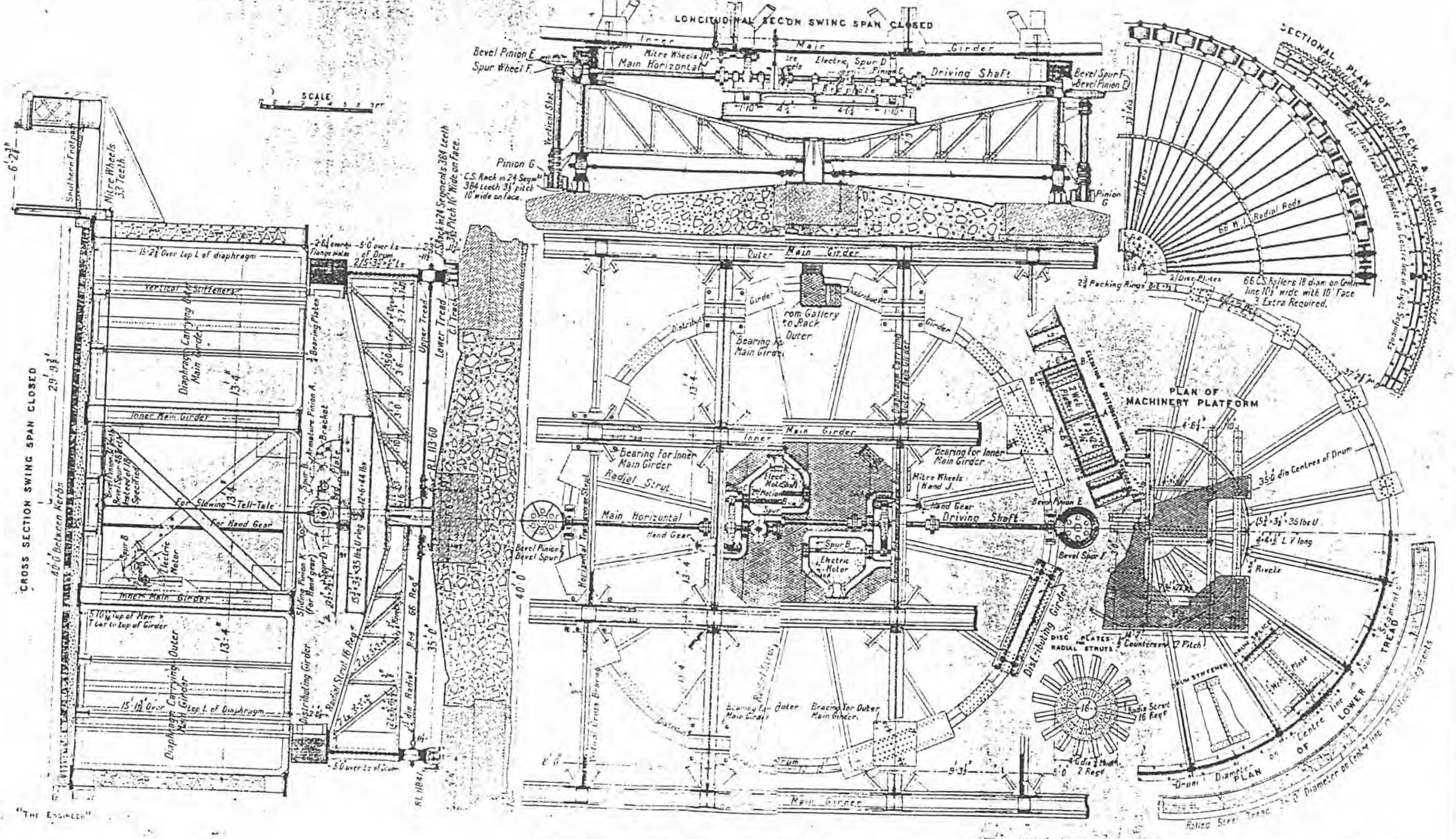

Fig. 19—GENERAL ARRANGEMENT OF PARTS OF PIVOT PIER

mouth of caisson (through the water); bottom 5ft. of Sydney rest pier (through the water); 17 cubic feet of basalt broken to pass through 1½in. ring, and be

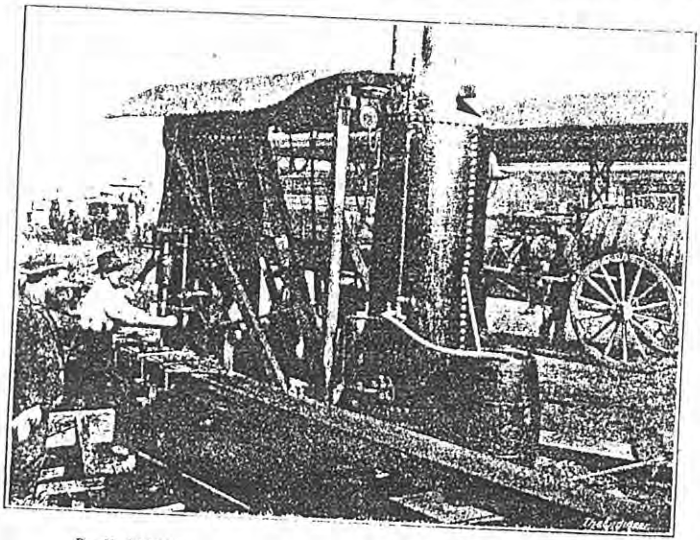

Fig. 20—DRILLING HOLES IN BOTTOM CHORD JOINT OF TIMBER TRUSS

caught on a ⅝in. screen, 9 cubic feet of sand, 374 lb. of cement. Bag concrete under cutting edge, and special concrete under the bell-mouth of caisson (through the water); 11 cubic feet of basalt broken to pass through a ⅝in. ring, and be caught on a ⅛in. screen, 4 cubic feet of sand, 374 lb. cement. Between inner walls of caisson to a height of 12ft. above cutting edge (laid in the dry); in rest piers to within 1ft. of low water mark (through the water); 17 cubic feet of sandstone broken to pass through a 2in. ring and be caught on ⅝in. screen; 9 cubic feet of sand, 374 lb. of cement. Hearting in rest piers from 1ft. below low water mark to top (laid in the dry); hearting in pivot piers from 12ft. above cutting edge to top (laid in the dry with blocks of sandstone embedded in the concrete); 26 cubic feet of sandstone broken to pass through a 2in. ring, and be caught on a ⅝in. screen; 11 cubic feet of sand, 374 lb. cement.

Pyrmont sandstone was used for facing, and for the dressed work in both the pivot and rest piers, the bed stones under the pivot and pedestal blocks on the rest piers being of trachyte. The total weight on the foundations of the pivot pier, neglecting friction and buoyancy, is 6800 tons. To protect the swing span from injury by passing vessels a timber platform 325ft. long and 3ft. 4in. wider than the overall width of the swing span was constructed of turpentine piles and ironbark girders and bracing. This platform, in conjunction with the dolphins in line with the rest piers, has prevented all but minor damage during the many years the swing span has been in operation.

The swing span is flanked by timber truss spans of the Howe type, four on the Pyrmont side and eight on the city side, making, with the swing span, a total length of 1207ft. 6in. between centre of bearings on the stone abutments. The timber used for the floor beams and truss work was ironbark, the truss members being sawn free from heart and sapwood to ensure mature and sound timber. The average of a number of small specimen tests shows this most favoured of Australian hardwoods—for structures exposed to the weather—to have a tensile strength of 8 tons per square inch, a crushing strength of 4¾ tons per square inch, and a shearing strength along the grain of 1 ton per square inch. Its durability may be inferred from the fact that roughly constructed bridges in the State of New South Wales have, in some cases, attained a life of over 50 years, many over 35 years, and but few less than 25 years. A prolonged life may therefore be anticipated for bridges of more mature design, such as that at Pyrmont, in which greater attention is paid to the inspection of timber and more care taken in the work of construction.

The six trusses in each span carry transverse floor beams, on which is laid 6in. × 4in. longitudinal hardwood planking alternately on flat and edge covered with basalt concrete, carrying tallow wood blocks to form the road surface, asphalt being laid on the footpaths. A wrought iron parapet, of similar design to that on the swing span, is carried from abutment to abutment, the whole presenting from the deck the same appearance as would have obtained had steel side spans been adopted. The trusses are 8ft. deep and 80ft. span, measured between centres of main gudgeons, forming spans of 82ft. over centres of piers. Each truss is formed of wrought iron [illegible] rods with upset ends, diagonal timber struts and timber top and bottom chords arranged in twelve panels. To prevent lodgment of water, open top and bottom chords consisting each of two flitches some space apart were adopted, thus permitting of easy renewal, whilst being always accessible to the brush. The joint in each flitch in the bottom chord is effected by means of two 12¾in. × ⅝in. wrought iron covered plates placed on either side. To each of these plates four wrought iron strips 2in. × 1¼in. × 12¾in. are riveted, and fit tight into notches cut in the timber. The plates were left blank—see Fig. 20—the bolt holes being drilled out after the plates were clamped up for the 12 turned bolts, which were then driven to complete the joint. By this means the bolts had a full bearing on the two iron plates and the timber—see Fig. 21. Three full-sized tests were made of the joint in a machine specially designed for the purpose, a 700-ton hydraulic jack being used, which was connected up to a 50-ton Alsen testing machine, upon which was read the load applied to the specimen—see Fig. 22.

In the three tests failure occurred by the shearing of the bolts and the timber between the notches, the ultimate strength of the joints being 151, 160 and 182 tons respectively, whilst the maximum stress on the joint in the actual bridge, due to any manner of loading, is 59 tons, which figure includes an allowance of 32 per cent. upon the maximum live load stress for dynamic action. These full-sized tests clearly show how necessary it is in timber structures to allow large "factors of safety" when working on test results obtained with small-sized specimens. This conclusion, it is considered, holds good no matter how numerous the tests may have been, or how carefully carried out. The trusses were put together on the wharf close to the site; each truss, weighing 15 tons, was, on completion, hoisted about 30ft. on two pile-driving machines, and was then towed to site and placed on the piers—see Fig. 23, page 110. The work of transporting the trusses was quickly performed, as many as 12 trusses being placed in [illegible] hours. The cost of the 12 side spans, including gas and gate machinery complete, was £43,256.

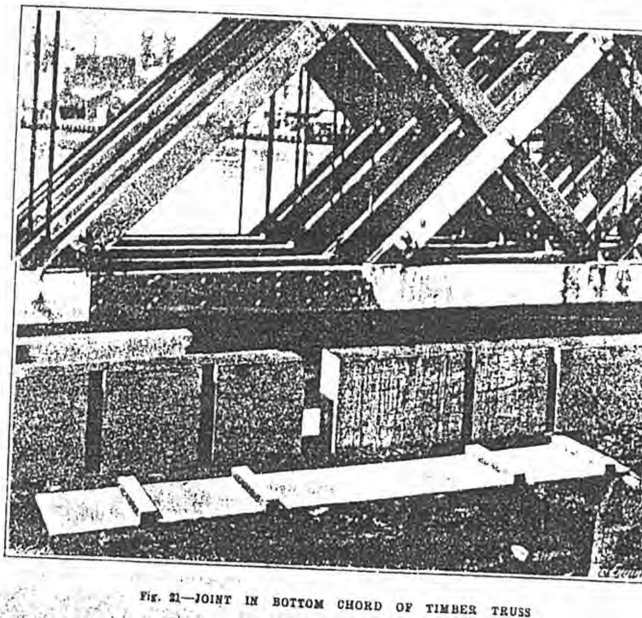

Fig. 21—JOINT IN BOTTOM CHORD OF TIMBER TRUSS

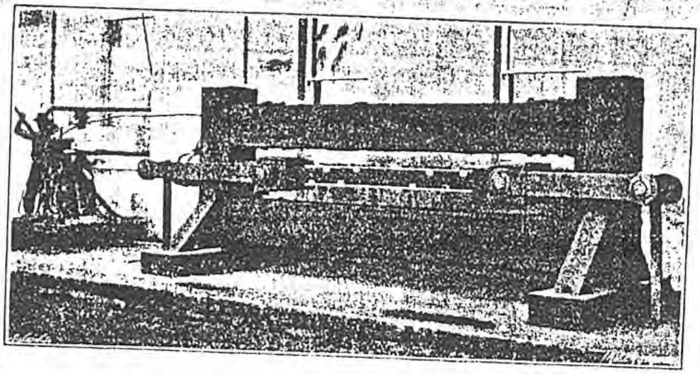

Fig. 22—MACHINE FOR TESTING CHORD JOINTS

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For the new electrical services to Watford, which will be a continuation of the "Bakerloo" services from Elephant and Castle to Willesden, the London Electric Railways Company will, for the present, provide the rolling stock. In order to meet the difference of, we believe, 13in. between the height of the London and North Western and the "Bakerloo" platforms, the gangways of the electric cars are to be raised 6½in., so that on alighting passengers on the London and North Western line will step up 6½in. and on the tubes will step down 6½in. The level of the floor will not be interfered with, but at the entrance to the gangway the difference of 6½in. in the height will be met by a ramp.

# PYRMONT BRIDGE, SYDNEY, NEW SOUTH WALES

(For description see page [illegible])

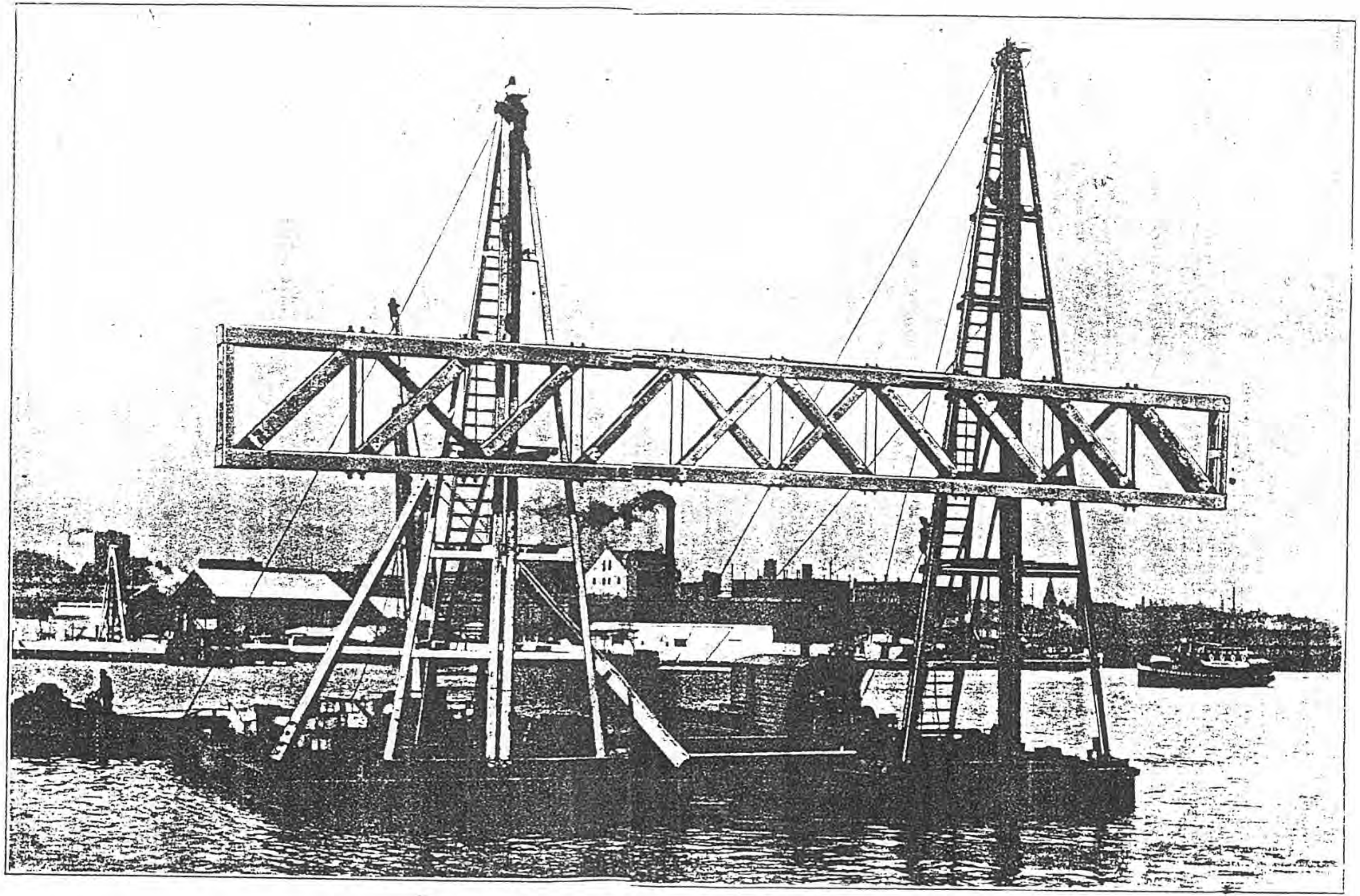

FIG. 23—TOWING THE FIRST TIMBER SIDE SPAN TRUSS TO BRIDGE SITE

to recover the remaining oil. It is to be noticed that in discussing the relative advantages of the two processes it is not wise always to confine our argument to the general case. Our conclusions must be modified not only by local conditions as to the outlet for the oil and seed residue—that is, the press cake or extracted meal—but also by the particular oil bearing seed which is to be treated. Thus the residue of certain seeds, rape seed for example, has little or no value as a food stuff however it is obtained. It seems therefore only reasonable in such cases to adopt that process which recovers most oil from the seed, and which, moreover, leaves the residue in a form which is directly suitable for manurial purposes. On the other hand, the solvent extraction process should be studied cautiously if castor seeds are in question. Castor oil is in several respects an exceptional oil and appears to suffer some chemical change by the action of solvents.

In conclusion, it may be remarked that any objection to solvent extracted meal as a food stuff on the ground that it is deficient in oil can be overcome by mixing it with the desired proportion of oil and moulding it into cakes. Again, it can be mixed with ground-up press cake and the whole remoulded. Both practices are followed on the Continent. We may add that so far as we can discover there is no ground for the assertion made in an authoritative work that extracted meal cannot be sold in this country as a cattle food.

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The Board of Trade returns for the last six years show that, whereas in 1911 we imported of soft woods 9,740,436 loads at a cost of £25,847,077, during the last year our imports declined to 6,318,872 loads, whilst the cost rose to £40,199,469. These figures do not include the very large amounts now imported direct for Government account. The drop in quantity of imports is still more strongly emphasised by the figures for the year immediately before the war, when we imported 11,589,811 loads at a cost of £33,789,356. Another interesting effect of the war on timber imports is seen in a comparison of the relative proportions from the principal different exporting countries. In 1913 Russia supplied 51 per cent. of our imported soft woods, Scandinavia 25 per cent., Canada and the United States 22 per cent. For last year the figures were: Russia 16 per cent., Scandinavia 50 per cent., Canada and U.S.A. 27 per cent.

## PYRMONT ELECTRIC SWING BRIDGE.

No. III.*

The swing span is of the ring bearing type, the whole weight—800 tons—with the exception of some 9.4 tons—which is carried directly by the pivot—being equally distributed on 66 cast steel rollers upon which the span revolves. A view showing the rollers, radial rods, discs, plates and pivot is given in Fig. 38, page 132.

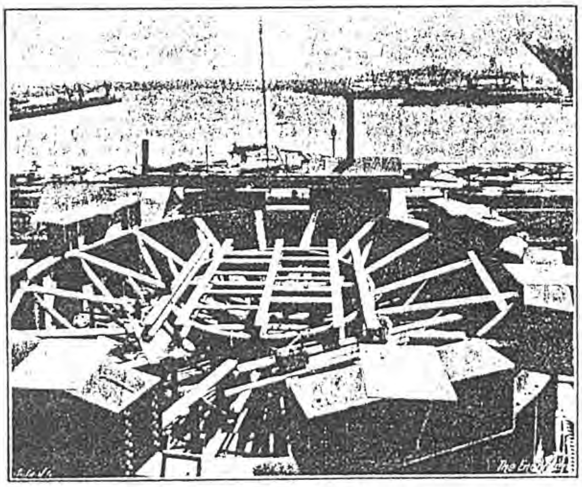


Fig. 24 DRUM AND DISTRIBUTING GIRDERS

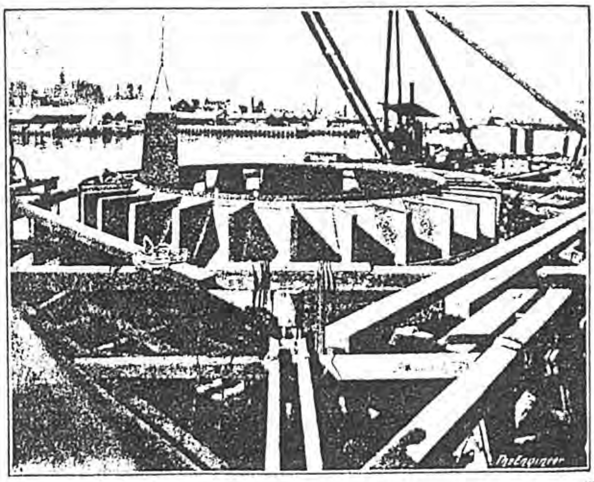
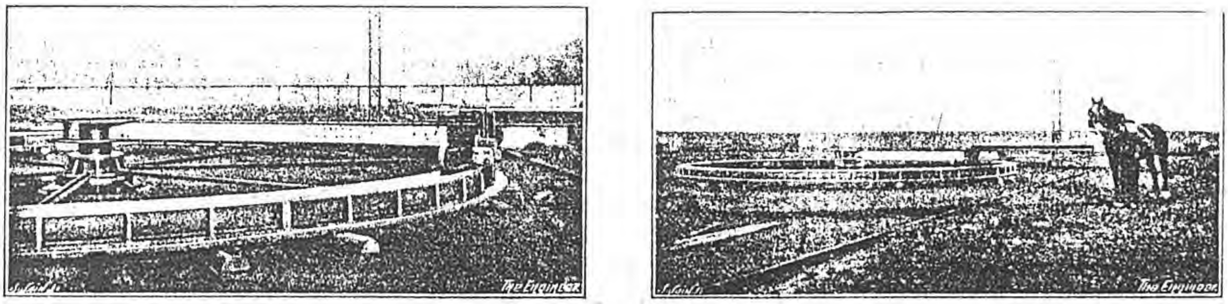


Fig. 25 FIRST SECTION OF CAISSON

The cast iron track is of bridge section, is machined top and bottom, and is bedded hard on the masonry. To the top flange of the track is secured by set screws a steel coned bottom tread. This tread is machined on all surfaces with the view of obtaining the best possible roller path. The conical rollers, which are 18in. in diameter on the centre line, with a 10in. bearing face, are connected by 1¼in. radial rods to two circular disc plates, which revolve round the pivot with ¼in. play, the whole forming a flexible turntable. The top tread is of the same section as the bottom tread, and is secured to the bottom flange of the drum with set screws. The drum, which is 35ft. diameter, and 5ft. deep, is provided with 16 radial struts connected at their inner ends to two disc plates fitted over and revolving round the pivot. A view showing the distributing girders, drum, radial struts, and the machinery platform is given in Fig. 24. It was found impossible to machine the treads and tracks as required by the specification without building a special lathe with a rigid face plate or table at least 37ft. in diameter, and it was therefore decided to carry out this portion of the work in the manufacturers' yard, as follows:—The cast iron track segments were planed parallel top and bottom in an ordinary planing machine; the ends were then machined, and the whole of the segments bolted up in a ring, as seen in Fig. 26. The ring was laid down and carefully levelled with a dumpy level, the pivot being mounted in the centre. A special carriage was constructed with the two rollers running on the top of the ring, and constrained to move round the centre by a radius rod. A tool in the tool box fixed on the carriage could be brought to bear on the vertical edges of the cast iron ring, and the carriage was pulled round by a horse trained to work a roundabout—see Fig. 27.


