in America on account of the cheapness of timber. No. 28 in the table, with iron pneumatic caissons sunk through sand and shale: the skin friction developed is given as 525 lbs. per square foot of exposed surface, at a depth of 60 feet below L.W.M. Unfortunately the table omits the depth actually sunk in the shale and sand.

Jacoby and Davis give values for the skin-friction when the pneumatic caissons were well down for a number of bridges, including Brooklyn and Williamsburg. The general average for nine bridges was 554 pounds per square foot.

For a 6 foot diameter cylinder, with a frictional resistance of 500 lbs. per square foot, the total skin friction per lineal foot of cylinder length would be about $4\frac{1}{4}$ tons, or, say, 25 tons per 6 foot section. With a depth of 40 feet, the loading required on these figures would give a very awkward pile of sand-bags to pack on a six-feet diameter lock.

The friction, of course, increases with the depth of soil penetrated, but the resistance can generally be largely overcome by keeping the column moving regularly, the cast-iron shell being well lubricated with the air escaping under the cutting edge. This escaping air has about the same lubricating effect as a water-jet.

It frequently happens, however, that a cylinder column will "hang"—that is, the cutting edge will not follow the excavation. In these cases a common practice is to pile on as much loading as possible, take the men out of the working chamber, and blow off the pressure. The sudden loss of an upward air-thrust of, say, 10 pounds per square inch, generally brings down the cutting edge, and the extra lubrication given by blowing out the water—which, as a consequence of the reduced pressure, has flooded the working chamber—is generally helpful in keeping the column moving.

FRICTIONAL RESISTANCE IN POUNDS PER SQ. FT. OF EXPOSED SURFACE IN CAISSONS

Table by H. L. WILEY, M. Am. Soc. C.E.

No.	Type of Caisson.	Method of Sinking.	Material Penetrated.	Skin friction	Depth below L.W.M. ft	Area of base in sq. ft.
1			Gravel, clay	240	60	125
2	Cast iron		Sand, clay	250	75	225
3			Sand	250	60	125
4	Wrought Iron		Sand, clay	285	140	1000
5			Sand, clay, gravel	300	100	125
6	Cast iron		Sand	325	60	125
7			Silt	350	60	125
8	Steel Construction		Silt, sand, clay	375	55	190
9	Cast Iron	Open excavation	Silt, mud, clay	390	75	100
10	Timber Construction		Sand	450	30	1200
11			Silt, clay	450	60	700
12	Steel Construction		Silt, clay, sand	450	60	1200
13			Mud, sand	450	65	1300
14			Clay	450	75	1509
15	Iron Construction		Sand, gravel, clay	480	65	200
16	Cast Iron		Clay	500	60	125
17	Steel Construction		Clay	700	65	1300
18	Masonry		Sand, mud	205	40	70
19	Timber Construction		Clay	250	35	805
20	Steel Construction		Clay, sand	275	60	150
21			Silt, sand, mud	310	75	2550
23			Sand, clay, gravel	350	100	1200
23	Timber Construction		Sand, clay, boulders	400	48	1925
24			Clay, sand, gravel	400	95	4500
25			Sand, gravel clay	425	55	1300
26	Steel Construction	Pneumatic.	Sand, boulders	450	68	2700
27	Timber		Silt, clay gravel	500	75	1800
28	Iron Cylinder		Sand, shale	525	60	1200
29			Sand	540	75	1700
30			Sand, clay	600	75	1400
31	Timber Construction		Sand, gravel, clay	650	80	2000
32			Sand	650	90	1200
33			Sand, boulders	660	101	2100
34			Silt, sand, clay	900	45	1700

An electric light plant was installed at Luskintyre, and work in the air chambers much more comfortable than at Kempsey. The writer was very thankful that he was able to scrap his troublesome nose-cleaning plant.

The Reinforced Concrete Arch Bridge over the Hawkesbury River at Richmond is illustrated by Plate No. 23.

This bridge consists of thirteen reinforced concrete arch spans, each 50 feet in the clear, with an overall length of 722 feet. The piers were of concrete throughout. The caissons, two for each pier, were built in position on plate-steel shoes provided with cutting edges.

These caissons, 10 feet x 5 feet, with rounded ends, were sunk by the pneumatic process, carried about 2 feet into solid rock, and further secured in the upstream caissons by iron anchor-rods.

As far as there is any record, there is only one other bridge constructed of this character—a low level structure of reinforced concrete in a river subject to high floods. The other example, constructed upon a somewhat different principle, is the Maryborough Bridge, Queensland, which has successfully withstood several high floods.

The Richmond Bridge has not only successfully withstood many high floods during its life of 14 years, but also many severe batterings from floating logs carried down against it at high velocity.

Many of the local residents remembered floods which submerged the old timber bridge for a depth of 52 feet, and predicted that a line of concrete arches could never be carried across the Hawkesbury. When the first flood arrived, several of the caissons were down to rock, and one was in process of sinking, with air-lock in position.

As will be shown later, there was a cableway, with "flying-fox" hoisting gear stretched across the river, but even with this facility the flood beat the salvage gangs by sending down a battering ram in the shape of a log, which struck the pneumatic caisson amidships, carrying away a length of about 4 ft., together with the air-lock and miscellaneous plant.

After the water subsided, the air-lock was rescued, little the worse for the battering, and the work resumed. The local residents consoled the constructors by informing them that this little affair was only a skirmish—a bit of a fresh, in fact.

Despite the gloomy predictions as to what would happen when a real flood came down, all the caissons were successfully anchored to rock, and all the arches built in position without further damage of consequence, although the writer has several times pulled in a flood boat with the river bank high, and not seen the bridge workings for days.

Another view of this bridge, taken during construction, is given on Plate No. 24.

The old timber bridge, which was erected by a private company in the year 1860, is shown still standing. This old bridge cost the company between £9,000 and £10,000 to erect; they collected tolls from the public for 17 years, and then sold it to the Government for £7,000!

The old district of the Hawkesbury was the first to supply foodstuffs in Australia. It supplied also a race of Hawkesbury natives whose achievements in agriculture have a world-wide reputation. Their business reputation was certainly not lowered by their bridge construction projects.

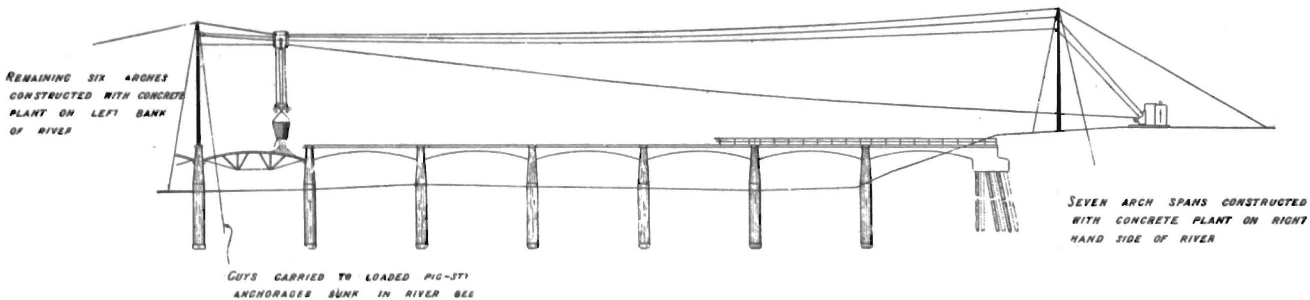
The construction of the concrete caissons for the new bridge was greatly facilitated by the steel cableway which was carried across the river in two spans. The general arrangement of this cable-way, with "flying-fox" hoisting gear, is shown on Plate No. 25.

Hoisting engines were erected, one on each side of the river, on the high banks of which Gilbreth's Gravity Concrete Mixing Machines were installed, with a light feeding tramway for running the concrete skips under the aerial wire.

BRIDGE OVER THE HAWKESBURY RIVER AT RICHMOND

13 ARCHES OF 54 FEET SPAN

"FLYING-FOX" ARRANGEMENT FOR RE-INFORCED CONCRETE CONSTRUCTION



DETAILS OF FLYING-FOX

A A. GUIDE SHEAVES FOR TRAVERSING ROPE
B B. SHACKLES FOR CONNECTING TRAVERSING ROPE

Plate No. 25

This aerial wire carried all concrete in large skips, with double doors, opening downwards; the overhead-way was also used for lifting the large air-lock, and shifting it from one caisson to another.

An additional hoisting engine was installed on the old bridge, in a machinery shed, which also housed the air-compressor and electric light plant.