Figs. 26 and 27—MACHINING THE ROLLER PATH

Each segment of the conical tread, after being machined on one surface, was connected by set screws to the planed top flange of a segment of the cast iron track. This segment of track was connected to, and formed the rim of a wrought iron framed sector of a circle, so arranged as to move freely round a pivot, the planed bottom flange of segment sliding on rests attached to an ordinary planing machine. Whilst there was no difficulty in securing the bottom tread to the cast iron track when once the track was level and bolted down to its temporary foundations, yet some difficulty was anticipated by the manufacturers in obtaining a good job with the top treads which had to be secured to angle bars of the drum without intervening packing. When, however, the cast iron track was fixed perfectly level in position on temporary foundation, the drum with the bott flange angle bars loosely bolted to the web, was put rest on the track, the angle bars being then secu clamped down thereto, and whilst in that positi the holes were rimered through the web plate an angle bars, and the rivets were then closed. Ow no doubt to the very highest class of work bei specified, and to the great care taken by the manuf turers of this portion of the work, there is not in t bridge as working to-day one idle roller in the l ring.

The span was built out from the pivot pier with staging—see Fig. 39, page 132—which shows t distributing girders being erected on the top of t drum—a stationary crane on the timber protecti platform alongside raising the material to a cra travelling on the top of the span, by which the diff ent members were placed in position pneuma riveters being used wherever practicable. T specification provided for the temporary erection the manufacturers' yard and turning of the sw span by hand. This necessitated the provision solid concrete foundations for the track and p the weight on foundation at time of swinging in yard having been some 500 tons. The specificat also stipulated that the main girders were to hav initial camber, and in the temporary erection in manufacturers' yard the girders were packed up the top booms were quite horizontal, and the through the ties and struts were then rim through with pneumatic tools. Turned bolts parallel drifts were used when swinging the sp The main girders were calculated to have a deflec of 4in., and to avoid the cracking of the coke conc

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* No. II. appeared February 2nd.

the cement rendering on them, the ends of the swing span during erection *in situ* were weighted down with cement bags to give this deflection—see Fig. 28. The bags were removed as the concrete blocks were placed in position, thus keeping the ends of the swing floating at the same level. The superstructure of the swing span, in which the bracing together of the main girders is well shown, is given in Fig. 30. The cost of the swing span erected *in situ*, including electric equipment, was £21,959.

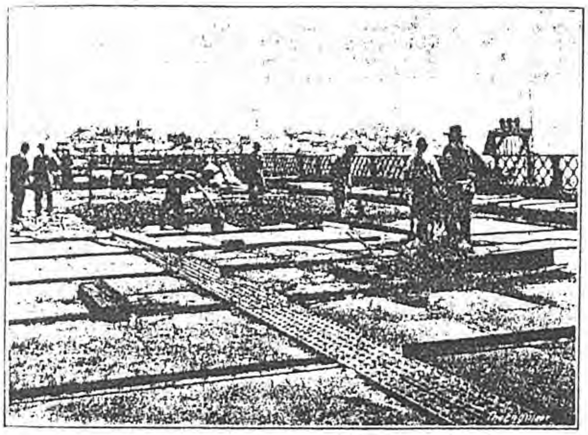


Fig. 28—COKE-CONCRETING DECK OF SWING SPAN

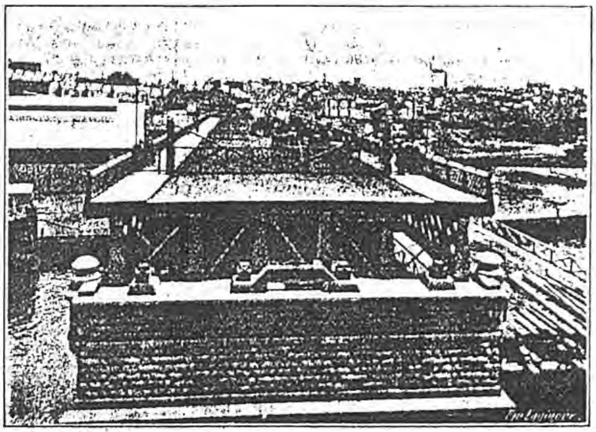


Fig. 29—ROADWAY—SWING SPAN OPEN

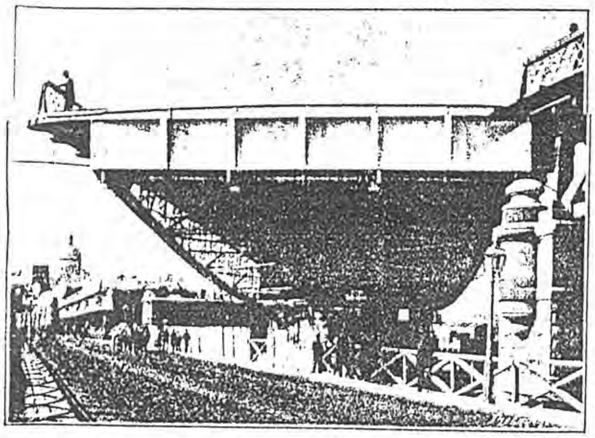


Fig. 30—SUPERSTRUCTURE OF SWING SPAN

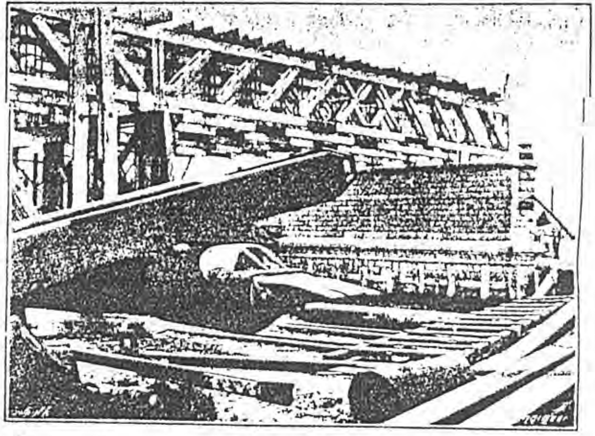


Fig. 31—JUMPERS FOR EXCAVATING

At the site of the pivot pier there were 3ft. of soft mud, and some 25ft. of clay overlying the sandstone rock which sloped 8ft. in the diameter of the pier. With such a large body of clay it was decided to sink a permanent wrought iron caisson to the rock by open dredging; then to pump out the water within the caisson, and to excavate the trench in the sloping rock sufficiently to enable the cutting edge to be bedded on the solid for its whole periphery. A temporary caisson, extending to 2ft. above high-water mark, was also provided to permit of the masonry top of pier being built in the dry. The first section of the caisson, weighing 50 tons, was put together directly over the pier site on a square ironbark frame—see Fig. 25—the ends of the four beams projecting and forming the eight points from which the frame with its load was suspended by wire ropes from the protecting platform already in position.

The ropes were eased away by hand until the caisson was sufficiently immersed with a draught of 7ft. 3in. to float with its own buoyancy, the framing being then pulled from underneath the cutting edge. Fresh sections were then built on to the concentric walls of the caisson, and sinking was proceeded with by depositing concrete within the space between the walls. When the cutting edge was close to the mud bottom, the caisson was brought into its true position by means of folding wedges working between the four sets of timber guides bearing against the caisson and the piles of the protecting platform. Concreting between the walls was then proceeded with at the bottom of a tide, so that with the following ebb the caisson was easily grounded, and with sufficient weighting to prevent its lifting with the rising tide.

The mud and clay within the caisson were excavated with a clam bucket worked from a floating crane, concrete being deposited within the walls to force the caisson down. But little difficulty was experienced in keeping the caisson level, four draught gauges painted on the inner wall at once showing by the cut of the water any movement out of level, thus allowing prompt measures to be taken by weighting and dredging to counteract the same. When the caisson touched the rock on the high side the water within the caisson was pumped out, the caisson taking a list of 11in. A view of the caisson before it was pumped out is given in our Supplement, and a view of it after pumping out is shown in Fig. 32. The rock on the high side was quickly excavated, the caisson being lowered 2ft. when a blow occurred, the water filling the caisson within a few minutes.

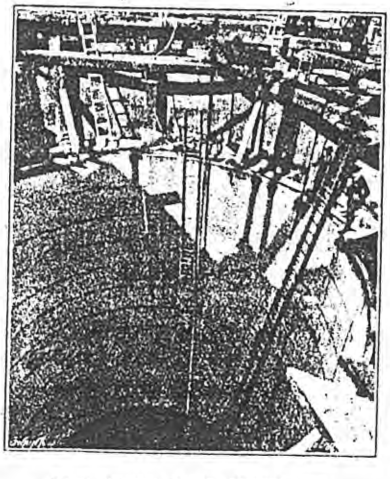


Fig. 32—CAISSON AFTER PUMPING OUT

It was then decided to place a large body of clay around the outside of the caisson, and to excavate the remaining 6ft. of rock through the water with jumpers. The vertical jumper consisted of a square ironbark pile, some 64ft. long, carrying on its lower end a heavy steel casting provided with three steel cutters. This jumper was hoisted by a steam crane, and was tripped with a 6ft. to 8ft. drop, the rock being excavated from 5ft. inside of the inner wall until a vertical face in line with the wall was obtained. Two of the jumpers are shown in Fig. 31, while a view showing a jumper being operated in the caisson is given in our Supplement.

Upon obtaining a face the rock under the bell mouth and cutting edge was removed with a jumper consisting of a flat-footed rail provided with a steel chisel point at its lower end. This jumper worked in a hollow timber chute fitted with a wrought iron bearing plate, upon which the flat-foot of the jumper worked, the jumper being hoisted with a steam crane and giving a drop of from 10ft. to 12ft. By means of wire ropes attached to the top and bottom of the chute the jumper could be set at the required angle to reach anywhere under the cutting edge, the position of the cut being fixed by a diver.

During the rock excavation the water was kept near the top of the caisson, and upon the rock being cleaned for 10in. or 12in. the water within the caisson was pumped out sufficiently to allow the caisson to settle by its own weight. This method was followed until the contract depth of 54ft. below low water mark was reached, by which time the caisson had been gradually "straightened up," until finally within 2½in. of level, the cutting edge being in its true position, and the top of caisson well within the 12in. margin allowed for errors in placing and sinking. The few places where the cutting edge was not bearing on the solid rock were then cleaned off by divers with a water jet, the spaces being filled with basalt concrete in bags packed by divers. At a distance of 1ft. from the cutting edge a ring of concrete bags, headers and stretchers was laid to a height of 1ft., the narrow space thus formed being filled with concrete deposited in the loose by means of a bell mouthed canvas bag, the bag being lowered through the water and tripped when in position by a diver. This work was carried out in eight sections, the rock being well washed with a jet before depositing the concrete. To stiffen the ring of concrete under the bell-mouth, a ring of sand bags, 4ft. high, was placed some 11ft. inside of the cutting edge, the intervening space being filled with basalt concrete deposited through the water in self-tripping iron boxes, the rock being cleaned off with a jet before concreting in each of the eight sections in which the work was carried out. The concrete was allowed to set for nine days before pumping the water out of the caisson. The latter operation was effected in twelve hours.

After pumping out the water the sand bag wall was removed, and the rock and concrete were thoroughly washed with a jet—see Supplement—the concrete being found to have set very hard, and being remarkably well placed by the divers, the line of bags showing how accurately the divers worked to the gauges in over 50ft. of water so discoloured with clay as to necessitate all work being done by "feel." When the last of the water had been bailed out of the caisson—see Supplement—three small leaks were found which were collected in 3in. iron pipes and led to a sump, the pipes being surrounded with neat cement. After securing an absolutely clean bottom by scrubbing and hosing down, sandstone concreting was proceeded with to a height of 12ft. above the cutting edge—see Supplement. This concrete was allowed to set for three days when the caisson was filled to the top with rubble sandstone concrete, the plums in some cases weighing over three tons—see Supplement.

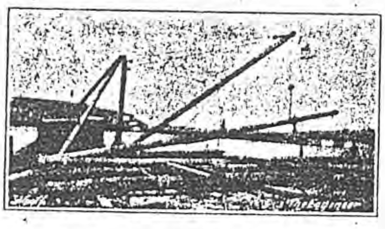


Fig. 33 FOUNDATION PILE AND FOLLOWER

To enable all the concrete within the caisson to be laid in the dry without trouble from water pressure, the sump was carried up to low-water mark before being finally filled, the water in the sump in the meanwhile being easily kept down by occasional bailing. When the concreting of the caisson had been completed the top was carefully levelled for the receipt of the masonry, whilst the pivot center having been accurately determined, a central iron rod was concreted in. Round this rod a wooden trammel revolved, to which the radial facing stones were set, a loose gas pipe, the depth of the course, being slipped over the central rod—see Supplement—in which may also be seen a view of the pivot pier when practically completed. The whole of the masonry was laid in the dry, and on completion of the pier the temporary wrought iron caisson was removed, leaving only the stonework visible. The total weight on the foundation of the pier, including superstructure and swing span, is 6800 tons, neglecting friction and buoyancy, whilst the completed cost was £14,320, the protecting platform and dolphins having cost £3379.

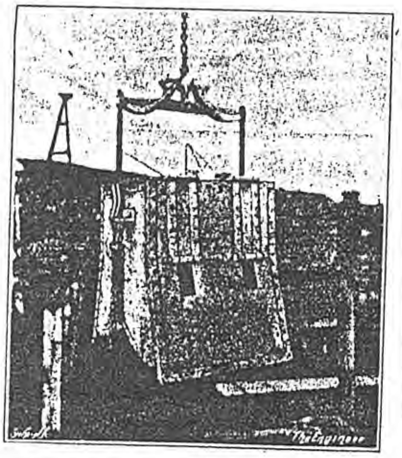


Fig. 34—DEPOSITING BOX, FILLED

The rest pier at the Pyrmont end of the swing span is founded on the rock, whilst the Sydney rest pier is carried on 58 piles driven to the rock bottom about 64ft. below low-water mark. At the site of the Sydney rest pier an area, somewhat larger than the base of the pier itself, was dredged with a ladder bucket dredge until a level bottom was secured 32ft. below low-water. The foundation piles finishing alternately 2ft. and 3ft. 6in. above the clay bottom were then driven with a follower—see Fig. 33—to refusal, when, by tapping out the bolts which passed in slack holes through the four flitches and the pile head, the followers were released by a diver. The followers were provided with a ring top and bottom, but no ring was used on the pile heads, the tough ironbark obviating trouble from brooming or splitting. After the foundation piles had all been driven, a rectangular hardwood frame was lowered to the bottom, and having been accurately positioned, was secured in place by strutting off the foundation piles. Guide piles were then accurately pitched by means of this frame, and were all driven to a depth of 10ft., and the frame was removed. Horizontal walings provided with guides fitting round each pile were next bolted to vertical runners, and with these runners were then forced through the water, successive walings being added at intervals of about 5½ft. until bottom was reached. Vertical hardwood sheathing, formed of two thicknesses of 1½in. planking and in 6ft. sections, was next lowered, the back of each section being at each waling provided with two battens blocked off at an angle to engage with the walings, and to bring the sheathing hard up against the walings when forced down from above water, the sheathing thus providing a smooth face for the concrete.

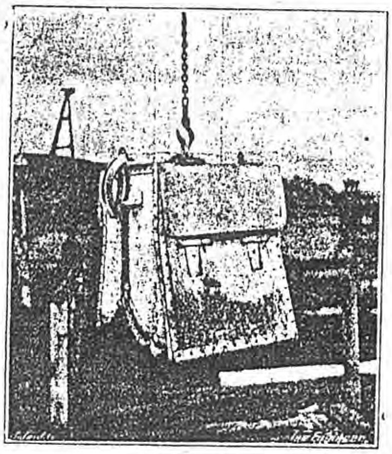


Fig. 35 DEPOSITING BOX—EMPTY

On completion of the sheathing the silt was removed from between the pile heads, and concreting was then proceeded with, the timber depositing boxes fitting between the pile heads, the boxes being guided into place by divers. The concrete above pile heads, and within 2ft. of low water, was deposited by means of single rope self-tripping iron boxes, specially designed by Mr. Percy Allan, M. Inst. C.E., for the purpose—see Figs. 34 and 35. Each box held 22 cubic feet of concrete, and was provided with top and bottom bars, the lower set at an angle so as to minimise disturbance in depositing. By means of pins on the lower edge of bottom doors projecting outside the box, the doors were suspended from the crane rope, so that when the box landed on the bottom the slacking of the crane rope allowed the weight of the concrete to force open the doors and bring into engagement the two hooks by which the box was then hoisted with the doors hanging free.

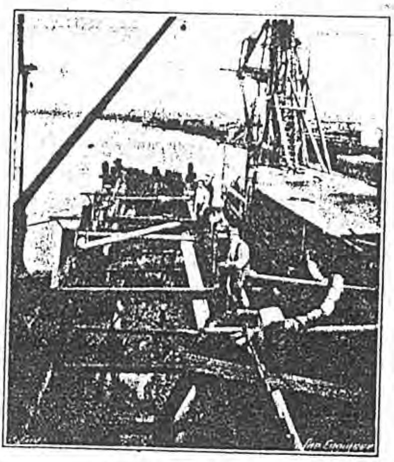


Fig. 36—BUILDING REST PIER

The concreting was carried through without a break, little trouble being consequently occasioned by laitance. After the concrete had been allowed to set for 14 days the water was pumped out of the dam—see Fig. 36—and after the laitance of the consistency of chalk had been removed from the surface, concrete in the dry to within 1ft. of low water mark was laid, a sandstone masonry facing with concrete backing from this point to above high water mark being carried out in the dry—see Fig. 37. When this portion of the work was completed the guide piles were cut off with a saw worked from above water, the waling and sheathing being then removed, leaving the concrete bases with smooth faces. The masonry of the facing consists of rock faced sandstone, laid in courses, with chisel-dressed plinths, mouldings, copings, &c., the whole having a pleasing appearance, as indicated in the view given in Fig. 29, which also shows the approach to the bridge, with the traffic stopped, when the swing span is open. The cost of the two rest piers complete was £9217.

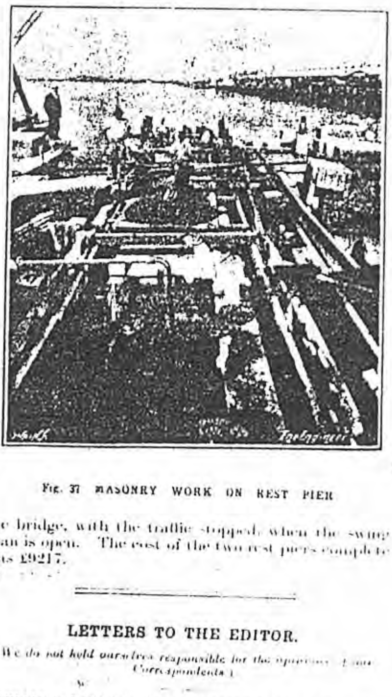


Fig. 37 MASONRY WORK ON REST PIER

## LETTERS TO THE EDITOR.

(*We do not hold ourselves responsible for the opinions of our Correspondents.*)

### A CHAIR OF ENGINEERING HISTORY AS A PROTECTION OF NATIONAL PROPERTY.

SIR,—It is very well known to engineers—even though it may not be allowed publication, with the names in print—that a study of ancient engineering and of its old inventions, now long forgotten, has been and is to-day the means of making huge fortunes with the minimum of effort.

All that is required to make money by such research is a short memory on the part of those who are to be called upon to pay the money, and a certain cleverness in phrasing patents and of "conciliating" the Press.

A Chair of Engineering History would so equip every would-be engineer in the history of the past, that he would not become the easy dupe of the professional patentee as actually occurs at present. It seems a hundred pities that your article on page 112, in quoting from page [illegible] of M. Anatole Mallet's work on the origin of the steam engine, did not allow it to appear that M. Mallet's suggestion for a Chair of Engineering History was forced by his knowledge of the amazing ignorance among engineers of what has been done before with superheated steam, as appears from the context on page 8, where he speaks of "facts hardly ever published before." This has been confirmed in a personal conversation with M. Mallet.

The fact cannot be denied, by anyone, that through British, French, and American ignorance of the history of superheaters and of superheating, all three countries became tributary to Prussia—not for an ounce of metal received in return for hundreds of thousands of pounds sterling paid by them, but merely for a paper permission to use inventions which had been patented fifty to sixty years before in Great Britain and in France.

Even Prussia itself was almost equally ignorant, and a Hanoverian engineer of great distinction wrote to a friend:—"I do not believe our *Patentamt* would have granted the patents had it been aware of these sixty-year-old French Patents."

In Great Britain and in the United States every engineering journal strenuously opposed the revelation of the existence of those old inventions upon which an excellent friend, the Prussian, was to make such immense sums of money, and which were to so powerfully aid Germany in her war on the Allied countries of the West.

Even to-day, our Press still "puffs" up these Prussian re-patents—proving that our Press has still its "soft side" for the clever student in Germany of our ancient engineering history.

The suppression of facts by the engineering Press has led to the humiliating spectacle of British naval engineers of distinction asserting, in learned papers, that superheating was never heard of before the German patent [illegible] came forward and introduced it into this country within the last decade or so."

From this, it appears that a Chair of Engineering History would, in all probability, find itself in frequent disagreement with aggressive commercial engineering, through its revelations of past history; which Germans, and others, might seriously deprecate—for the German, like the Japanese, is essentially a copyist; but his business methods are simply irresistible to the English and Americans—hence, from an earnest re-research of old, long-forgotten inventions, the clever German is able to create a world-wide Octopus Monopoly, so powerful, that at

# PYRMONT SWING BRIDGE, SYDNEY, N.S.W.

*(For description see page 124)*

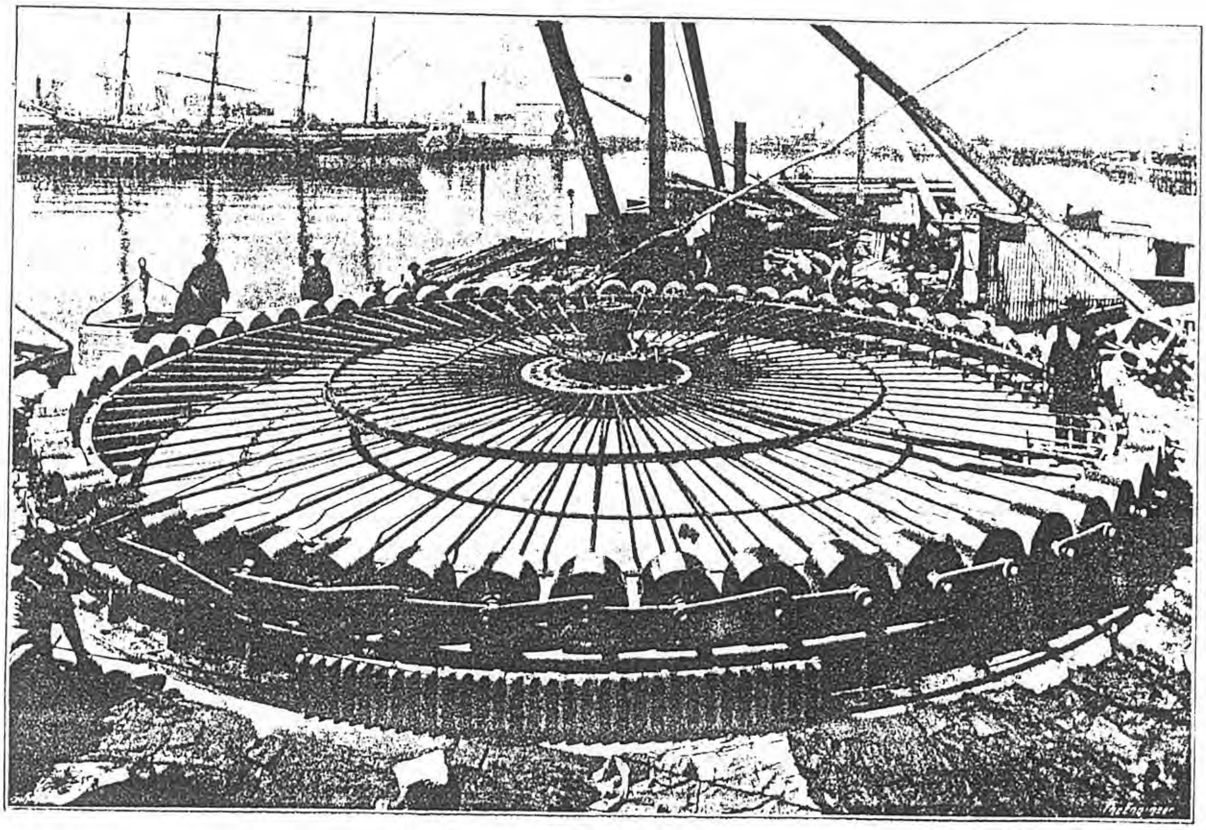


Fig. 38—ROLLERS, RADIAL RODS, DISC PLATES, AND PIVOT

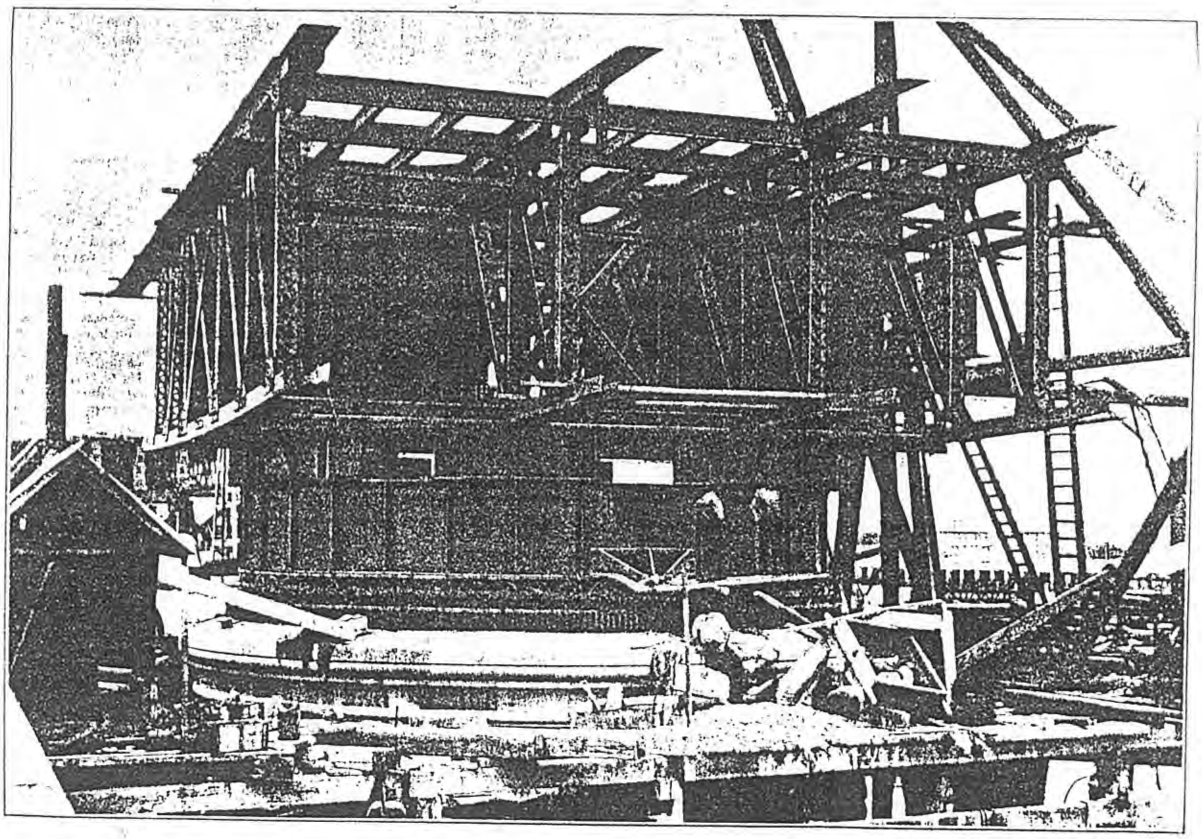


Fig. 39—THE DRUM IN POSITION, SWING SPAN UNDER CONSTRUCTION

# PYRMONT BRIDGE, SYDNEY, N.S.W.—PARTS OF SWING SPAN

*(For description see opposite page.)*

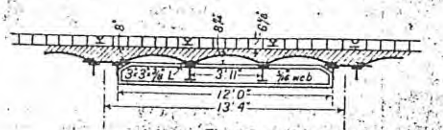


Fig. 40.

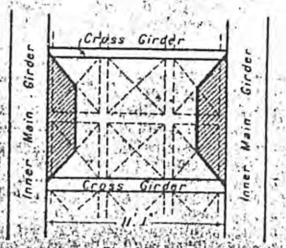


Fig. 41.

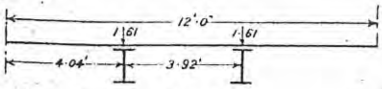


Fig. 42.

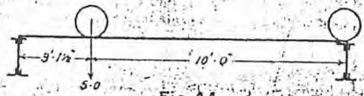


Fig. 44.

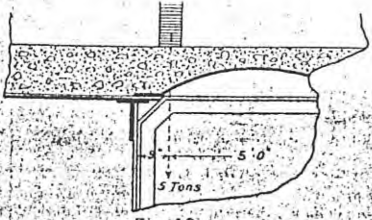


Fig. 43.

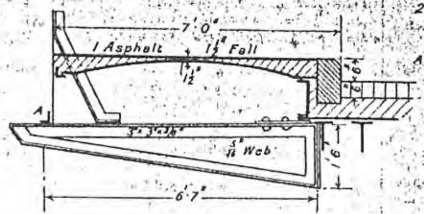


Fig. 45.

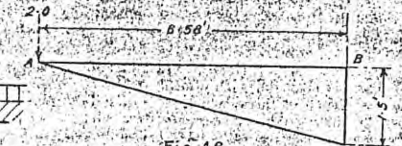


Fig. 46.

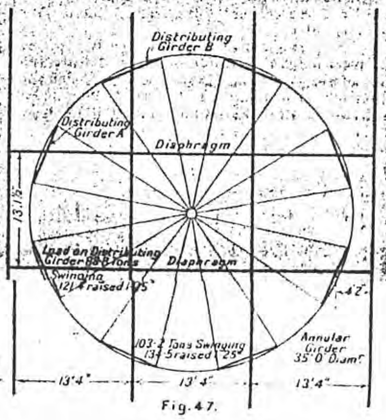


Fig. 47.

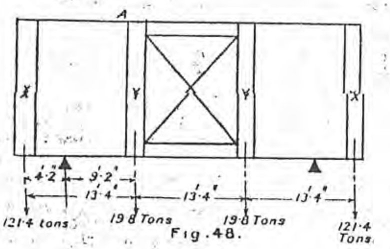


Fig. 48.

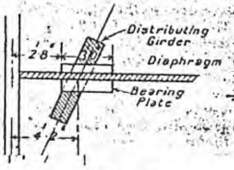


Fig. 49.

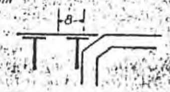


Fig. 50.

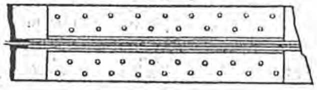


Fig. 51.

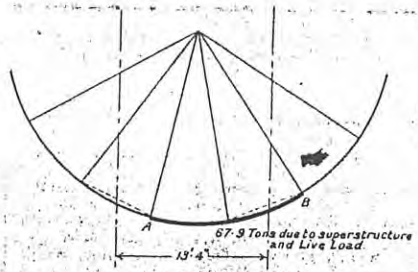


Fig. 54.

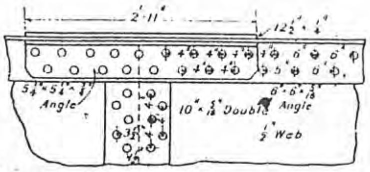


Fig. 56.

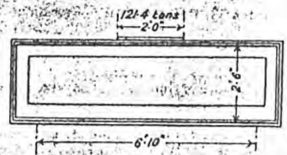
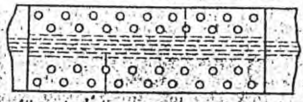


Fig. 52.

Fig. 53.



All rivets ⅞" dia except those through lower cover horiz. Flange which are ⅞" Countersunk

Fig. 57

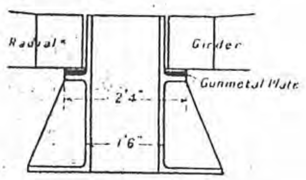


Fig. 58.

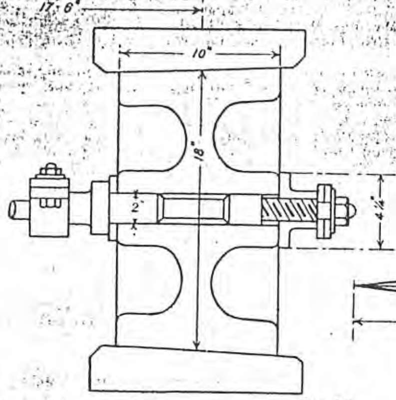
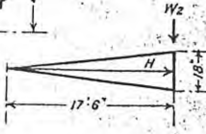


Fig. 59.



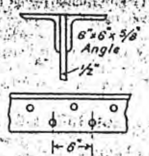


Fig. 55.

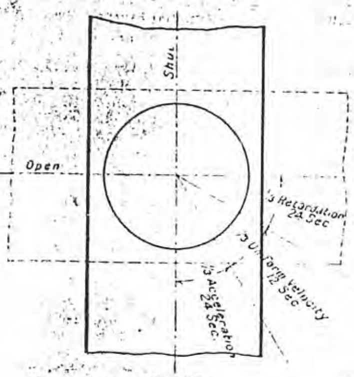


Fig. 60.

"The Engineer"

Swain Sc.

## PYRMONT ELECTRIC SWING BRIDGE.

No. IV.*

The bridge was designed to carry a distributed live load of 100 lb. per square foot of deck, and also for concentrated loads of 20 tons on four wheels with a 8ft. by 5ft. wheel base. The swing span is 219ft. 8in. between centres of bearings on the rest pier, and when it is open for the passage of vessels it affords two clear waterways of 70ft. each.

Calculations for various portions of the bridge lie before us, but, unfortunately, we cannot afford the space to publish them in full detail. We can only refer briefly to some of them. In deciding the unit stresses to be adopted for the swing span, the steel used was taken as having an ultimate strength of 27 tons per square inch; a repetition strength—(0 to a maximum)—of 18 tons per square inch; and a vibrating strength—(+ to −)—of 9 tons. With these figures the unit stresses adopted were:—

*Tension*, unit stress $= 5.14\left(1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right)$

*Compression*, chord segments, unit stress =

$$5.14\left(1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right) - \frac{0.62}{2240}\left(\frac{L}{r}\right)^2$$

Verticals and diagonals, unit stress =

$$4.5\left(1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right) - \frac{0.62}{2240}\left(\frac{L}{r}\right)^2$$

For shear on the field rivets—compression bars—the unit stress adopted was four-fifths of the unit stress adopted for the bar, with a minimum limit of 4.5 tons per square inch; while for tension bars the stress adopted was four-fifths of that adopted for the bar, less 25 per cent., also with a minimum limit of 4.5 tons per inch.

For the stringers in the 8ft. bays rolled joists 10in. by 5in. by 29 lb. were employed. The maximum dead load supported by one of these stringers due to wood blocks, rail, concrete, buckled plate, and the girder itself, was 1.4 tons, and the bending moment due to dead load was 16.8 inch-tons. That due to the rolling load worked out at 120.0 inch-tons, so that the maximum bending moment was 16.8 + 120.0 = 136.8 inch-tons. The unit stress, taking the same ratio as for the main girders, worked out at 5.45 tons per square inch, and taking $\frac{I}{y}$ for the 10in. × 5in. × 29 lb. joist at 28.33, the safe moment of resistance worked at was 28.33 × 5.45, or 154.4 inch-tons. For the connection of the stringer to the cross girder the maximum shear worked out at 5.7 tons, and the strength of the four ¾in. rivets in connection at 6.2 tons.

For the stringers in the 13ft. 1¼in. bays, rolled joists 12in. × 5in. × 30 lb. were used. The maximum dead load on one stringer was 2.3 tons. The bending moment due to dead load was 45.3 inch-tons, and that due to rolling load 196.9 inch-tons, so that the maximum bending moment was 242.2 inch-tons. With $\frac{I}{y}$ = 42.41 the unit stress worked out to 5.7 tons, so that the safe "moment of resistance" was 42.41 × 5.7 = 241.7 inch-tons. For the connection of the stringer to the cross girder the maximum shear worked out 7.3 tons, and the strength of the six ¾in. rivets in connection was 9.2 tons. The arrangement of the inner main girders in the 8ft. bays is shown in the sketches—Figs. 40 and 41. The portion of the load shown by hatched lines in Fig. 41 is taken by the main girders. The area of one bay between the main girders is 88.64 square feet, and of the hatched portions 24 square feet, so that the area of the portion carried by the cross girders is 64.64 square feet. The dead load on each of the cross girders, due to the weight of the girder itself, with its connections for stringers and rivets, and with the weight of the wood blocks, concrete, buckled plates, rails, stringers and tie bars, was 7224 lb., or, say, 3.22 tons. The bending moment due to dead load was 1.61 × 4.04ft., or 6.5 foot-tons—see Fig. 42—and that due to rolling load is 5.0 × 3.5ft., or, 17.5 foot-tons, so that the maximum bending moment was 24.0 foot-tons. The effective depth was 15in., and the unit stress was 5.86 tons per square inch. The area actually required in the flanges was 24.0 ÷ (1.25 × 5.86) or 3.3 square inches. The gross area provided was 4.2 square inches, or, deducting the metal removed for rivet holes, 3.6 square inches net. The maximum shear for the connection of the cross girder to the main girder was 8.9 tons, and the strength of the six ¾in. rivets employed was 9.2 tons—see Fig. 43.

The cross girders in the 13ft. 1¼in. bays carried a dead load of 4.5 tons, and the bending moment due to worked out at 9.1 foot-tons. The bending moment due to the rolling load was 21.7 foot-tons, so that the maximum bending moment was 30.8 foot-tons—see Fig. 44. The effective depth was 15in., and with unit stress 5.91 tons per square inch; the area required in the flanges was 30.8 ÷ (1.25 × 5.91), or, say, 4.2 square inches. The area actually provided was 5.5 square inches gross, or—allowing for the rivet holes—4.7 square inches net. For the connection of the cross girder to the main girder the maximum shear worked out at 11.3 tons, and the strength of the six ¾in. rivets which were used were 12.6 tons.

The general arrangement of the cantilevers carrying the footpaths is shown in Fig. 45. The dead load at the point A, which was made up of the hand-rail and its connecting angles, asphalt, concrete, buckled plate, and the cantilever itself, worked out at 2055 lb. The live load was taken at 2400 lb.—24 square feet at 100 lb. per square foot—so that the total load at A was 4455, or, say, 2 tons. The tension in the member A B—Fig. 46—was therefore 2 × (6.58 ÷ 1.5), or 8.8 tons, and the compression in the member A C was 2 × (6.8 ÷ 1.5), or 9.1 tons. The area required in A B was 8.8 ÷ 6.3, or 1.4 square inch, and the area actually provided was 4.2 square inches gross and 3.6 square inches net. Six ¾in. rivets were employed for connecting the plate at the top.

Fig. 47 is a diagram showing the turntable. The load on the distributing girder A with the bridge swinging was 88.8 tons, and with the bridge raised 1¼in. 121.4 tons, made up of 79.8 tons dead load and 41.6 tons live load. The load on the distributing girder B was, with the bridge swinging 103.2 tons, and with the bridge raised 1¼in. 134.5 tons, made up of 92.2 tons dead load and 42.3 tons live load. The arrangement of the diaphragms between the main girders is shown in Figs. 48, 49 and 50. The load on the outer girders X, X is, with the bridge swinging, 88.8 tons, and with the bridge raised 1.25in. 121.4 tons, made up of 79.8 tons dead load and 41.6 tons live load. The load carried by the inner girders when the bridge is raised 1.25in. is 19.8 tons, made up of 13.1 tons dead load and 6.7 tons live load. The maximum bending moment measured up to the centre of the bearing is 121.4 tons × (4ft. 2in. − 8in.), or 424.9 foot-tons. The unit stress, with 79.8 tons as minimum and 121.4 tons as maximum, working out at 6.85 tons per square inch, the area required in the flanges is 424.9 ÷ (15 × 6.85) = 4.2 square inches. There were actually provided two angles measuring 5½in. × 5½in. × ⅝in., in each of which there were two ¹³⁄₁₆in. holes, so that the gross area was 13.0 square inches, and the net area 10.9 square inches. The web was ⅜in. thick, so that the shear worked out at 121.4 ÷ (180 × ⅜) = 1.8 tons per square inch. For the connection to the outer main girders the cross sectional area of the rivets required was 121.4 ÷ 3.5 = 34.7 square inches. There were, as a fact, 60 1in. and 62 ¾in. rivets, so that the sectional area provided was 78.8 square inches.

For the joint in the diaphragm—top flange—the net area provided by the two angles—5½ × 5½ × ⅝—already alluded to, was 10.9 square inches, so that the strength with unit stress of 6.85 tons per square inch was 74.9 tons. The actual strength of the joint employed was 98.6 tons—see Fig. 51. For the connection at A—Fig. 48—12 rivets were, in all, provided, ten being in double shear and two in single shear, with a combined cross section of 9.68 square inches, so that the stress on them was 424.9 ÷ (15 × 9.68) = 3 tons per square inch.

In the case of the distributing girder A—Fig. 47—with its maximum load of 121.4 tons, the bending moment was (121.4 × 6.83) ÷ 4, or 207.4 foot-tons. The section provided by two 5 × 5 × ½in. angles, and a plate 24 square inches by ⅜in. thick—see Figs. 52 and 53—was 18.5 square inches gross, and 16.3 square inches net, there being two ¹³⁄₁₆ holes in each. The stress on the tension flange worked out therefore at 207.4 ÷ (2.5 × 16.3), or 5.1 tons per square inch; and in the compression flange 207.4 ÷ (2.5 × 18.5), or 4.5 tons per square inch. The maximum shear at the ends, due to superstructure and live load, was 121.4 ÷ 2 = 60.7 tons, and due to the girder 1.3 ÷ 2, or, say, 0.7 tons, the total shear therefore being 61.4 tons; the shear on the web being 61.4 ÷ (30 × ⅜ × 2), or 2.7 tons per square inch. As there were twelve ¾in. rivets per foot run, with a total cross section of 5.28 square inches, the shear on these rivets was 61.4 ÷ (2.5 × 5.28) = say, 4.7 tons per square inch, and the bearing pressure on the web 61.4 ÷ (2.5 × ¾ × 12 × ⅜), or, say, 7.2 tons per square inch. In distributing girder B—Fig. 47—which carried a maximum load of 134.5 tons, the bending moment was (134.5 × 6.83) ÷ 4, or 229.7 foot-tons. The section provided was the same as for girder A. The stress per square inch on the tension flange was therefore 229.7 ÷ (2.5 × 16.3), or 5.6 tons per square inch, and on the compression flange 229.7 ÷ (2.5 × 18.5), or 5 tons per square inch, the maximum stress being (134.5 + 1.3) ÷ 2, or 67.9 tons. The maximum shear on the web was therefore 67.9 ÷ (30 × ⅜ × 2), or, say, 3 tons per square inch. The shear on the rivets worked out at 5.1 tons per square inch, and the bearing pressure on the web 8.0 tons per square inch.