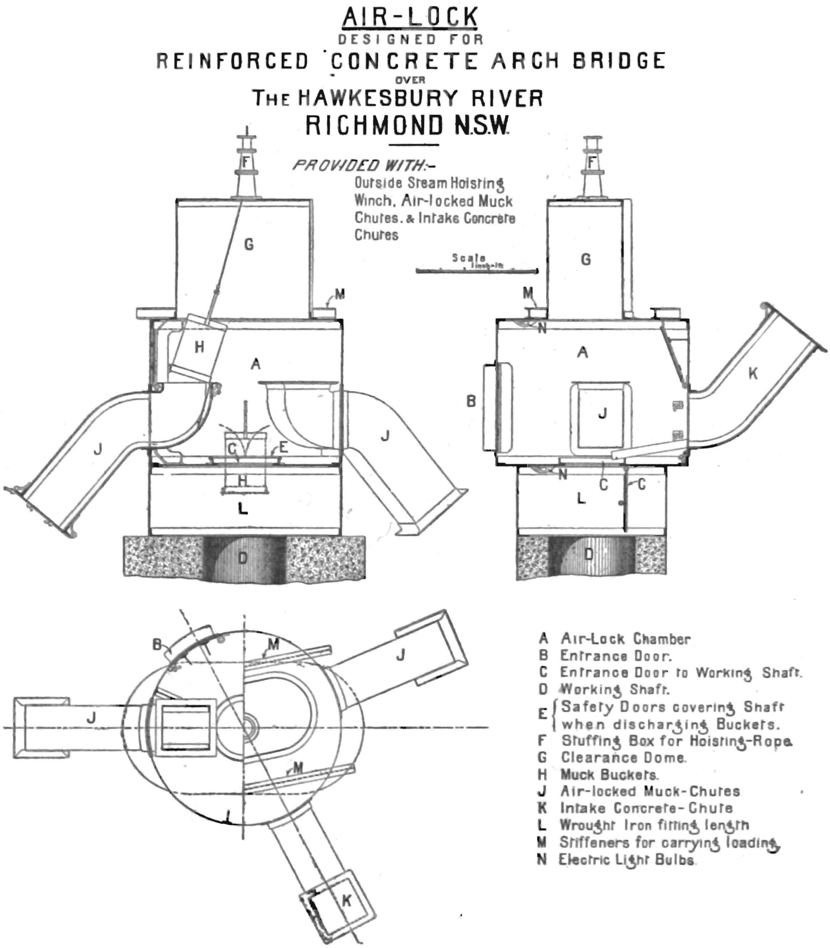


Plate No. 26.

The air-lock, which was specially designed for this bridge, is shown on Plate No. 26. The excavated material from the working chamber was lifted by a wire from the outside hoisting engine. By tagging the wire, and a code of signals, the buckets, equipped with safety hooks, were stopped exactly as desired, and discharged into a chute within the lock chamber, as shown in the diagram. Some very rapid sinking was done with the gear described.

The material discharge chutes were very effective. As indicated, the doors of the chutes were packed with rubber, and when screwed up were airtight. When sinking commenced, the outside doors of the chutes would be screwed up, and the inside doors opened against the air-lock wall as shown. When a chute was filled, the inner door would be screwed down, and the signal given to the outside lock attendant, who opened the outside door and discharged the material into the river. Meanwhile filling would be going on in the opposite chute. There was no lost time, and very little loss of air. The entrance for men was at the side, as shown on the diagram.

This system was much easier on the men that the old method of passing the material through the lock, which required the opening of the air-lock door, thereby altering the pressure each time on the air-lock top men.

Certainly the pressure in these caissons rarely exceeded 15 lbs. on the gauge, but even that is hurtful if constantly taken off to empty the air-lock.

No harmful effects are felt on entering the compressed air, or while remaining in it: it is the decompression, and coming out of the lock, which causes trouble.

The writer used this lock to test the theory put forward by Jacoby and Davis that since no cases of aerenia are caused by rapid decompression from about 19 pounds gauge pressure, it was quite safe to blow off quickly from that pressure downwards.

The writer had one of the chutes partly filled with excavated material, and then entered the chute himself—feet foremost. The inner door was then closed, and the signal given to the attendant outside, who opened the bottom door and precipitated the contents of the chute into the river.

This certainly was rapid decompression, and the man in the chute experienced something which felt like a crack on the head with a hockey stick.

He was able, however, to swim easily to the bank, but was quite convinced that even at 15 pounds pressure, a decent period for decompression, was to be desired in the interests of health.