The annular girder was 35ft. in diameter and 5ft. deep, and in the calculations it was treated as a straight girder, having a length equal to one-eighth that of the total circumference, loaded at the centre and supported at the ends. The length of A B—see Fig. 54—was therefore $\frac{1}{8} \times 35 \times \pi = 13.74$, or, say, 14ft. The bending moment with maximum stress of 67.9 tons was (67.9 × 14) ÷ 4, or, say, 237.7 tons, and the flange stress 237.7 ÷ 5, or 47.5 tons. The section provided for this was afforded by two 6 × 6 × ⅝ angles—see Fig. 55—with two ¹³⁄₁₆ holes in each, so that it was 14.2 square inches gross and 12.19 square inches net. The stress per square inch on the flange sections was therefore: on the tension flange 237.7 ÷ (5 × 12.19), or 3.9 tons per square inch, and on the compression flange 237.7 ÷ (5 × 14.2), or, say, 3.4 tons per square inch. The maximum shear being 67.9 ÷ 2, or, say, 34 tons, the shear on the web—see Fig. 55—was 34.0 ÷ (60 × ½), or, say, 1.1 tons per square inch. There were four rivets of ¾in. diameter—or 1.76 total cross section—per foot, so that the shear on them amounted to 34.0 ÷ (5ft. × 1.76) = say, 3.9 tons per square inch, and the bearing pressure on the web was 34.0 ÷ (5ft. × ¾ × 4 × ½), or, say, 4.5 tons.

With regard to the joints in the annular girder—see Figs. 56 and 57—the safe load of the main angles was 12.19 × say, 6.5 tons, or 79.2 tons, and that of the covers 12.18 × 6.5, or, say, 79.2 tons. There were sixteen ¾in. and sixteen ⅞in. rivets in single shear in the bottom cover, so that the shear was 2.9 tons per square inch. The maximum shear on the web splice was 34 tons, and as 23 ¾in. rivets in double shear were provided, the shear on them was 34.0 ÷ (0.44 × 23 × 2), or, say, 1.7 tons per square inch. The bearing pressure on the web was 34 ÷ (23 × ½ × ¾), or, say, 4.0 tons per square inch.

The swinging span revolves on 66 rollers, each 18in. in diameter and 10in. in face. The load on the rollers, with the bridge swinging, was made up as follows:—

| | | Tons. |
|---|---|---|
| Superstructure (177.5 + 172.5 + 206.3 + 204.3) | = | 760.6 |
| Distributing girders, eight at 1.3 tons each .. .. | = | 10.4 |
| Drum .. .. .. .. .. .. .. .. .. .. | = | 13.0 |
| Radial girders, say, ⅓ × 0.5 × 16, say .. .. | = | 5.3 |
| Upper roller track .. .. .. .. .. .. .. | = | 5.0 |
| Machinery and platform, say, ⅓ × 10 .. .. .. | = | 3.3 |
| Total .. .. | | 797.6 |

The load, with the bridge raised 1.25in., was:—

| | | Tons. |
|---|---|---|
| Superstructure (159.5 + 154.5 + 184.3 + 182.3) | = | 680.6 |
| Distributing girders, &c., as above .. .. .. .. | = | 37.0 |
| Live load 2 × 2 (41.6 + 42.3) .. .. .. .. | = | 335.6 |
| Total .. .. .. | | 1053.2 |

The pressure on each of the rollers was therefore:—

*Bridge swinging:* 797.6 ÷ (66 × 10) = 1.21 tons = 24.2 cwt. per lineal inch.

*Bridge raised:* 1053.2 ÷ (66 × 10) = 1.60 tons = 32.0 cwt. per lineal inch.

The area of the masonry under the lower track is given as being 110 square feet, so that with the bridge swinging the load per square foot on it was, say, 825 ÷ 110, or 7.5 tons. With the bridge raised this load became 1070 ÷ 110, or, say, 9.7 tons per square foot. The load on the pivot was 9.4 tons, made up of 2.7 tons for the radial girders, and 6.7 tons for the machinery and platform.

Detailed calculations were made to ascertain the resistance to be overcome in working the swing bridge. They were divided under five headings as follows:—

(1) Rolling friction, referred to as *Fr*;

(2) Sliding friction between the discs of the pivot under the radial girders, referred to as *Fs*;

(3) Collar friction of the rollers, referred to as *Fc*;

(4) Inertia, referred to as *Fa*;

(5) Unbalanced wind pressure, referred to as *Fw*.

Taking (1) first: The formula applied was *Fr* (or the force required at the rack to overcome the rolling friction $= Q_1 W_r (R_1 \div R)$, where $Q_1$ is the co-efficient of rolling friction, taken as 0.003; $W_r$ the weight of the rollers under the drum, which was 797.6 tons, or 1,786,624 lb.; $R_1$ the radius of the drum, 17ft. 6in.; and R the radius of the rack circle, which was 18ft. 7½in., or 18.625ft. Substituting these values the equation becomes $Fr = .003 \times 1{,}786{,}624 \times (17.5 \div 18.625)$, or *Fr* = 5036 lb. For calculating the sliding friction *Fs*, between the discs of the pivot under the radial girders—see Fig. 58—the formula worked to was:—*Fs* (or the force required at the rack to overcome this friction) $= Q_2 W_s \times \frac{2}{3} \times \frac{r_2^3 - r_1^3}{r_2^2 - r_1^2} \times \frac{1}{R}$, where R is the radius of the rack circle, in this case 18ft. 7½in., or 223.5in.; $Q_2$ the co-efficient of sliding friction, taken as 0.1; $W_s$ the weight of the pivot, in this case 9.4 tons, or 21,056 lb.; $r_1$ the interior radius of the gun-metal plate, which was 9in.; and $r_2$ the exterior radius of this gun-metal plate, *i.e.*, 1ft. 2in., or 14in. Substituting these values the equation became:—$Fs = 0.1 \times 21{,}056 \times \frac{2}{3} \times ((14^3 - 9^3) \div (14^2 - 9^2)) \times (1 \div 223.5)$, or *Fs* = 110 lb.

For ascertaining the force—*Fc*—required at the rack to overcome the friction due to the pressing of the rollers against their collars—see Fig. 59—the formula used was $Fc = \phi_3 \times H \times d \times (R_1 \div R)$, where $\phi_3$ is the coefficient of friction taken as 0.1; H is the horizontal force exerted by the roller against the collar by reason of the spreading action caused by the downward weight of the structure acting on the conical periphery of the roller—see Fig. 59; *d* the lever arm of friction or the mean radius on the collar at which this force may be considered as being concentrated; $R_1$ the radius of the roller path, and R the radius of the rack circle. The value of H was obtained by the formula $H = W_r \times 2 (r \div R_1)$, *r* being the radius of the rollers; and the value of *d* by the formula $d = (2 \div 3) \times ((r_2^3 - r_1^3) \div (r_2^2 - r_1^2))$, $r_1$ being the interior radius of the collar, and $r_2$ being its external radius. The values of the various factors involved were as follows:—

$r_1$ = interior radius of collar = ½ × 2in. = 1in.

$r_2$ = exterior radius of collar = ½ × 4¼in. = 2⅛in. = say, 2.13in.

$r$ = radius of rollers = 9in.

$\phi$ = coefficient of friction = 0.1in.

$W_r$ = weight on rollers 797.6 tons = 1,786,624 lb.

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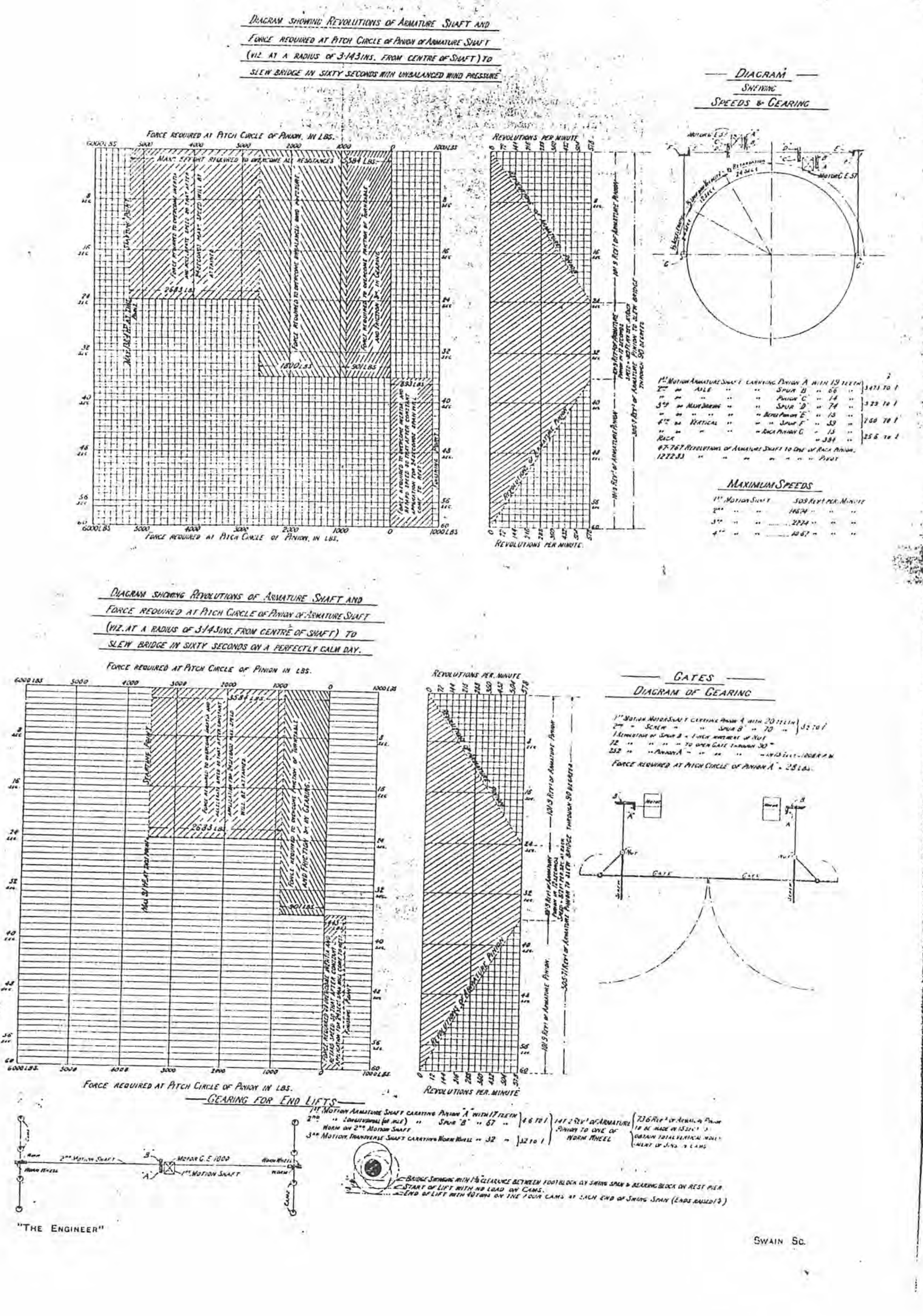
* No. III. appeared February 9th.

# PYRMONT BRIDGE, SYDNEY, N.S.W.—DIAGRAMS OF SWING SPAN AND GATE GEARING

(For description see page 151)



r = radius of roller path = 17ft. 6in. = 210in.
R = radius of rack circle = 18ft. 7½in. = 223.5in

The equation finally became Fc = (2 × 1.63 × 0.1 × 1,786,624) ÷ 223.5, which is equal to 2606 lb.

The moments of inertia were calculated under the following six headings:—

(1) That due to the handrail;
(2) That due to the deck, roadway, and footways, including the cross girders;
(3) That due to the fenders, cams, shafting and roadway cantilevers at the ends;
(4) That due to the diaphragms at the centre;
(5) That due to the main girders and vertical and horizontal bracing;
(6) That due to the distributing girders, drum, &c.

It will not be necessary to go in detail into the calculations involved, but we may give the results arrived at, which were as follows:—

| | Weight. Tons. | Moment of Inertia. |
|---|---|---|
| (1) Handrail | 25.1 | 271,899,264 |
| (2) Deck, cross girders, &c. | 482.5 | 4,781,815,864 |
| (3) Fenders, cams, &c., at ends | 15.2 | 424,045,141 |
| (4) Diaphragms at centre | 18.3 | 7,222,485 |
| (5) Main girders and bracing | 219.5 | 2,128,602,182 |
| (6) Distributing girders, drum, &c. | 37.0 | 25,382,000 |
| | 797.6 | 7,638,974,936 |

This figure divided by 32.2 for gravity yields 237,235,247 lb.

Now, in making the calculation to arrive at the force required at the rack in order to overcome the inertia, it was taken that the bridge was to be opened in 60 seconds. During the first 24 seconds the span was to be accelerated; during the next 12 seconds it was to travel at uniform velocity; and during the remaining 24 it was to be retarded, so that at the end of the 60 seconds it would have come to rest—see Fig. 60. The velocity in feet per second at the rack which the span would reach at the end of the first 24 seconds—that is to say, its maximum velocity—worked out at 0.81, and the formula employed was $Fa = Iv \div R^2t$, where Fa is the force required at the rack to overcome the inertia, I the moment of inertia of the moving mass, i.e., 237,235,247 lb., v the velocity, or .81ft. per second; R the radius of the rack circle, say, 18.63ft., and t the time of acceleration. On substitution the equation becomes—

$$Fa = \frac{237,235,247 \times 0.81}{(18.63)^2 \times 24} = 23,069 \text{ lb.}$$

The total force required at the rack circle, leaving wind forces out of account, and allowing the span to be opened in 60 seconds, may therefore be summarised as follows:—

| | | |
|---|---|---|
| 1. | Fr = rolling friction | 5,036 lb. |
| 2. | Fs = sliding friction between discs | 110 lb. |
| 3. | Fc = collar friction of rollers | 2,606 lb. |
| 4. | Fa = inertia | 23,069 lb. |
| | Total power required at rack | 30,821 lb. |

In making an estimation of the force to be provided to overcome the resistance due to unbalanced wind pressure, the wind was assumed to be blowing at 30 miles per hour, and to be acting on the whole of one arm of the swing span. The pressure due to a wind of 30 miles per hour is taken as being 3.6 lb. per square foot. The total area exposed—arrived at by adding the area of the handrail to twice the area of the main girders—was 1430 square feet, so that the total unbalanced wind pressure on one arm was taken as being 1430 × 3.6 = 5148 lb. The centre of wind pressure being at, say, 56ft. from the centre of the bridge, and the radius of the rack circle being 18.63ft., the force required at the rack circle to overcome unbalanced wind pressure Fw was calculated as follows:—Fw = (5148 × 56) ÷ 18.63 = 15,475 lb. Adding this to the total force required at the rack—without unbalanced wind pressure—i.e., 30,821 lb., the figure of 46,296 lb, is arrived at, and this was the estimated force required at the rack to operate the bridge with wind blowing at 30 miles per hour, and when the swing span is opened in 60 seconds.

A calculation is also given for the force required at the rack when the swing span is opened in two minutes—or 120 seconds. The factor which is altered is the force required to overcome inertia which, as the speed is halved, is divided by four, and becomes 5767 instead of 23,069. The total force required at the rack, allowing for unbalanced wind pressure, is therefore 28,994 lb.

In calculating the power of the motor required for working the bridge, it was decided to add exactly 100 per cent. to the force calculated as being required at the rack pinion. The forces required for opening the bridge in 60 seconds with no wind, and in 60 seconds and 120 seconds with unbalanced wind, may be summarised as follows:—

| | No wind. Open in 60 secs. No. 1. lb. | Unbalanced wind. Open in 60 secs. No. 2. lb. | Unbalanced wind. Open in 120 secs. No. 3. lb. |
|---|---|---|---|
| Force required at rack circle | 30,821 | 46,296 | 28,994 |
| Add 100 per cent. for overcoming friction in shafting and machinery between rack and armature pinion | 30,821 | 46,296 | 28,994 |
| Total force required | 61,642 | 92,592 | 57,988 |
| Maximum velocity at rack circle | .81ft. per sec. | .81ft. per sec. | .41ft. per sec. |

The horse-powers required in the three cases were therefore arrived at as follows:—

Case No. 1: (61,642 × 0.81) ÷ 550 = 90.8 H.P.
Case No. 2: (92,590 × 0.81) ÷ 550 = 136.3 H.P.
Case No. 3: (57,988 × 0.81) ÷ 550 = 43.2 H.P.

The arrangement of the gearing is shown diagrammatically on page 152, which, in addition to giving diagrams of the gate gearing and of the gearing for the end lifts, also gives diagrams showing the revolutions of the armature shaft and the force required at the pitch circle of the pinion of the armature shaft, both with and without unbalanced wind pressure. With regard to the gearing it may be explained that the armature spindle (A) of the motor, which was 2¾in. in diameter, was furnished with a pinion 6.286in. in diameter and 4½in. face. It had 19 teeth placed at 1.0393in. pitch. The wheel (B) into which the pinion geared, was 21.838in. in diameter, and had 66 teeth. The shaft to which it was keyed was 3¾in. in diameter, and it carried at its other end a pinion (C) 7⅞in. in diameter, having a 5½in. face and 14 teeth, 1⅞in. pitch. This pinion in turn meshed with a spur wheel (D) which was 3ft. 5¼in. in diameter, and had 74 teeth. It was carried on a shaft 5in. in diameter in its general length but 4½in. in the neck, on which was keyed the bevel pinion (E) 1ft. 2¾in. diameter and 7in. face. It had 15 teeth spaced at 3in. pitch, and it geared with the bevel wheel (F) which was 3ft. 1¼in. diameter and had 39 teeth. It was keyed to the top of the rack pinion shaft which measured 7¼in. in diameter generally in its length, but was 6¾in. in diameter at the top and 7in. at the bottom. The rack pinion (G), at the bottom of this shaft, was 17$\frac{15}{32}$in. in diameter with a 10in. face, having 15 teeth at 2$\frac{21}{32}$in. pitch. This pinion finally geared with the main rack, which was 37ft. 2⅞in. in diameter and had 384 teeth. The gear ratios were therefore as follows:—

| | |
|---|---|
| 1st motion | 3.473 to 1. |
| 2nd motion | 5.20 to 1. |
| 3rd motion | 2.60 to 1. |
| 4th motion | 25.60 to 1. |

For every revolution of the rack pinion, therefore, the armature spindle revolved 47.767 times. For a complete revolution of the bridge 1222.83 revolutions of the armature spindle were required, and the speed of the motor, when opening the bridge through 90 deg. in 60 seconds, would be 305.71 revolutions per minute.

Space will not permit us to enter into the interesting series of calculations by which Mr. Allan estimated the amount of friction in the gearings and the power transmitted by each shaft. It must suffice to say that he ascertained that:—

| | Horse-power. |
|---|---|
| The fourth motion shaft would have to transmit | 51.2 |
| The third motion shaft would have to transmit | 61.0 |
| The second motion shaft would have to transmit | 67.5 |
| The first motion shaft would have to transmit | 72.8 |

It will be remembered that the total power required at the rack, leaving gearing friction out of account, was (30,821 × .81) ÷ 550, or 45.4. The calculated horse-power developed at the pitch line of the pinion (A) was, as stated above, 72.8. This, however, was a figure only arrived at by theoretical calculation, and, as has been stated above, 90.8 horse-power was actually allowed. As a check of this figure Mr. Allan gives the following calculation. The force required at the pitch line of the rack, allowing 100 per cent. for friction in the gearing, shafting, &c., is 30,821 × or 61,642 lb. One revolution of the rack pinion is 15 × $3\frac{21}{32}$ ÷ 12, or 4.57ft., and one revolution of the armature pinion equals 19 × 1.039 ÷ 12, or 1.645ft. The force required at the pitch line of A and B—see the drawing on page 152—is (61,642 × 4.57) ÷ (47.767 × 1.645) = 3585 lb. The horse-power therefore is (3585 × 13.95) ÷ 550, or 91. The 13.95 is, of course, the maximum velocity in feet per second at the pitch line of A and B.

The accompanying table is interesting as showing the actual results met with in a special series of tests with the swing span moving at different speeds.

The completed cost of the bridge, including £24,070 for the approaches on either side, £484 for the installation of arc lighting and lamp standards, was £112,500, which amount also included items of £5443 for engineering expenses and minor works, and £352 for the removal of portions of the old bridge and sundry expenses.

The work was designed by Mr. Percy Allan, M. Inst. C.E., M. Am. Soc. C.E., who also supervised its construction. To him we are indebted for the particulars from which this series of articles has been prepared, and for the photographs and drawings from which the illustrations accompanying them have been reproduced. The calculations were prepared by Messrs. Dare and Bradfield, MM. Inst. C.E., whilst the late Mr. Lincoln Buswell was the principal assistant in supervising the work of construction. The steel portion of the structure was supplied by La Société Anonyme des Ateliers de Construction de Hal, of Hal, near Brussels.

*Summary of Tests Made to Show the Power Required and Cost of Current for Slewing Span at Different Speeds. Calm Day. No Wind.*

| [illegible] | Time taken to slew span through 83 degrees, seconds. | Maximum effort exerted by motors, horse-power. | Maximum speed of armature shaft, revolutions per minute. | Time for which current was applied, seconds. | Distance travelled by span at time of cutting off current, degrees. | Distance coasted by span between time of cutting off current and bringing span to rest with brake, degrees. | Power consumed by motors, watt-hours. | Power consumed by motors and resistances, watt-hours. | Cost of current for each run at 1d. per unit, pence. | Time taken to slew span through 83 degrees, seconds. |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 30 | 89 | Not recorded. | — | — | — | 269 | 357 | 0.357 | 30 |
| [illegible] | 47 | 97 | 480 | 14 | 20 | 63 | 160 | 232 | 0.232 | 47 |
| [illegible] | 47 | 78 | 580 | 18 | 21 | 62 | 156 | 240 | 0.240 | 47 |
| [illegible] | 47 | 72 | 480 | 24 | 40 | 43 | 185 | 228 | 0.228 | 47 |
| [illegible] | 47 | 57 | 540 | 26 | 40 | 43 | 166 | 213 | 0.213 | 47 |
| [illegible] | 48 | 64 | 500 | 18 | 30 | 53 | 160 | 235 | 0.235 | 48 |
| [illegible] | 49 | 74 | 540 | 17 | 28 | 55 | 168 | 240 | 0.240 | 49 |
| 10 | 51 | 51 | 540 | 30 | 40 | 43 | 154 | 237 | 0.237 | 51 |
| [illegible] | 53 | 58 | 480 | 16 | 28 | 55 | 121 | 210 | 0.210 | 53 |
| 19 | 53 | 78 | 550 | 18 | 25 | 58 | 158 | 232 | 0.232 | 53 |
| 13 | 54 | 40 | 480 | 26 | 37 | 46 | 146 | 212 | 0.212 | 54 |
| 16 | 55 | 70 | 480 | 12 | 13 | 70 | 100 | 192 | 0.192 | 55 |
| 12 | 55 | 72 | 540 | 14 | 13 | 70 | 131 | 204 | 0.204 | 55 |
| 20 | 55 | 48 | 480 | 22 | 35 | 48 | 133 | 183 | 0.183 | 55 |
| 14 | 55 | 45 | 530 | 25 | 33 | 50 | 146 | 207 | 0.207 | 55 |
| 11 | 60 | 67 | 540 | 10 | 14 | 69 | 98 | 186 | 0.186 | 60 |
| [illegible] | 64 | 44 | 440 | 25 | 40 | 43 | 151 | 217 | 0.217 | 64 |
| 21 | 64 | 34 | 480 | 32 | 40 | 43 | 141 | 211 | 0.211 | 64 |
| 15 | 68 | 62 | 480 | 11 | 13 | 70 | 89 | 168 | 0.168 | 68 |
| [illegible] | 69 | 15 | 360 | 45 | 53 | 30 | 113 | 221 | 0.221 | 69 |

Weight of span when swinging 800 tons. Area of floor space on swing span 12,000 square feet. Being slightly on the skew, the span is opened only through 83 deg.

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## ON THE SUITABILITY OF CURRENT DESIGN OF SUBMARINES TO THE NEEDS OF THE UNITED STATES NAVY.*

By CAPT. W. L. RODGERS, U.S.N., Associate.

In accepting the invitation which the secretary of the Society did me the honour to extend in asking me to contribute a paper on submarines, I do not assume that he had any idea that I would undertake to tell the members of this Society anything in regard to the technical and mechanical features of submarines, with which they are already well acquainted. But, as President of the Naval War College some years ago, and ever since then, I have given attention to the strategic and tactical fields of work which are open to submarines in naval warfare. A sketch of these fields and a consideration of possible modifications and variations in design of submarines to meet the requirements of warfare seem to me to offer interest to naval architects, and it is along these lines that this paper will be developed.

In thus discussing the subject, it must be borne in mind that, while the constructional and engineering possibilities of design are pretty well known, and form a stock of knowledge common to designers of all nations, nevertheless the application of this stock of knowledge to the production of concrete designs suitable to the national policy and geographic situation of particular nations will result in types of ships which will differ much according to nationality. This paper will consider some of the controlling factors which should influence American design. In so doing we need not fear the betrayal of any national secret. It is the business of foreign navies through the agency of their general staffs not only to study in advance the requirements of their own forces, but also to examine the situation of other Powers which may become hostile to them, so as to draw deductions as to the enemy's probable efforts and employment of his forces.

Any enemy in thus considering our types of submarines, and their probable employment in war, will no doubt start from very much the same premises as we ourselves assume, namely, the well-known constructional possibilities of submarines varying with the progress of invention, the tactical development of the present war in attack by, and upon, submarines; and, finally, the national policies and geographic situation of the United States. Assuming the enemy has equally good reasoning power as ourselves, and granting he knows the ordinary constructional data as to submarines, it is clear that he will necessarily arrive at conclusions much like our own. If we avoid general discussion in the hope of withholding information from foreigners, it is ourselves who will suffer most, since goodwill and a common understanding between the sea-going navy and the industries which support it are essential to success, and particularly necessary in a democratic nation. In fact, a basis for such a common understanding is provided in the public hear-

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* Read at the twenty-fourth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 16th and 17th, 1916.

# HIGHWAY BRIDGE CONSTRUCTION

FROM INDUSTRIAL AUSTRALIAN AND MINING STANDARD
14 AUGUST 1924
reduced copy

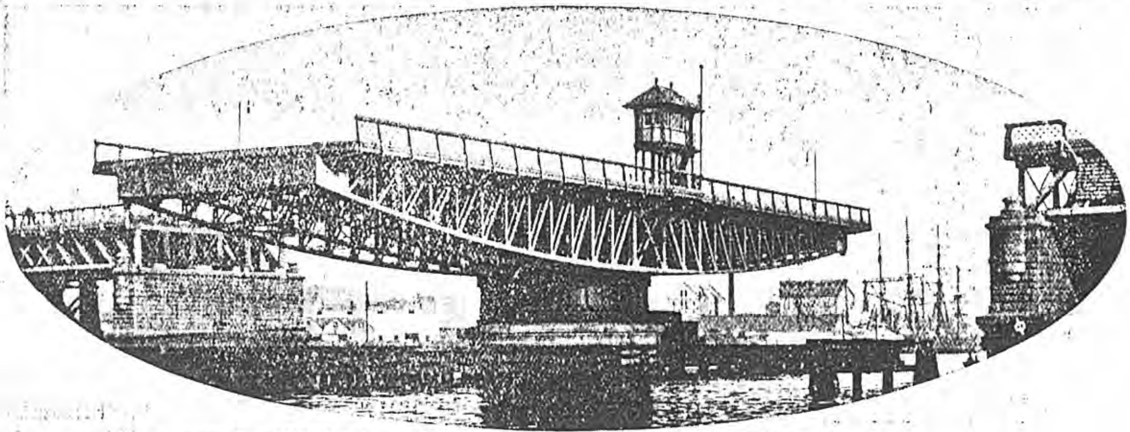

*Fig. XXXIV.—Pyrmont Bridge—Electric-driven Span open for Shipping Traffic.*

# Highway Bridge Construction

## The Practice in New South Wales

**By Percy Allan, M.Inst.C.E., M.Am.Soc.C.E.**

## VI.

*The following article is one of a series that we propose to publish on the practice followed in bridge construction in Australia. The conditions to be met in satisfying the requirements calling for the construction of a bridge, vary widely, according to those conditions and the natural features on site. For this reason alone the activities of those responsible for the design and construction of bridges, provide a field full of instruction and interest to engineers. But the subject has an additional charm, in that the bridge building art calls for the exercise of much original thought in the choice of materials available locally, and their adaptation to the work in hand.*

*The series opens with several articles by Mr. Percy Allan, Chief Engineer for National and Local Government Works, and the light that is thrown on his original work, in the use of New South Wales timbers, illuminates one detail of the excellent work done by him during his 46 years' service to that State. During his period of Public Service, Mr. Allan has designed over 550 of the bridges built in New South Wales, including the well known Pyrmont and Glebe Island Electric Swing Bridges, which were constructed under his immediate supervision.—Editor.*

### MOVABLE BRIDGES.

**Bascule Bridges**

So far back as 1890 several bascule or end lift bridges of a cheap character were erected in New South Wales. The leaf and towers were of timber, the varying of counterweight, as span is raised, being provided for by successively dropping sections of the weights on stops secured within the hollow towers which were of the same height above top of pier as span of opening, as shown in the following photograph of bridge over Shea's Creek (Fig. XXXII.), erected in 1895 at a cost of £3494.

The great height of tower with the pull on the top thereof consequent upon the raising or lowering of leaf, has resulted in the top of towers canting, in spite of the tie rods anchoring the top of towers back to the side spans, clearly showing the necessity of a large based tower with this class of bridge.

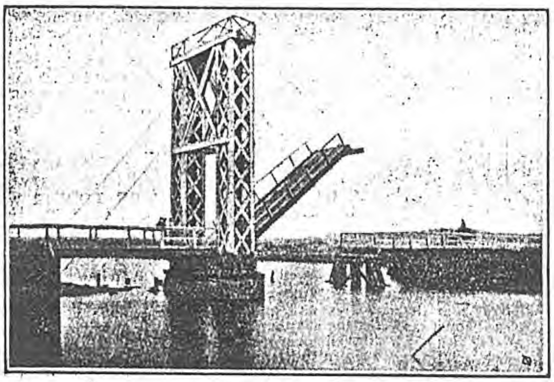

*Fig. XXXII.—Shea's Creek Bridge.*

Although these bridges have met the requirements of the small amount of shipping traffic at the sites where erected, yet in busy locations on the coastal rivers such structures were quite unsuitable, whilst with masted vessels to be provided for, lift bridges with limited headway were inadmissible.

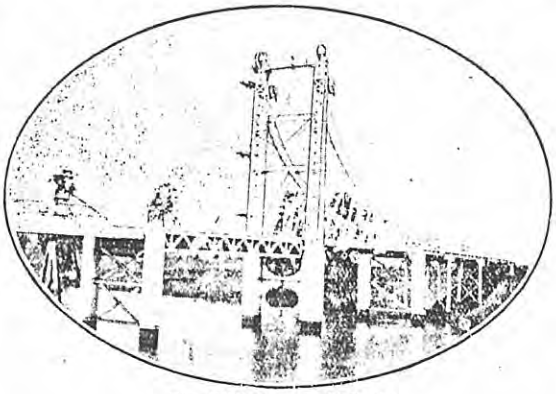

*Fig. XXXIII.—Coraki Bridge.*

Mr. Dare, M.Inst.C.E., accordingly in 1903 prepared the design for bascule type of movable span shown in the accompanying photo. (Fig. XXXIII.) of the bridge over the Richmond River at Coraki, erected at a cost of £9275.

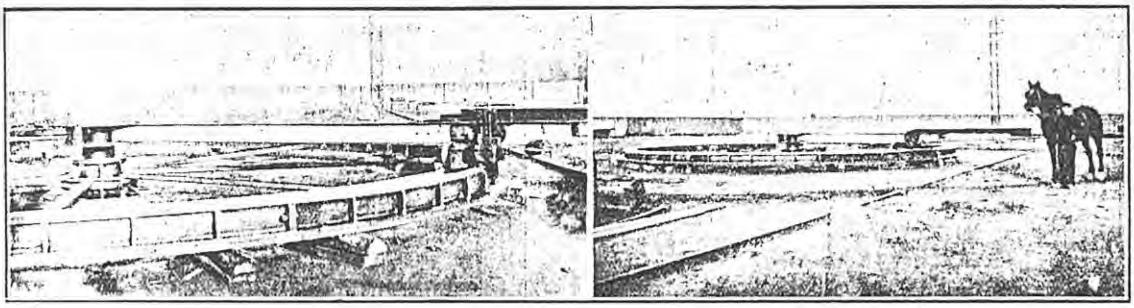

*Fig. XXXV.* *Fig. XXXVI.*

*Pyrmont Bridge—Turning up Edges of Treads and Track.*

In this type of bridge the curved roller path with constant weight ensures bascule span being balanced in all positions, and, being easily operated by hand gearing, has well met requirements.

**Swing Spans**

Although there are swing bridges over the Murrumbidgee River at Hay, the Lane Cove River at Figtree, and over the Parramatta River at Gladesville, yet the most important structure of this type in New South Wales is the Pyrmont electric swing bridge (Fig. XXXIV.), designed by the writer, erected under his supervision, and opened for traffic on 28th June, 1902. At that time this bridge was said to be provided with the fastest and most up-to-date swing span in the world, the ends of the span attaining a maximum speed of over four miles per hour, whilst all the operations, including the working of the gates, were performed electrically.

When, however, in 1907 a paper on this bridge by the writer was read before a meeting in London of the Institution of Civil Engineers, a doubt was expressed in the ensuing discussion as to the reliability of electrical operation, it being pointed out how serious a stoppage of traffic would be, and that bridges in such important positions should always be ready to work, many hydraulic swing spans being cited as having fully met such requirements.

In view of this, and of the fact that the Pyrmont swing span has been in operation for 21½ years with but one stoppage of 18 hours due to the crushing to pieces of a 6-in. diameter solid steel worm actuating one of the end lifts, some particulars of the bridge, with details of power costs of operating the swing spans and other data, are furnished as follows:—

The swing span is of the rim-bearing type, the whole 800 tons weight—with the exception of some 9.4 tons which is carried directly by the pivot—being equally distributed on 66 cast steel conical rollers on which the span revolves.

The cast iron track is of bridge section machined top and bottom, and is bedded direct on the masonry of pivot pier; to the top flange of the track is secured a steel coned tread, this steel tread being machined on all surfaces with the view of obtaining the best possible roller path. Upon this path the 66 conical rollers, 18in. diameter (on centre line), revolve.

The top tread is of the same section as bottom tread, and is secured to the bottom flange of a steel drum 35ft. diameter by 5ft. deep, carrying the distributing girders and superstructure. There being no lathe in England or on the Continent with a rigid face plate or table of 37ft. diameter, this portion of the work was carried out as follows:—

The cast iron track segments were planed paralleled top and bottom in an ordinary planing machine; the ends were then machined, and the whole of the segments bolted up in a ring, as seen in Fig. XXXV. The ring was laid down and carefully levelled with a dumpy level, the pivot being mounted in the centre. A special carriage was constructed with the two rollers running on the top of the ring, and constrained to move round the centre by a radius rod. A tool in the tool box fixed on the carriage could be brought to bear on the vertical edges of the cast iron ring, and the carriage was pulled round by a horse trained to work a roundabout, seen in Fig. XXXVI.

Each segment of the conical tread, after being machined on one surface, was connected by set screws to the planed top flange of a segment of the cast iron track. This segment of track was connected to, and formed the rim of, a wrought iron framed sector of a circle, so arranged as to move freely round a pivot, the planed bottom flange of segment sliding on rests attached to an ordinary planing machine. Whilst there was no difficulty in securing the bottom tread to the cast iron track when once the track was level and bolted down to its temporary foundations, yet some difficulty was anticipated by the manufacturers in obtaining a good job with the top threads, which had to be secured to angle bars of the drum without intervening packing. When, however, the cast iron track was fixed perfectly level in position on its temporary foundation, the drum with the bottom flange angle bars loosely bolted to the web, was put to rest on the track, the angle bars being then securely clamped down thereto, and whilst in that position the holes were rimered through the web plate and angle bars, and the rivets were then closed. Owing, no doubt, to the very highest class of work being specified, and to the great care taken by the manufacturers of this portion of the work, there is not in the bridge as working today one idle roller in the live ring.

The two 50-h.p. series wound tramway motors for slewing the swing span are fixed to a platform over the pivot, see Fig. XXXVII., and drive through cut steel gearing a main horizontal shaft carrying at each end a bevel pinion meshing with bevel gears keyed to the tops of the two vertical shafts on the outside of the drum. The vertical shafts (Fig. XXXVIII.) carry pinions on their lower ends which mesh with a rack fixed to the cast iron track running right round pivot pier.

The gear reduction is 1223 revolutions of the armature shaft to one complete revolution of span. To stop the span in its correct position without jarring, a latch and catch are provided for each rest pier.

The latch (see Fig. XXXIX.), carrying on its end a small wheel, is free to move vertically upwards in brackets secured to swing span and is adjusted by a counterweight so as to drop into catch with the required velocity.

The catch (see Figs. XXXIX. and XL.) is pivoted and secured at its lower end to a girder on the rest pier, whilst near the upper end of the catch are placed two heavy coil springs.

The latch wheel rolls up the inclined plane on the

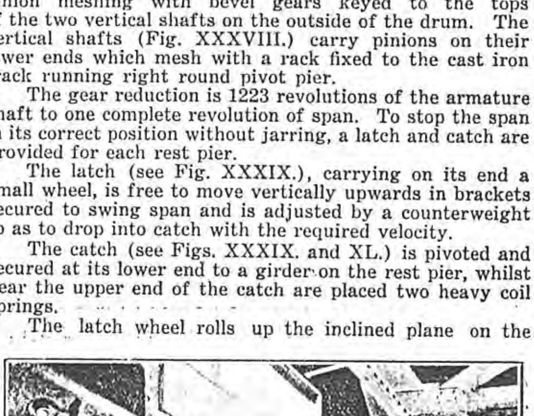

*Fig. XXXVII.—Pyrmont Bridge—Machinery Room, showing Slewing Motors and Gear.*

# PYRMONT BRIDGE - CONSTRUCTION AND RESTORATION

BY E.G. TRUEMAN
INSTITUTION OF ENGINEERS AUSTRALIA
VOLUME GE14 NO.1, 1990

catch and drops into the recess, the momentum of the span bringing into play the coil springs, which either bring the ends of the span back to correct position or move sufficiently to allow the latches to release themselves, when, by reversing the controller, the latches are again brought into engagement.

The end lifts are operated by a 35-h.p. series wound tramway motor fixed at centre of span (see Fig. XLI.), driving through a cut pinion and spur wheel, a longitudinal shaft running the whole length of span which actuates at each end of span, by means of right and left hand worm gearing, two transverse shafts each provided with four cams of 1½in. throw which raise or lower the ends of the span 1¼in. and leave the foot blocks 1⅜in. clear of the pedestal on rest piers, as shown in Figs. XLII. and XLIII. The gear reduction is 147 revolutions of armature shaft to one of cam shaft.

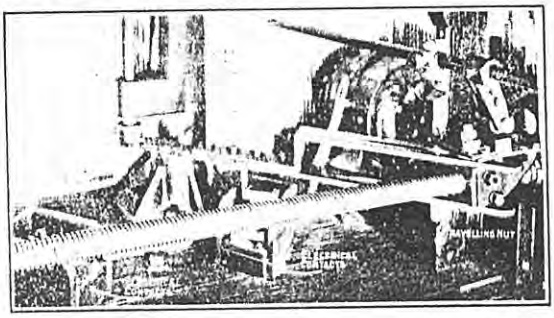

*Fig. XLIV.—Pyrmont Bridge — Motor, Gearing, Screwed Shaft, Travelling Nut, Levers and Electrical Contacts for operating Gates.*

The hinges of each footpath gate are keyed to the spindle of the roadway gate, the spindle being extended below the deck to the machinery platform below.

For each gate a 5-h.p. series wound motor drives through a bevel pinion and gear a longitudinal threaded shaft carrying a gunmetal travelling nut, having projecting pins at top and bottom. The motor, gearing, screwed shaft, travelling nut, levers, and electrical contacts for operating the gears are shown in Fig. XLIV., the gates being controlled from the overhead cabin at centre of swing span.

The whole of the operations for working the swing span, which involves the opening and closing of gates, the drawing of the latches by hand, the lowering and raising of the ends of span and footblocks, and the slewing of the swing span, are performed by one man from a cabin over the footpath at centre of swing span.

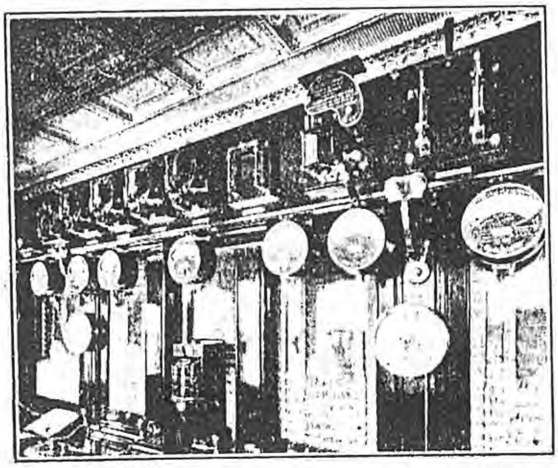

*Fig. XLV.—Pyrmont Bridge—Interior of Controlling House.*

The controllers are of the series parallel type and are arranged in line in the cabin, with switchboard immediately over same, as shown in Fig. XLV.

In the 21 years ending the 30th June, 1923, the swing span was opened 126,522 times for the passage of 202,063 vessels, which involved 1,012,176 individual gate movements of the four roadway gates on the side spans in a busy traffic. This traffic, at the last count on 8th September, 1922, totalled, per diem, 9219 rolling stock and 9637 pedestrians.

With current obtained from the Railway Commissioners' power house at Ultimo at 1d. per unit, the total cost of power for operating the swing span for the 21 years was £378, which amount covered the opening and closing of the swing span 126,522 times, the opening and closing of the four gates and lowering and raising the ends of the span, the cost for power for performing one complete cycle of operations being 0.717 of a penny, and the time of opening or closing swing span one minute.

The wrought iron caisson for the pivot pier carrying swing span is 32ft. and 42ft. internal and external diameter respectively, the inner skin at bottom being bell-mouthed to meet the outer skin to form a cutting edge. The caisson was sunk by open dredging and weighting with concrete between the shells. The caisson finished 1ft. below low water. A temporary wrought iron caisson from this point reached to 2ft. above high water mark, this having been used for building the masonry work between tides. The whole of the masonry was laid in the dry, and on completion of the pier the temporary caisson was removed, leaving only the stonework visible. The total weight on the foundation of the pier, including superstructure and swing span, is 6800 tons, neglecting friction and buoyancy, whilst the completed cost of pier was £14,320.

The rest pier at the Pyrmont end of the swing span is founded on rock, whilst the Sydney rest pier is carried on 58 piles driven to the rock bottom about 64ft. below low water mark. At the site of Sydney rest pier an area somewhat larger than the base of the pier itself was dredged with a ladder bucket dredge until a level bottom was secured 32ft. below low water. The foundation piles, finishing alternately 2ft. and 3ft. 6in. above the clay bottom, were then driven with a follower to refusal, when, by tapping out the bolts which passed—in slack holes—through the four flitches and the pile head, the followers were released by a diver. Guide piles were then driven and horizontal walings placed in position surrounding the foundation piles. Vertical hardwood sheathing, formed of two thicknesses of 1½in. planking and in 6ft. sections, was next lowered, the inner surface forming a mould with a smooth face for the concrete base of pier.