The bottom of the caisson was filled with concrete, deposited by means of the third material-chute shown on the diagram.

This sealing up of the caisson with concrete placed under pressure is very often a very troublesome business, especially when the concrete has to be passed into the lock in buckets. The old practice was to ram the concrete around the cutting edge, and then fill up the caisson, or cylinder, for about 6 feet. As soon as the cutting edge was well packed, the escape of air underneath was blocked, and ventilation smothered. It was trying on the men, and even when the utmost care was used to keep the gauge at a balancing pressure for the usual 24 hours specified after laying, there would be blow-holes in the concrete, which allowed water to come through after the pressure was taken off.

A fairly dry concrete was sometimes tried, but without success, as under compressed air the moisture is absorbed very rapidly, and the sealing concrete put in dry is usually of poor quality.

The most satisfactory system is to put in a few pipe air-vents about 1½ inch diameter, kept well above the 6 feet height specified, and fill up the bottom of the caisson with good wet concrete. After 24 hours under air pressure the concrete will have attained its permanent shrinkage, and the writer found, in the large number of caissons filled in this way under his supervision that the bottom chamber was perfectly sealed, with no water showing after removal of the air-lock.

A continuous girder bridge over the Hunter River at Aberdeen is illustrated by Plate No. 27. The girders, 180 feet centres for the middle span, and 140 feet for the side spans, were carried on cast-iron cylinder piers sunk by the pneumatic process.

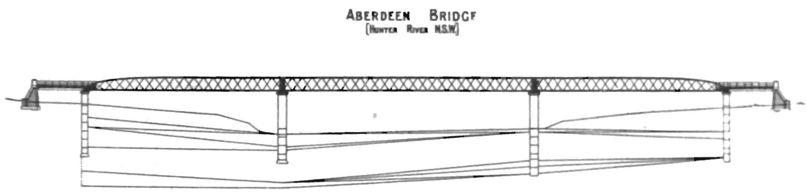
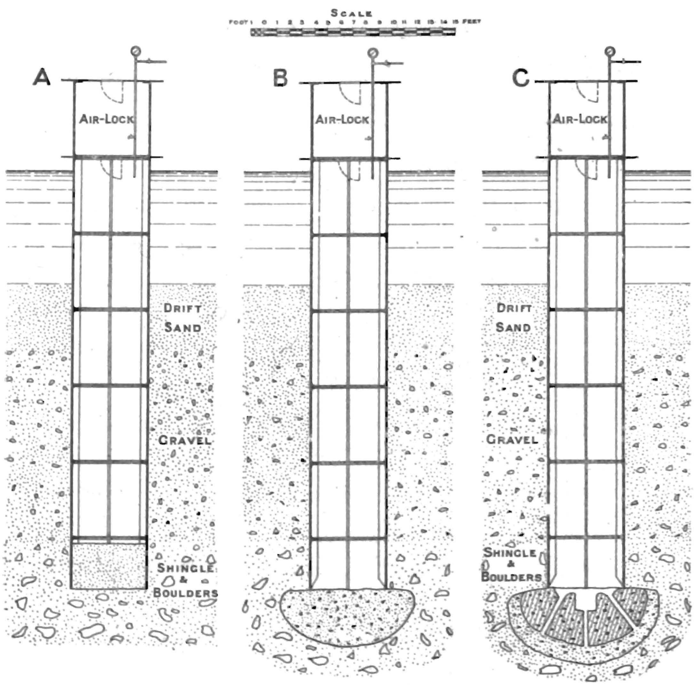


Plate No. 27

When the cylinders were about down to the specified depth it was found that the formation was not of the character to withstand the pressure for live and dead load—9.5 tons per square foot. It was not considered advisable, for this type of bridge, to give a pressure of more than 4 tons per square foot on the river pier foundations. To carry the cylinders to rock would have meant an additional sinking of about 26 feet below that specified. After considering the estimated costs, it was decided to spread the foundations, from 6 feet diameter to 10 feet, which, allowing for irregularities, was the area necessary for a pressure of 4 tons per square foot.

At the Merrimac River Bridge, U.S.A., the caissons were founded on a bed of gravel and boulders, a novel method being used to transform this formation into a good bearing foundation. The pressure in the cylinder was reduced a little, allowing about a foot of water to rise in the working chamber. Portland cement was then mixed with the water to form a grout, which was kept well stirred, while the air pressure was increased to force the grout into the gravel. After completion of the grouting, a depth of about 10 feet of 4:2:1 concrete was laid under air pressure, and allowed to harden, after which the remainder was laid in the open. The caissons consisted of 8 feet diameter cast-iron cylinders, and as far as the writer can discover, the work proved an excellent job, with no indication of settlement.