On completion of the sheathing the silt was removed from between the pile heads and concreting was then proceeded with, the timber depositing boxes fitting between the pile heads, the boxes being guided into place by divers. The concrete above pile heads, and within 2ft. of low water, was deposited by means of single rope self-tripping boxes specially designed by the writer for the purpose. Each box held 22 cubic feet of concrete and was provided with top and bottom bars, the lower set at an angle so as to minimise disturbance in depositing.

The concreting was carried through without a break, little trouble being consequently occasioned by laitance. After the concrete had been allowed to set for 14 days the water was pumped out of the dam, and after the laitance of the consistency of chalk had been removed from the surface, concrete in the dry to within 1ft. of low water mark was laid, a sandstone masonry facing with concrete backing from this point to above high water mark being carried out in the dry. The cost of the two rest piers complete was £9217.

The bridge was designed to carry a distributed live load of 100 lb. per square foot of deck, and also for concentrated loads of 20 tons on four wheels with a 10ft. x 5ft. wheel base. The swing span is 219ft. 8in. between centres of bearings on the rest pier with a 40ft. carriageway and two 7ft. footpaths.

In deciding the unit stresses to be adopted for the swing span, the steel used was taken as having an ultimate strength of 27 tons per square inch, a repetition strength (0 to a maximum) of 18 tons per square inch, and a vibrating strength (+ to —) of 9 tons. With these figures the unit streses adopted were:—

Tension, unit stress $= 5.14 \left\{1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right\}$

Compression, chord segments, unit stress =

$$5.14\left[1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right] - \frac{0.62}{2240}\left(\frac{L}{r}\right)^2$$

Verticals and diagonals, unit stress =

$$4.5\left[1 \pm \left(\frac{1}{2} \times \frac{\text{min.}}{\text{max.}}\right)\right] - \frac{0.62}{2240}\left(\frac{L}{r}\right)^2$$

For shear on the field rivets—compression bars—the unit stress adopted was four-fifths of the unit stress adopted for the bar, with a minimum limit of 3.5 tons per square inch; while for tension bars the stress adopted was four-fifths of that adopted for the bar, less 25 per cent., also with a minimum limit of 3.5 tons per inch.

In concluding the particulars regarding Pyrmont Bridge, it may be of interest to recall that in 1891 competitive designs were invited for a new bridge, and the conditions calling for a swing span with only 38ft. deck and two 60ft. fairways. £1200 was paid in premiums, and the premiated design was estimated to cost £295,000, as against the actual cost of £112,500 for the existing bridge, with a swing span having a deck width of 54ft. and affording two fairways of 70ft., the time of opening being but one minute, as against three minutes estimated as required in the prize design.

In the foregoing articles on highway bridge construction in New South Wales the writer has only mentioned the engineers responsible for the different designs, but wishes to make clear how much—so far as his own works are concerned—he is indebted to the officers who made the calculations and the mechanical engineering draftsmen who, in a number of cases, originated the more important details on which the success of the designs has been so largely dependent. The period covered, however, is so long that the writer feels it would be invidious to single out for mention a few of the many excellent men who were engaged from time to time on the different designs, and accordingly thinks it better to meet the case with a general acknowledgment of the valuable and efficient assistance received.

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# Accident Causation in Factory and Elsewhere*

**By Frank R. Kerr, D.S.O., M.D., D.P.H., Division of Industrial Hygiene, Commonwealth Department of Health.**

(Continued from page 400.)

### Discussion of Tables.

**Causes of Accidents (Table No. 1).**—Pneumatic tools should rightly be included under "working machinery," but are considered with hand tools as it was impossible at times to make a distinction.

In the under 21 class the principal causes were hand and pneumatic tools 35.4 per cent.; falls of persons, 18.3 per cent.; and working machinery, 15.1 per cent. Among the adults tools were responsible for 22.2 per cent., handling without machinery 19.9 per cent., and falls of persons and falling objects each 16 per cent.

Thus, taking all ages together, hand and pneumatic tools caused 25.4 per cent., handling without machinery 17.3 per cent., and falls of persons 16.5 per cent.

The relative importance of machinery as a cause of accidents is shown thus:—

| | Machinery. | Non-Machinery. |
|---|---|---|
| Under 21 .. .. .. .. | 17.2 per cent. | 82.8 per cent. |
| 21 and over .. .. .. | 13.8 per cent. | 86.2 per cent. |
| All ages .. .. .. .. | 14.7 per cent. | 85.3 per cent. |

Thus among the apprentices machinery was slightly more important as a factor than among adults.

**Location of Injury (Table No. 2.).**—The injury was located in the head and neck of those under 21 in 35.5 per cent., in the upper extremities 31.2 per cent., and in the lower extremities 16.1 per cent. In the case of adults the upper extremities were injured in 28.5 per cent., the lower extremities 23.6 per cent., head and neck 21.5 per cent. In both groups together upper extremities were responsible for 29.1 per cent., head and neck 24.9 per cent., and lower extremities 21.8 per cent.

Injuries to the head and neck, plus injuries to upper extremities, included 66.7 per cent. of all accidents under 21, 50 per cent. 21 and over, and 54 per cent. all ages together.

The high figure (35.5 per cent.) for head and neck injuries under 21 was largely due to an undue prevalence of eye injuries. (See Table No. 3.)

**Nature of Injury (Table No. 3).**—The nature of the injuries sustained by those under 21 were:—Eye injuries, 28 per cent.; contusions and abrasions, 19.4 per cent.; sprains and strains, 19.4 per cent.; cuts and lacerations, 15.1 per cent.

In the case of adults, contusions and lacerations were the nature of 28.1 per cent. of all injuries, sprains and strains 24.7 per cent., cuts and lacerations 22.2 per cent., and eye injuries 13.2 per cent.

Considering all ages there were 26 per cent. contusions and abrasions, 23.4 per cent. sprains and strains, 20.5 per cent. cuts and lacerations, and 16.8 per cent. eye injuries.

The eye injuries practically exclude everything except foreign bodies in the eye, and it is interesting to note the much greater frequency of this type of accident among the apprentices (28 per cent.), as compared with adults (13.2 per cent.). Most of these cases occurred while the men were chipping or hammering plates, a piece of rust accidentally being caused to enter the eye.

There were three amputations, one among the younger employees and two among the adults. No fatal injuries occurred. The more serious injuries (concussions, amputations, dislocations, and fractures) were found to be, in the case of those under 21, 5.4 per cent. of the total, in adults 6.3 per cent., and both groups 6 per cent.

**Monthly Incidence (Table No. 4).**—There is not much of moment in this table, except that on the whole the tendency was for more accidents to occur in the colder and darker months, as shown by the following:—

| | May to Oct. | Nov. to April. |
|---|---|---|
| Under 21 .. .. .. | 57 accidents | 36 accidents |
| 21 and over .. .. .. | 157 ,, | 131 ,, |
| All ages .. .. .. | 214 ,, | 167 ,, |

Taking all ages, the smallest figures occurred in November, December and January.

**Days of the Week (Table No. 5).**—Friday was the principal day for those under 21, Tuesday for adults. Taking both groups, more accidents occurred on Tuesday, with Monday very close, after which there was a gradual diminution throughout the week.

**Hours of the Day (Table No. 6).**—No information was given in 111 cases, 27 under 21, and 84 21 and over. In the case of apprentices there was a gradual rise to 12 noon, and an irregular distribution during the afternoon, the greatest number being between 2 and 3 and between 5 and 6.

In the case of adults, there is again a steady rise to 12 noon, a sudden drop after lunch, and again a gradual increase to 5 o'clock. After this hour there were small numbers working overtime, but exact numbers could not be ascertained. It must be noted that the majority of accidents between 12 and 1 occurred just after 12 noon (knocking-off time), and should strictly be included in the previous column.

**Period and Extent of Disability (Table No. 7).**—(a) Temporary: 255 out of the total 378, or 67 per cent., were incapacitated for two weeks or less, 80 or 21 per cent. two to four weeks, 34 or 8.9 per cent. four to thirteen weeks. There were also six others thirteen weeks to six months, two others over six months and up to one year, and one over one year and up to two years. There were no apprentices incapacitated for a longer period than six months. (b) Permanent: The three amputations are considered here. Under 21, one case, 5 per cent. disability. Twenty-one and over, there were two cases, one with 0 per cent. disability, and the other with 75 per cent.

**Average Number of Working Days Lost per Man (Table No. 8).**—This worked out as 3.55 working days lost per employee—those under 21, 3.35; those 21 and over, 3.59. Thus the adults lost slightly more time per man than the apprentices.

In the case of those under 21, 1919 was the most expensive year, after which there was a gradual improvement until 1922, when a secondary rise took place. The adults lost more time per man in 1922 and 1923, which phenomenon is also obvious when all ages are considered together.

This figure (3.55) is high for the number of working days lost by employees through accident. Assuming that six days is the average time lost per year through sickness and accident, about one-fifth of this, or 1.2 days, would be due to accidents alone. Thus the number of days lost by the dock workers is almost three times the average figure among the various Australian occupations about which information is available.

**Percentage of Men Injured (Table No. 9).**—19.24 per cent. of all employees were injured some time or other through each year, 26.65 per cent. of those under 21 meeting with accidents, and 17.66 21 and over.

Thus it is noticed, comparing this table with No. 8, that apprentices were more often injured than adults, but their injuries were less serious, so that they lost fewer working days per man. The average length of time off was, in the case of apprentices, 12.6 days, but 20.4 days in the case of adults. This percentage injured (19.24 per cent.) is high when other occupations are considered. During 1920-1922 the highest accident rate among occupational groups in New South Wales (the only State which furnishes comparative statistics) occurred in the smelting and mining classes, 19.03 and 19 per cent. of employees being injured respectively each year. The accident rate was above the average (6.83 per cent.) in the following groups:—

| | Per Cent. |
|---|---|
| Motor car and motor bus services .. .. .. | 16.41 |
| Sea transport .. .. .. .. .. .. .. .. .. .. | 14.77 |
| Pastoral and rural .. .. .. .. .. .. .. .. | 14.61 |
| Quarrying .. .. .. .. .. .. .. .. .. .. .. | 14.29 |
| Mineral treatment .. .. .. .. .. .. .. .. | 13.03 |
| Iron trades, metals, machines, implements, conveyances .. .. .. .. .. .. .. .. .. .. .. | 11.08 |
| Brick, cement, pottery, etc. .. .. .. .. | 10.27 |
| Building .. .. .. .. .. .. .. .. .. .. .. | 9.96 |
| Furniture and wood-working trades, etc. .. | 9.43 |
| Electrical power supply .. .. .. .. .. .. | 9.23 |
| Labouring, general .. .. .. .. .. .. .. .. | 9.23 |

**Compensation Paid.**—The amount of compensation paid to the dockyard employees from 1919 to 1923 on account of the 381 accidents was £3364 7s. 11d., or an average of £8 16s. 7½d. per accident.

**Precautions Taken against Accident Occurrence.**—There is no accident prevention organisation at the dockyard, nor are any means taken to educate the employees in the principles of safety. What machinery there is is fairly well guarded, but from the figures in Table 1 machinery caused but 14.7 per cent. of all the total accidents. A great many accidents were of the nature of contusions and abrasions, sprains and strains, cuts and lacerations, caused by tripping over or knocking against objects, treading on rusty nails, or being hit by a falling object. The great amount of waste material lying about—planks, bars of iron, plates, etc., was most noticeable during an inspection. A great deal of this is unavoidable from the nature of the work, but a method of "shop housekeeping" and a good clean up would prevent a great number of accidents. Hand and pneumatic tools caused 25.4 per cent. of all injuries, and it is perhaps possible that complete instruction in the use of these tools is not given.

(To be continued.)

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# TAURANGA (N.Z.) SCHEME OF POWER DEVELOPMENT.

The Tauranga Electric Power Board took a poll of ratepayers on August 30 on the proposal to raise a loan of £100,000.

Great interest was manifested in the poll. The scheme is the most important that has yet been launched in the Tauranga county. As a result of the poll, the ratepayers have sanctioned the loan, and the money will be expended in erecting reticulation lines and assisting settlers in installing motors and lighting.

Dairying is the most important industry in the Tauranga county, and it is expected that the service provided will be the means of greatly facilitating the progress of the districts served.

The board has completed an arrangement under which electrical energy will be purchased in bulk from the Tauranga Borough Council. Supplies will be given from the McLaren Falls power station, which, it is anticipated, will be in operation in April next.

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[illegible] "Health." [illegible]

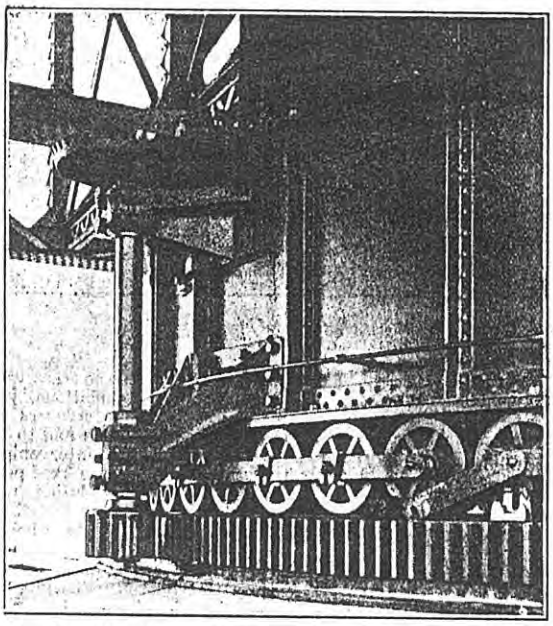


*Fig. XXXVIII.—Pyrmont Bridge — Rack, Driving Pinion, Vertical Shaft and Bevel Gears for Slewing.*

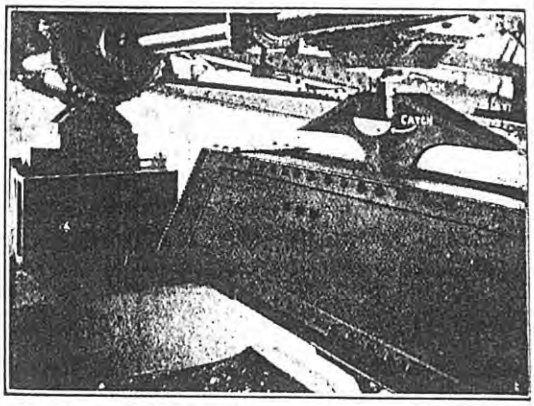


*Fig. XXXIX.—Pyrmont Bridge—Latch and Catch—Latch drawn up.*

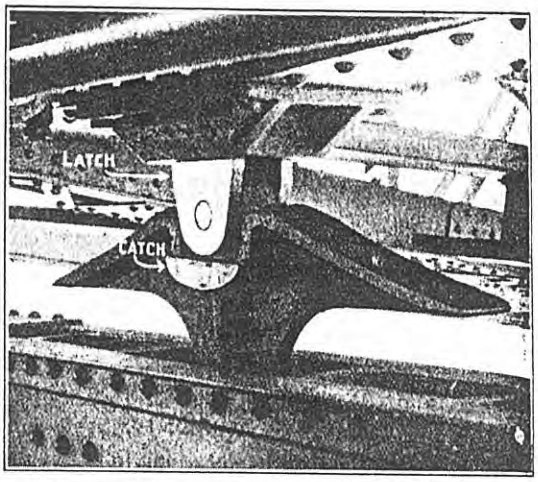


*Fig. XL.—Pyrmont Bridge—Latch and Catch for Stopping Span—Catch Engaged.*

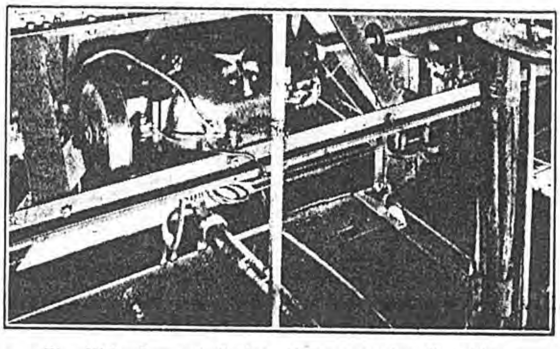


*Fig. XLI.—Pyrmont Bridge—Motor operating End Lifts.*

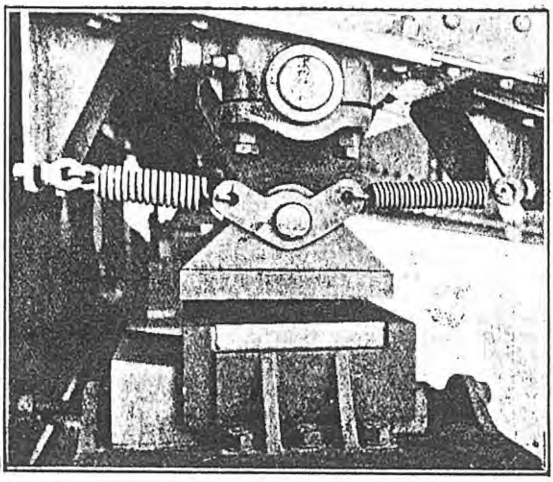


*Fig. XLII.—Pyrmont Bridge—End Lifts, ends of Span lowered and foot blocks raised clear of Pedestals ready for swinging.*

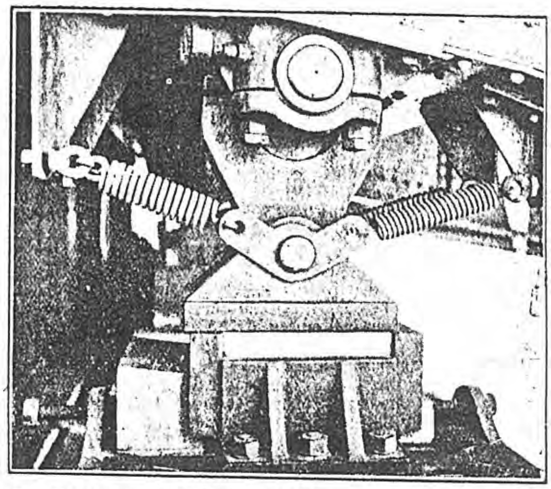


*Fig. XLIII.—Pyrmont Bridge—End Lifts, ends of Span raised full height.*

# Pyrmont Bridge - Construction and Restoration

E.G. TRUEMAN
Director, Hughes Trueman Ludlow

SUMMARY This paper describes the construction of Pyrmont Bridge and the features that justified its significance, both at the time of construction and in present day terms. It also describes the investigation and restoration carried out to incorporate the bridge as an important element in the Darling Harbour Project.

## 1. INTRODUCTION

Pyrmont Bridge must be considered one of the most important bridges in Australia. Started in 1899 and completed in 1902, this bridge stands as an outstanding example of Australian engineering. It was a focal point for national pride at the time of Federation.

The bridge is worthy of comment for its many innovative engineering design features. It was a masterpiece of construction and compares most favourably with the Tower Bridge in London which was finished only 8 years earlier.

Pyrmont has approximately 6,100 sq m of area, while Tower Bridge has 4,700 sq m. Pyrmont was built in 2 years and 9 months, while Tower Bridge took 8 years. Pyrmont opens in 38 seconds, Tower Bridge 90 seconds. Pyrmont cost £1.53 psf including approaches, Tower bridge UK £5.4 psf. At the time of its completion it was said to be larger in area than any bridge in the UK and had the largest and most up-to-date swing span in the world.

Above all, it was Australian designed and Australian built. Even now few major bridges in this country can claim this distinction.

The bridge is 369m (1210 ft) long with twelve timber trussed spans each having six 25m (82 ft) timber trusses, and a central electrically operated steel swing span with twin 34m (112 ft) fairways. It was designed by Percy Allen, who also supervised the construction. He was an outstanding engineer by any yardstick. In his 46 years of practice he was responsible for the design of over 550 bridges built in NSW, and his work includes the development of the truss that bears his name.

## 2. EARLY HISTORY

The bridge replaced an earlier timber girder bridge, also with a swing span, which was built by a private company in 1857 and charged tolls until purchased by the Government in 1884, after which the tolls were abolished. As well as being a traffic problem, the earlier bridge was rather unstable despite having been strengthened around 1890. In 1894 an average days traffic included 3505 horse drawn vehicles, 97 horsemen, 360 animals alone, and 7359 pedestrians. The bridge opened an average of 14 times each day with a total delay to traffic of 1 hour 7 minutes. A new bridge was essential.

A competition was announced in 1894 for designs for a new bridge. The entries were described in "The Building and Engineering Journal" as

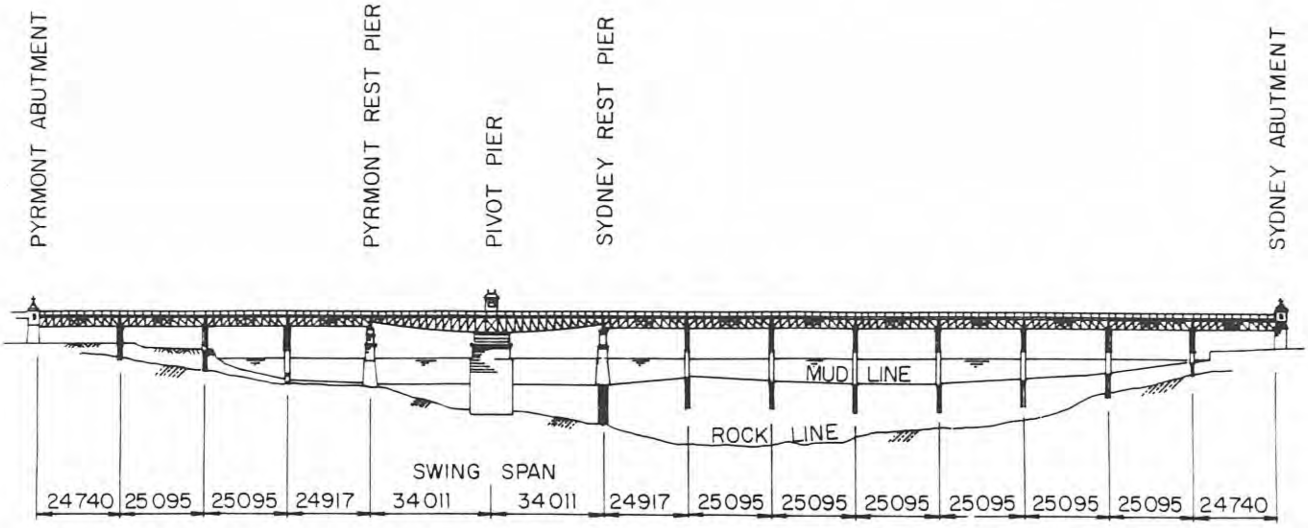
> "unique in many ways, in that they excite all sorts of emotions-admiration, sympathy, laughter and respect"

Forty-one entries were received, with the first prize of £700 being awarded to two gentlemen, one of whom was Chief Assistant Engineer on the Forth Bridge. The cost of the bridge was estimated at £296,000. An Australian design was placed fifth.

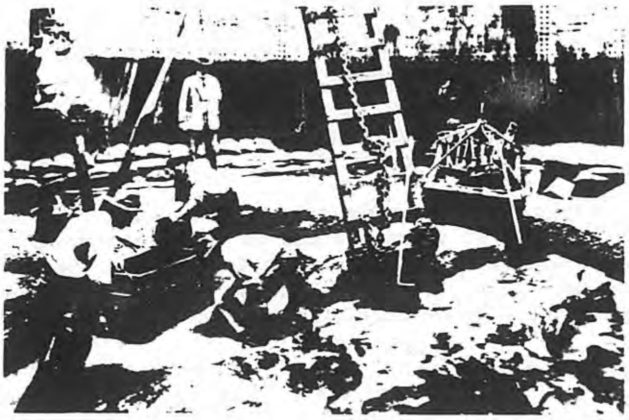
The designs were judged by two government engineers and one private "consulting engineer and architect". They were awarded points out of a possible 500 for suitability, appearance, durability, etc. Only 9 of the 41 entries scored more than half marks. The judges also modified the estimates of the entrants quite severely.

Following the award of prizes no action was taken for two years, at which time Parliament referred the matter to the Parliamentary Standing Committee on Public Works for Enquiry and Report. The competition conditions had included requirements for a 42ft wide road but 38ft wide swing span and twin 60ft fairways. At the opening of the enquiry the PWD submitted 3 schemes.

1. A bridge in accordance with the competition conditions but with two 70ft openings. The design had a series of 100ft plate girder spans.
2. The filling of Darling Harbour from the present bridge to the head of the harbour.
3. The filling of Darling Harbour to Bathurst Street, and a bridge from Bathurst Street to Pyrmont (i.e. roughly on the line of the

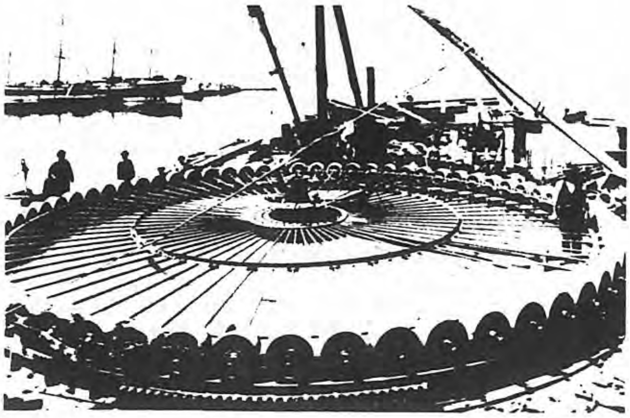


Bridge elevation

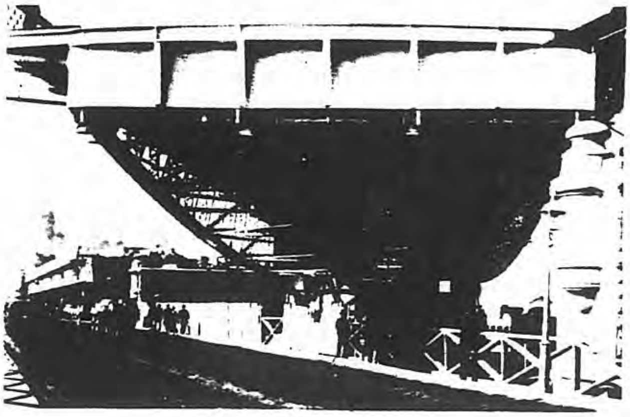


Percy Allan (left) supervises work in the caisson for the pivot pier

Machining the roller path



Rollers and radial rods in position



New swing span over the old bridge

current overpass).

The Department leaned heavily in favour of option 3 - the reclamation to Bathurst Street. The cost, at £200,000 approximately, was the cheapest, although the bridge option at £220,000 was only slightly more expensive. The main advantage seen was the elimination of the opening span and consequently better traffic handling capabilities.

A total of 29 schemes were submitted to the committee ranging from the practical to the ludicrous. One of the more exotic proposed an embankment across the line of the present bridge, and the pumping out of the harbour above it. It was then intended to erect on the bed of the harbour, two floors of "immense storages and grand city improvements". Another scheme proposed a high level embankment, then a spiral down to a tunnel, and back up the other side.

The committee, who favoured a bridge, had considerable evidence that timber approach spans were cheaper than steel, but Robert Hickson, Engineer-in-Chief for Roads and Bridges, was determined that steel should be used. Mr Darley, Engineer-in-Chief for Harbours and Rivers favoured timber.

The Department eventually weakened and submitted a timber scheme, which was estimated to cost £88,500 compared to the steel bridge at £220,000. The timber approach spans were intended to be temporary and to be replaced in twenty five years. The committee resolved to accept this proposal but reduced the cost by £6,000 by reducing the fairways to 60ft each.

As seems to be normal with Parliamentary Committee requirements, the Department went ahead and ignored them completely, producing a design with two 70ft openings and an estimated cost of £112,000.

## 3. CONSTRUCTION

Three contracts were let, the swing span, the approaches and the abutments, and the timber approach spans.

### 3.1 Swing Span - Pivot Pier

The construction of the main pivot pier was an ingeneous and difficult task. The five bore-holes sunk on the site of the pivot-pier passed through an average of 3 feet of mud and 25 feet of clay before reaching sandstone which had a dip of 8 feet in the diameter of the pier. With such a large body of clay it was decided to sink a wrought-iron caisson to the rock by open dredging, to pump out the water within the caisson, and to excavate a trench in the sloping rock sufficient to enable the whole periphery of the cutting edge to be bedded on the solid rock.

The first section of the caisson was put together directly over the pier-site on a square ironbark frame, the ends of the four sticks being allowed to project. These formed eight points from which the frame with its load was suspended by wire ropes, which were then eased away by hand by twelve men until (after 4 hours) the caisson floated. Fresh sections were quickly built on, and sinking proceeded by depositing concrete between the shells. When within a few inches of the bed of the harbour, the caisson was brought into correct position by folding wedges working between long timber guides bearing against the side of the caisson and the piles of the platform; concreting was then rapidly proceeded with at the bottom of a tide, so that with the next ebb the caisson was quietly grounded in a true position and with sufficient weighting to prevent it from lifting.

The material within the caisson overlying the rock was excavated with a bucket dredge worked by a floating crane. Four draught-gauges were painted on the inner wall, which showed at a glance any movement out of level, enabling prompt action to be taken by dredging and weighting to counteract the deviation. By excavating in the middle below the level of the cutting edge, it was generally found that the weight of the caisson forced the material into the "well" and allowed for very gradual and uniform settlement, working within 5 feet of the inner wall being rarely necessary until nearing the rock. A good bank of clay was left on the low side for the cutting length to bed in when the water was pumped out of the caisson.

Upon pumping out, the caisson listed 11 inches out of level, but only two small leaks showed, and these were easily dealt with. No time was lost in excavating the rock on the high side; and in 48 hours the caisson was lowered 2 feet. A blow then occurred, the water filling the caisson in 20 minutes and bringing with it a small quantity of sand and mud. The vertical line of the caisson, however, was not altered.

A large bank of clay was placed in position surrounding the caisson, and the excavation of the remaining 6 feet of rock by "jumpers" proceeded.

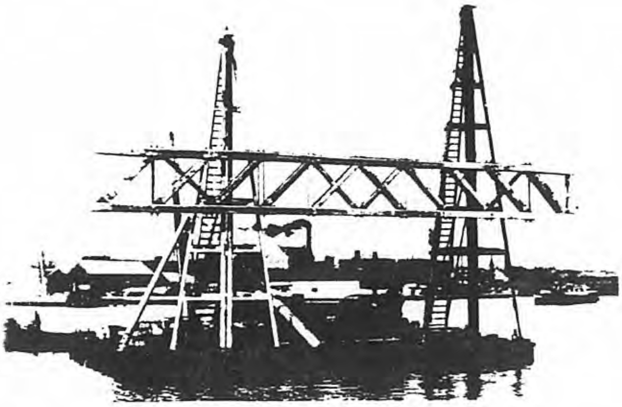
A jumper formed of an ironbark pile 64 feet long, carrying on its end a heavy steel casting provided with three steel cutters, was used for excavating the rock from the line of the inner wall 5 feet inwards; the jumper was hoisted vertically by a steam crane and was tripped with a 6 to 8 foot drop. On obtaining a face with the vertical jumper, the rock under the bell-mouth and cutting edge was removed with a jumper formed of a flat-formed rail having a steel chisel-point bolted to its lower end; this jumper worked within a hollow chute.

The few places where the cutting edge was not bearing on the rock were cleaned with a water-jet, and the space was filled with concrete deposited in bags and packed by divers. Around the caisson, for a distance of 4 feet from the outer shell, rings of concrete bags were laid to a height of 4 feet, the space between the ring of bags and the cutting edge being filled with concrete deposited by means of a bell-mouthed canvas bag lowered through the water and tripped by divers when in position. This work was carried out in eight sections to ensure the rock being well washed off with the jet before concreting. In order to stiffen the concrete under the bell-mouth, a circular sand-bag wall was built 11 feet inwards from the outer shell, and concrete was deposited in the space through 50 feet of water by automatic self-tripping boxes.

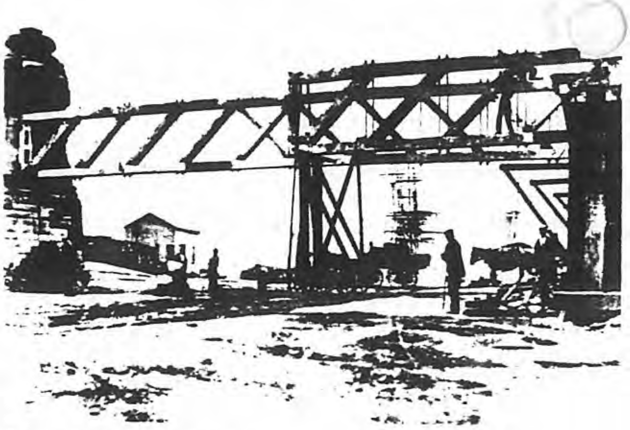
After the water had been pumped out the sand-bag wall was removed and the rock and concrete were thoroughly washed with a jet. The concrete was found to have set very hard and to have been well placed.

### 3.2 Approaches & Abutments

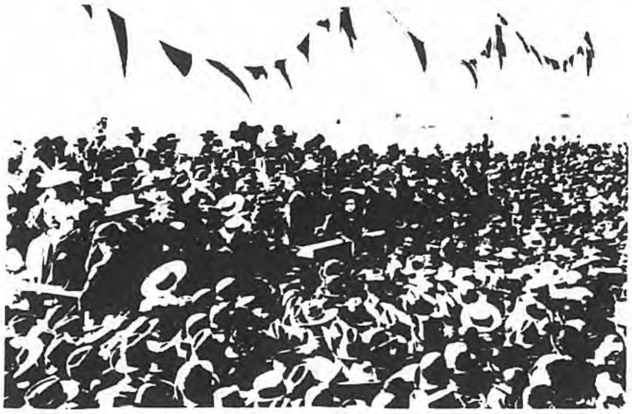
Little comment is needed on the rest piers, and



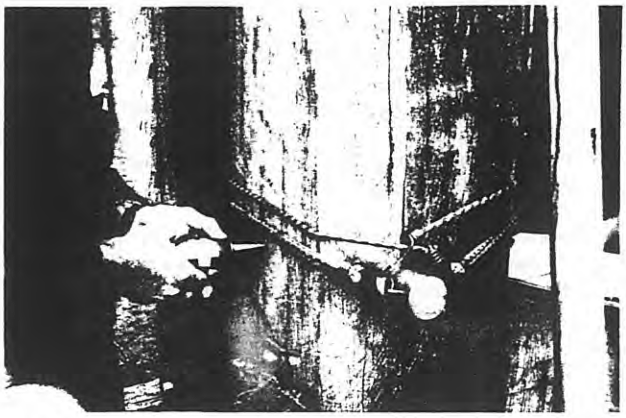
Transporting the trusses



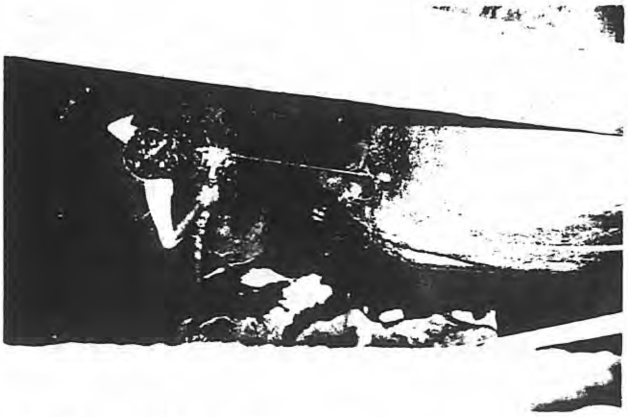
Erecting the trusses



The opening ceremony



Testing with the PURL



Drilling the piles
- note the tube through the encasement

Section of a pile thought to be unsatisfactory when drilled approach span piers. The Pyrmont rest pier is founded on rock, while the Sydney rest pier is carried on 58 piles driven to rock. Similarly the Pyrmont approach is founded on rock, while the retaining walls, which are gravity concrete walls faced in sandstone, were considered sufficiently novel, involving calculations, to justify a paper by Dr. (then Mr.) Bradfield to the Sydney University Engineering Society.

### 3.3 Swing Span Superstructure

The swing span was an engineering masterpiece. The span consists of four main trusses supported on eight distribution trusses so that the weight (of 800 tons) is evenly distributed at 16 points on the drum. The drum in turn bears on 66 tapered cast steel rollers. The fact that no rollers are "idle" was considered a piece of brilliant design. The rollers run between two machined treads, one fixed to the drum, and one fixed to the caisson. These treads were made in Europe, where there existed no lathe large enough to machine them. Consequently they were manufactured in segments, planed top and bottom, assembled, levelled and then machined by a special carriage pulled by horses trained to walk in a roundabout.

The swing span was built out from the pivot pier without staging. A stationary crane on the timber protecting platform raised the material to a crane travelling on top of the span, and the members were jointed with pneumatic rivetters. The girders were precambered 4 inches, and to avoid cracking of the coke concrete deck, the ends of the swing span during erection were weighted down with sand bags.

### 3.4 Swing Span Drive

The slewing operation is electrically powered by two electric DC motors each driving through a gear box and shafts to a rack mounted on the bridge central pier. The level of innovation involved in this choice is shown by the fact that Sydney at the time of the bridge opening had no electric street lighting! When Percy Allan gave a paper on the bridge to the Institution of Civil Engineers in 1907, five years after the bridge was opened, as Englishman, Mr Homfray, queried the wisdom of adopting such a new form of power, specially in "a very distant part of the Empire". Percy had great pleasure in writing in 1924 that after 21 1/2 years of operation there had been only one stoppage. At the same Civils meeting another paper was given on the swing bridge at Bristol. An Australian present quickly noted that Pyrmont opened in 30 seconds while Bristol took 1 min 45 secs. Mr Homfray suggested that this could only be due to the Australians giving their best time while Bristol was average time. Mr Burge, who presented Allan's paper, admitted that he had omitted the time for raising the span and commented dryly "really the comparison was between 38 secs. and 1 min 45 secs". The swing mechanism was designed by a PWD engineer called Gordon Edgell, who later, at the age of 40, resigned from the Public Service and went farming at Bathurst. He later used his engineering background to start a canning factory which was to grow to the empire of today.

### 3.5 Approach Spans - Timber Trusses

While the swing span and its operating gear were all great engineering advances, the approach trusses are equally innovative. The design approved by the Parliamentary Works Committee showed trussed arches of 35ft span. However, these were changed to 82ft spans of the "Allan" type, which had been developed by Percy Allan and first used at Wagga Wagga in 1895.

These trusses are sometimes mistakenly called "Modified Howe" trusses, which is to misunderstand the naming of truss types. It is arguable that the Allan truss represents the highest level of development of timber bridge trusses worldwide, and that these at Pyrmont are unique, probably being the only examples of deck type Allan trusses. They are also probably the best example of the use of this truss form.

There are many innovative features in an Allan truss - including easier maintenance, and the absence of bending in the chords, but Percy Allan felt the bottom chord splice was probably the weakest point in his trusses. At Pyrmont three full size splices were tested. These tests resulted in failure loads of 151, 160 and 182 Tons giving a factor of safety between 2.5 and 3. The maximum working load (including impact) on the splices was 59 tons. The factor of safety in the members of the trusses was also high, and was based on a permissible stress of 2000 psi tension, which compares to the allowance in the current timber code of 43 MPa (6500 psi) without an increase for short term loading. This has great significance when the future use of the bridge is considered.

The trusses were assembled on an adjacent wharf and towed to the site. On one occasion 12 trusses were placed in 7 hours.

### 3.6 Opening Ceremony

The bridge was opened on 28th June, 1902 by the Governor, Sir Henry Rawson, who, after his opening speech, gaffed badly by calling for 3 cheers for the engineers, before 3 cheers for the King. When the ribbon was cut the Minister for Works Mr O'Sullivan suggested to the crowd that the pieces of ribbon would one day be worth £5 per yard, and the official party were nearly killed by the rush.

## 4. LATER HISTORY

In 1947 the DMR removed the coke concrete deck and replaced it with a new deck of reinforced concrete. This modification increased the mass of the swing span by 170 tonnes or 21%.

In 1981 the bridge was closed to traffic following the building of new concrete crossings over Darling Harbour. It was intended to demolish Pyrmont Bridge to provide expanded wharfage in upper Darling Harbour. Fortunately, at this time people became aware of the significance of the bridge as part of our heritage and as a communication link for pedestrians between the City and Pyrmont. Led by the Lord Mayor of Sydney, Alderman Sutherland, and supported by many public organisations and professional bodies, including the Institution of Engineers, Australia, sufficient pressure was brought on the Government of NSW to preserve the bridge. Fortunately the Government proposed the redevelopment of Darling Harbour as a major Bicentennial Project, and the old bridge was seen as a necessary link in the circulation into and around this project. During the design stage it was also decided that the bridge should carry the monorail across Darling Harbour, rather than having a separate structure for this purpose adjacent to Pyrmont Bridge. This was considered a better solution from the aesthetic viewpoint, while adaptive reuse of the existing structure satisfied one of the criteria for conservation of historic structures.

## 5. RESTORATION

With the establishment of the Darling Harbour Authority work commenced on the bridge restoration. The bridge had been unused for more than six years and unmaintained for even longer.

Considerable argument had taken place as to the state of deterioration of the bridge, particularly of the piles, and the cost of repairs.

### 5.1 Testing and Assessment

A testing programme was developed to examine the state of all structural members and the mechanical and electrical equipment, with a view to preparing estimates and contract documents for the bridge repair and rehabilitation.

### 5.1.1 Substructure - piles and piers

The Sydney rest pier and all approach piers are supported on turpentine piles. These piles were part of the original bridge but had been protected with precast concrete sheaths filled with sand which extended from water level to below mud level. These were installed in 1925, and all piles are also individually sheathed with copper which had been installed at the time of driving. Piles in the fenders around the pivot pier, which were not protected, were badly deteriorated and many had broken.

Investigations had revealed that, because the piles were encased in layers of concrete, sand, and copper, ultrasonic or other non-destructive testing was not feasible.

Divers were engaged to undertake a testing programme on the piles. Testing was by drilling at mid-tide level, and assessing soundness by the degree of resistance experienced. A core was installed through the precast unit and the sand in order to allow drill access to the timber. Drillings were collected, visually examined and a selection sent to the Forestry Commission for analysis. Divers were in contact with engineers on the surface by radio and video. Video tapes and still photographs were made of the testing for record purposes. The protective precast sheaths were visually inspected.

The result of this sampling indicated that approximately one pile in every three would need repair, although some could be abandoned due to reduced loads. No marine borer attack was detected. The test results compared closely with testing carried out by the PWD approximately five years previously. It also appeared that the precast concrete protection was not effective and should be removed and replaced with a more modern barrier protection system. The divers also examined all below-water concrete and sandstone. The sandstone was found to be entirely free from deterioration. Some mechanical damage was found, but this was very minor and required no repair. The concrete matrix had slowly washed away, leaving cavities up to 250mm deep in many places.

### 5.1.2 Timber - piers and trusses

Timber exposed to moisture is subject to fungal decay unless adequately protected, and timber is also subject to termite attack, particularly in contact with the ground. The timber members at Pyrmont Bridge had been painted, but lack of maintenance had allowed the paint to chip and peel providing ideal conditions for fungal growth. Termite attack was evident in some spans.

It was proposed to examine all timber members, and test areas of likely deterioration for loss of cross sectional area. Areas considered at risk were joints, particularly splices, re-entrant corners, and horizontal surfaces. Diagrams showing exploded views of all piers, trusses, and deck timbers were prepared to allow recording of field results. Results of the latest (1976) testing by the DMR were obtained to identify any previously discovered areas of deterioration.

Testing was by three methods. Firstly the members were hammered with a three pound hammer to provide an overall check in soundness. Then any areas of doubt, together with all risky locations, were examined more closely with a PURL (Portable Ultrasonic Rot Locator). This consists of a transmitter and a receiver which are held in contact with different sides of a timber member. The lack of ability of the timber to transmit the sound indicates the presence of decayed or unsound timber. As a precaution all areas that failed PURL tests were drilled to determine the extent of decay. Correlation between PURL and drilling was excellent. Recording of deterioration was in accordance with DMR practice.

Access became a problem. Land based piers and spans, including those over wharves marked for demolition were accessible from "cherry pickers", scissor lifts, or temporary scaffolding. Cost of temporary scaffolding to suit safety requirements become prohibitive. Also, at this stage the decision was made to use the bridge to support the monorail and time became very critical. Consequently it was decided to proceed to tender on a schedule of rates based on the assessment of three spans, and continue testing from scaffolding erected for repair purposes by the contractor.

Deterioration in truss members was confined almost wholly to the top and bottom chords. Chords, having horizontal surfaces to collect moisture, were worst affected in outer trusses where not protected by the deck, and trusses 2 and 5 located under roadway gutters. Poorly maintained joints across the concrete deck at support allowed the ingress of moisture to piers and ends of trusses causing severe fungal degeneration in these locations. These proved some of the most difficult areas to repair.

Very few top chords were sufficiently reduced in section to be overstressed, but bottom chords were particularly poor at splices where moisture collected behind splice plates and where the section had already been reduced by keyways.

Approximately 17% of the transverse stringers had decayed, or in some cases, been attacked by termites. Water had passed through deck joints and collected on the top surface of the stringers.

As with the truss chords, horizontal elements of the bridge piers were the most susceptible to fungal attack with truss corbels and pier top and bottom walers being the worst affected.

### 5.1.3 Swing span - steel superstructure

The steel in the structure was assessed to identify missing or damaged members, and to determine the extent and severity of corrosion. Member sizes were measured using tapes and vernier calipers with the extent of corrosion being assessed visually and with the aid of an engineer's hammer.

The general condition of the swing span structure was good, despite lack of major maintenance since 1969. Extent of corrosion varied, being worst on the exposed faces and particularly the area exposed to salt spray and pollutants in southerly winds. In many cases members could be repaired, while some needed replacement.

### 5.1.4 Mechanical and electrical equipment

The mechanical drives and equipment on the swing span were assessed visually and by reference to DMR documents and original design calculations.

The mechanical equipment was in generally good condition, but a few parts were worn and some were cracked. Electrical equipment was in working order but had deteriorated. Concern was expressed about the DC power supply cables which were laid under the seabed. Some control cabin equipment was missing but fortunately was found to have been stored by the DMR, or reused at Glebe Is. Bridge.

### 5.2 Assessment of Required Repairs

Use of the bridge was proposed to be limited to pedestrians and occasional service vehicles. The monorail would be carried on the piers. The bridge structure members were assessed for this reduced live loading, and the extent of permissible deterioration at all cross sections determined. This provided field guidelines to permit rapid assessment of the need for repair or replacement.

The timber used in the trusses is grey ironbark, an immensely strong and durable timber. Permissible stresses adopted by Percy Allan were equivalent to a timber strength rating of approximately F14, while modern assessment would suggest that the correct strength group is F43, a very great increase. To be conservative it was decided to adopt F34 in assessing the sectional area necessary to carry the proposed loading.

The load of the monorail on the swing span was of concern. The earlier change in decking from coke concrete to concrete had greatly increased the load on the bearings. The additional load of the monorail was considered excessive if the tracks were mild steel. Samples of the roller and tread plate material were analysed to determine whether deterioration of the steel had occurred, and to ascertain the mechanical properties of the contacting materials. This information was required to enable assessment of the ability of the slewing mechanism to support the additional load of the monorail.

### 5.3 Repair Details and Conservation Philosophy

All consultants involved adopted the Burra Charter as the basis for all work on Pyrmont Bridge. It was strongly recommended that a Conservation Plan be prepared prior to commencing documentation. In fact a history was prepared, but finance was not forthcoming for the full Conservation Plan. Fortunately the consultants involved were sympathetic to the philosophy of the Charter and were able to informally develop a conservation strategy that resulted in controls on details that were appropriate to the significance of the bridge. Continual review was necessary to control the design team and prevent moves into alternatives that appeared to provide better economic or functional solutions, but would have resulted in unsatisfactory conservation changes - for instance a proposal to change DC drives to AC for more accurate control of swing span movements.

As the team became more understanding of the philosophy, they quickly accepted the principles and became enthusiastic in searching for techniques appropriate to the bridge and its construction technology.

### 5.4 Preservation Techniques

The tender documents included long term maintenance measures that were intended to prevent future deterioration of the structural members.

### 5.4.1 Timber

#### A. Piles

Piles were to be wrapped with a plastic barrier from above high water to below the mudline.

#### B. Timber Piers and Trusses

While suitable Australian hardwoods have always been extremely durable to fungal attack they have also been difficult, if not impossible, to impregnate effectively with preservatives. Recent years, however, have seen the development, mainly by CSIRO in Australia, of diffusing preservatives that can protect the heartwood of dense hardwoods. These preservatives are installed in the timber in the form of a gel or in rods, that are both soluble in water. Moisture is necessary for fungal growth, and as the moisture penetrates the timber it dissolves the preservative and becomes toxic to fungi. Diffusing preservatives are expensive and were only proposed for use in areas of high decay hazard, such as end grain, joints and top surfaces.

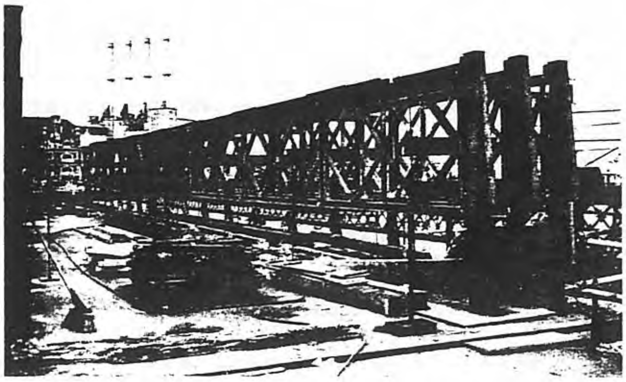
At the same time appropriate externally applied, or barrier, preservatives prevent most fungal entry into the timber. It was proposed to use barrier preservatives such as copper napthanate on all surfaces, in all joints, and under caps on all exposed end grain.

It was recommended that paint be not used, as flaking or cracked paint provides an ideal environment for fungal growth. After considerable discussion, involving conservation architects, on the appearance and colour of the bridge without paint, or with barrier preservatives, it was accepted that paint should be omitted.

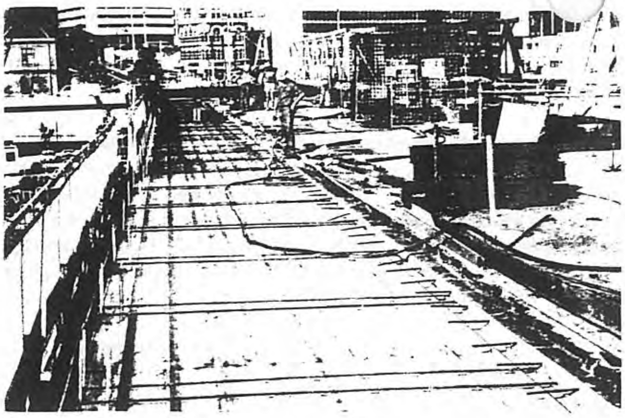
Unfortunately, when construction commenced budgeting requirements required the elimination of all preservatives until some future date when more money will be available, on the understanding that member sizes were adequate to allow for deterioration until this work eventuates. The Authority estimated that maintenance would occur after two years.

### 5.4.2. Structural steel

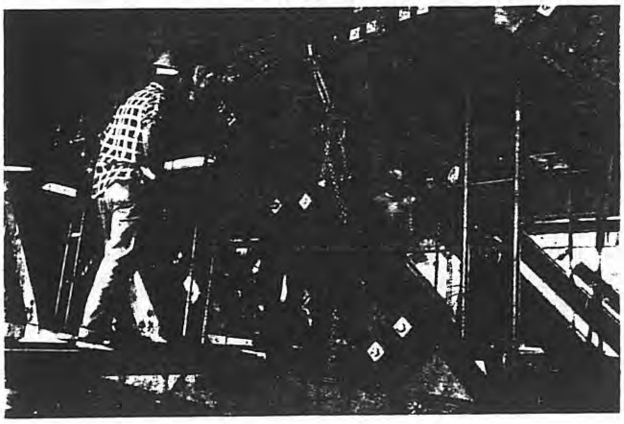
It was proposed that the steel swing span be wet abrasive blasted to base metal, then reprimed with epoxy zinc phosphate primer followed by two coats of micaceous iron oxide epoxy paint.



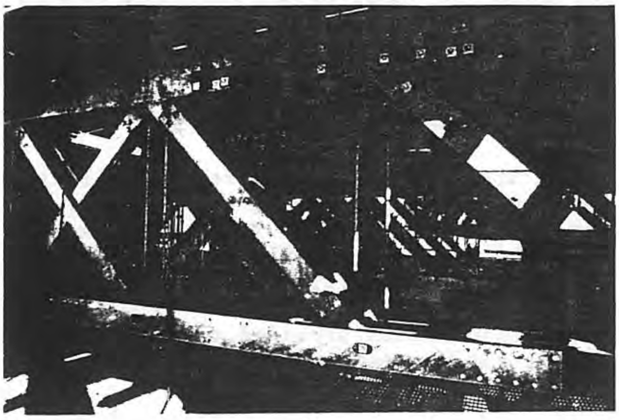
Bailey bridging for deloading



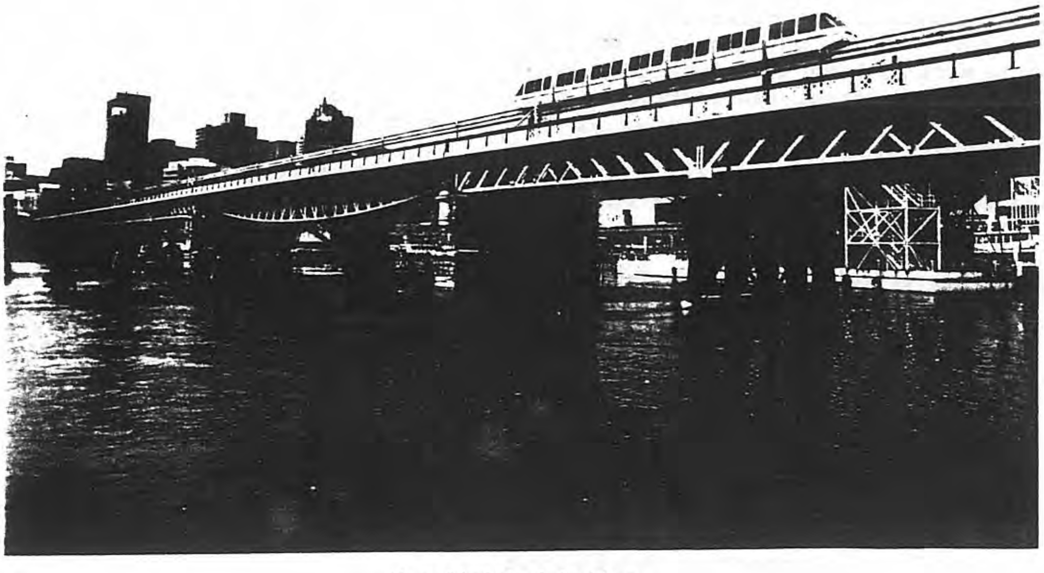
"Condeck" for new footway with deloading trusses in background



Inserting a new web



New top chord and extended bottom chord splice plates in position



The finished bridge

### Construction Tender Proposals

Drawings and documents were produced to permit tendering for a contract for the repair and replacement of bridge members unable to carry the proposed load. Documents also required preventative maintenance measures against future deterioration.

Estimates for the work were prepared with the assistance of the DMR who were the only body experienced in this work. Tenders received were considerably above estimates. This was probably due in part to contractor concern about the unusual type of work, availability of skilled workmen (particularly bridge carpenters), and time schedules. The necessity to be completed in time to allow the monorail to operate on schedule loomed as a finite limit on construction time. Finally, the industrial climate at Darling Harbour must have had a major effect on the tender prices.

The extent of works was revised to remove all work that was non-essential for immediate structural adequacy, with a view to reduction in cost. This involved deletion of all below-water concreting, and deck waterproofing, epoxy encapsulation of piles, preservation of sound pile groups, protection system for fender and dolphins, and worst of all - preservative treatment for timbers.

The contract was based on a schedule of rates with provisional quantities estimated on the experience of the preliminary investigation. Documents specified an order of works to allow testing from contractors scaffolding, followed by documentation of works and then construction. Also specified and detailed were proposals for deloading of members to allow repair or replacement.

### 5.6 Construction

Work commenced on site in October 1986 and was completed in November 1987. Construction was carried out by Costain-Pearson Bridge. The work was completed to a schedule that allowed erection of the monorail track without delay.

### 5.6.1 Piles

Piling repair was the first task undertaken. Precast units were removed from piles that had been identified for repair, and a start made on removal of decayed sections of some piles. It was immediately found that the piles were in fact in good condition below low watermark, and the timber cross section barely reduced. After similar experiences on several piles it became obvious that the testing procedure was defective and that the piles were in good condition. Due to the long sleeve through the protective sand and concrete, the diver had been unable to properly detect the resistance to drilling and consequently could not accurately detect deterioration. The divers undertaking previous investigations for the PWD had obviously experienced the same problem. The piles were wrapped with copper sheet to protect them against future deterioration and left in position.

Piles above the low water mark were found to have suffered fungal attack where exposed to rainfall. A number of piles were spliced below the low water mark and above the bottom waler. Ends of new sections were enclosed in a galvanised steel casing and the anulus and mating surfaces packed with epoxy. A concrete protective sleeve to match the existing shape was cast around the affected pile groups using re-useable formwork.

Fifty percent of land span piers were found to be termite infested in the top two metres below ground level and required replacement. The affected sections of piles in each pile group were removed and replaced with steel tube sections as a temporary support. Pile groups were then encased with mass concrete, around the steel supports. The ground was treated for termites around all pier groups.

### 5.6.2 Timber piles and trusses

The contract involved a schedule of rates with estimated quantities based on the limited earlier testing. It was therefore necessary to schedule the work to include erection of scaffolding to permit a continuous programme of testing of the remaining spans and preparation of drawings prior to carrying out of repair.

Temporary steel trusses were erected on the concrete deck spanning from pier to pier and designed to deload the timber trusses underneath by cables passing through the deck.

These temporary trusses, custom built for the purpose, were also designed to support an underslung steel work platform floated in place by barge and jacked up into position. Until this system was perfected Bailey Bridges were used as deloading trusses. Apart from limitations on load capacity, there proved not to be sufficient Bailey Bridge sections readily available to satisfy the contractors demand. Altogether 6 sets of custom built trusses were designed, each carried the load of 3 trusses, thus allowing access for construction traffic along the deck.

Work was intended to be on a 5-6 week cycle from erection of access scaffold and deloading, with 2 weeks for testing and drawing preparation, and 3-4 weeks for minor repairs. To allow for continuity of work and programming, access for testing was required to two spans in advance of construction. One major problem arose early in the project. One truss bottom chord was found to have failed in both flitches at the splice. This splice was developed by Percy Allan and was considered a great advance in timber truss engineering, utilising side plates and keys to transfer the load. It was widely copied, including much use in the USA. However it is very susceptible to decay having so many close abutting surfaces. It is a point of weakness in all Allan trusses. There are always two splices in the bottom chords at Pyrmont and in this case the truss was found to have failed completely at one of these joints. The contractor quickly installed a cable on each side of the chord to carry the load while work proceeded. Later in the project another such failure was located.

It is worth noting that the excess truss load carrying capacity, due to timber strength and capacity to redistribute loads between trusses into neighbouring trusses, prevented collapse of the failed truss. In fact the DMR used to deload truss elements onto neighbouring trusses to allow member replacement while traffic continued to use the bridge.

At first the contractor had problems finding bridge carpenters capable of carrying out the work to the standards and tolerances required. Several alternatives to carpentry were suggested but generally rejected either on structural grounds or conservation veracity. However, to reduce the necessity of replacing a large number of bottom chord timbers due to splice deterioration, a system of cover plates extending into the solid timber past the splice was approved and regularly adopted. As carpenters became more accustomed to the work involved, workmanship improved to the stage where pride in quality and respect for the bridge was resulting in detail of excellence.

Bridge piers proved difficult to repair. Truss seating corbels and pier walers were often deteriorated and needed replacing. Deloading was achieved by jacking off a temporary waler notched into the piers.

Timber supply was not a problem. To expedite the contract, timber had been pre-ordered and, after some help from DMR District Officers, supplies of grey ironbark in the sizes and lengths necessary were delivered to site. Unfortunately, the project schedule did not allow time for proper seasoning, but the design of the Allan truss permits the adjustment of the truss as shrinkage takes place.

All steel members such as tie rods and splice plates were carefully examined. Tie rods in Allan trusses often suffer from ´waisting´ at the section inside the timber chords. No tie rods at this bridge needed replacement. However, several splice plates were severely rusted.

Unfortunately no money was available for preventative maintenance by use of preservatives, so after the trusses were fully repaired they were water blasted to remove poor paint and repainted.

### 5.6.3 Deck

The major problem with the bridge lay in the lateral stringers which supported the deck on the trusses. When the concrete deck was installed in 1947, it was placed directly on the stringers which cantilevered beyond the side trusses and exposed their end grain. Water (and fungi) penetrated these ends and also the top surface under joints surfaces. Rot was prevalent and 17% had to be replaced.

As the bridge was intended for pedestrian use, it was desirable to remove the kerbs and footways to give a single level carriageway. The deck extension under the former footway was concrete on Condeck.

Deck joints, which had been a major source of moisture ingress to the timbers in the supporting structure, were replaced with a waterproof detail, and finally the bituminous surface was relaid.

### 5.6.4 Handrails

Handrails were generally in a poor state. They were originally constructed in wrought iron but were replaced with exact copies in steel.

### 5.6.5 The swing span

As with the timber trusses, the steel in the swing span required testing and documentation from the scaffolding used for construction. Testing was by visual examination, field measurement and, where in doubt, by ultrasonic testing. Member replacement used Huck bolts for connections to match the appearance of the original rivetted construction.

After repair, the steel was water blasted and repainted. The quality of metal preparation by water blasting is not as good as the original proposal using grit blasting, and maintenance of members will be necessary at a much earlier date.

### 5.6.6. Mechanical and electrical equipment

Although consideration was given to modernising the mechanical and electrical drive system the decision was ultimately taken to restore the existing equipment in line with the Burra Charter.

Although this system was in working order, it had deteriorated to the point where an overhaul of all equipment, including wiring, was necessary.

The DC traction motors for the slewing and end lift motion were originally supplied by the General Electric Company. These motors were in good condition, considering their age, and required no major reconstruction work.

The motors were completely stripped down and checked. Restoration work involved mainly:

- drying and re-varnishing of windings
- reconditioning of bearings, brush gear and commutators
- minor insulation restoration

All motors were fully load tested before being re-installed.

There was no record of submarine cables to the control cabin having been replaced during the life of the bridge. Testing showed a low insulation resistance on all cables due to absorption of moisture. As failure could seriously delay monorail travel, they were replaced.

Control cabin equipment including isolators, circuit breakers, contactors, ammeters, voltmeters and drum controllers for the variable speed DC drives were all restored to their original condition.

All power and central wiring associated with the swing span was replaced.

A number of shafts and gears were found to be defective because of wear and cracking and had to be replaced. A number of bearings were also replaced.

The end lift mechanisms located at the extremities of the swing span were modified in order to maintain operational clearance which had been reduced because of the increased mass of the swing span caused by the earlier change in deck material, and the load of the monorail.

The braking system was also modified and the old manually operated hand brakes located on the slewing motors were replaced with an electrically operated thrustor brake. Switches to limit the travel of the swing span were also installed.

### 5.6.7. Control cabin

The monorail would have interfered with the control cabin during the opening of the swing span. Consequently the cabin was both lowered and slightly relocated. The change in appearance of the bridge was only very slight.

## THE FUTURE

The bridge has now been repaired to a stage where all members are anticipated to have sufficient cross section to carry the current loading. However few adequate preventative maintenance measures have been used, particularly on the timber superstructure members. It is essential that a proper maintenance programme be commenced immediately to ensure that this wonderful example of Australian engineering continues in use as part of Sydney's heritage.

## 7. ACKNOWLEDGEMENT

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## 8. REFERENCES

Parliamentary Standing Committee on Public Works, Report together with Minutes of Evidence, Appendices and Plans Relating to the Proposed Removal of the Pyrmont and Glebe Island Bridges, Sydney: Government Printer, 1894.

Parliamentary Standing Committee on Public Works, Report together with Evidence, Appendix and Plan Relating to the Proposed Extension of the Pyrmont Bridge, Sydney: Government Printer, 1901.

ALLAN, Percy, "The Pyrmont Bridge, Sydney, NSW", Proceedings of the Institution of Civil Engineers, 170, (1907) 2-91.

ALLAN, Percy, "Highway Bridge Construction: The Practice in New South Wales", Industrial Australian and Mining Standard, (1924) 14 August, 243-46; 21 August, 281-85; 28 August, 318-85; 4 September, 356-58; 11 September, 394-96; 18 September, 432-36.

ANON, "Pyrmont Electric Swing Bridge", The Engineer, 26, (1917) 26 January, 75-78; 2 February, 103-106; 9 February, 124-26; and 16 February, 151-153.

DARE, H.H., "Recent Road-Bridge Practice in New South Wales", Proceedings of the Institution of Civil Engineers, 155, (1903-4) 382-400.

FRASER, D.J., "Timber Bridges of New South Wales", Transactions of the Institution of Engineers, Australia - Multi-Disciplinary Engineering, GE9 (1985), 92-101.

FRASER, D.J., "Movable Span Bridges in New South Wales Prior to 1915", Transactions of the Institution of Engineers, Australia - Multi-Disciplinary Engineering, GE9 (1985), 71-81.

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An interest in engineering heritage led him to complete a course in Conservation Studies at York University (U.K.) in 1982, being the first engineer to undertake this course. He combined both interests in a dissertation on "Conservation of Timber Bridges".

Mr Trueman has written the technical aspects of the DMR Maintenance Manual for Timber Bridges, and has been involved in the conservation work on many well known buildings, bridges and other important structures.

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