PROPOSED SCHEME FOR INCREASING THE AREA OF PNEUMATIC FOUNDATIONS
ABERDEEN BRIDGE HUNTER RIVER N. S. W.
USED FOR SECURING FOUNDATIONS FOR THE MERRIMAC RIVER BRIDGE, MASS. U. S. A.



CYLINDER CHARGED WITH CEMENT

CHARGE OF CEMENT FORCED BY AIR PRESSURE INTO SURROUNDING SHINGLE AND BOULDERS TO FORM ENLARGED CONCRETE BASE

HOLES DRIVEN THROUGH CONCRETE FORMED AS SHOWN AT "B", AND SECOND CHARGE OF CEMENT GROUT BLOWN THROUGH, TO INCREASE AREA OF CONCRETE BASE

Plate No. 28

This method was considered as one likely to be successful for the Aberdeen Bridge, but as the system had never been experimented with in this State, and the type of bridge requiring absolute security against settlement for the piers, it was decided to adopt the method of spread foundations shown on Plate No. 29.

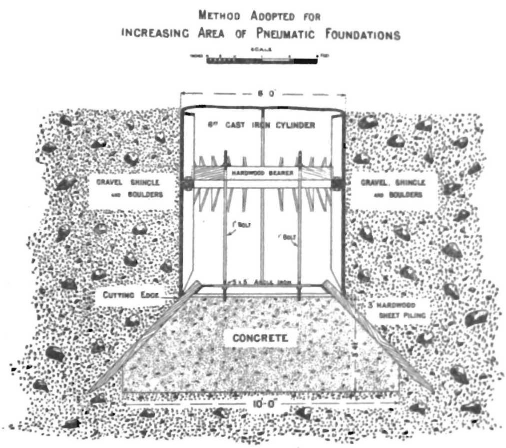


Plate No. 29

The weight of the cast-iron cylinders was taken by the staging, and sheet piling, cut to template, driven from the inside of the cylinder at an angle of 45 degrees to form a cone. The upper ends of the sheet piling were kept in place by an angle-iron ring slung from the flange of the cast-iron cylinder. After completing the sheet-piling, the enlarged excavation was proceeded with, as shown on the diagram.

The sheeting was not caulked, and it was not possible to keep the water out below the level of the cutting edge, so that the excavation, and subsequent laying of concrete, took place through the water.

Another of the many bridges crossing the Hunter River is shown by Plate No. 30, which gives an elevation of the Morpeth Bridge. This structure consists of three truss spans of 110 ft. 3 in. between centres; thirteen approach spans of 35 feet, and one of 30 feet span.

The bridge is illustrated during construction by Plate No. 31, which shows a system of staging sometimes adopted in a river liable to floods. Instead of carrying the staging piles 12 feet or so above the river, as is customary to support the guide timbers, the piles and staging stopped just above the surface of the water, as shown on the plate, a method which, although having good points during a flood, has the disadvantage of giving less control over the cylinder during the process of sinking.

A composite truss bridge over the Lachlan River at Cowra is given on Plate No. 32. This structure consists of three truss spans of 160 feet centres, four truss spans of 90 feet each, four approach spans of 35 feet, and two of 30 feet, giving a total length of 1040 feet.

The 160 feet spans are 27 feet between centres of the triangulation.

The cylinders in the river piers were sunk 50 feet below the surface level, and the land piers 40 feet. Mr. F. M. Smith, now of the Irrigation Department, was the Resident Engineer in charge of the construction.

The caissons were sunk by the pneumatic process, and the dry blow-out method was attempted for taking out the upper formation, but was not very successful, most of the material having to be excavated by the usual digging.

The dry blow-out process is a very simple matter, the principle being that of using the air-pressure in the working chamber to drive out sand or mud when it is piled around the inlet of a pipe, which, regulated by a suitable valve, leads from the working chamber to the open air, the top being provided with an elbow to throw the material away from the pier.

Sometimes there is not sufficient air in the pipe, and the material clogs; then again there is too much, which is nearly as bad. The lowering of pressure, due to the air rushing up the sand-pipe, causes a thick fog, and generally brings in a lot of water and slurry from outside the cylinder. The men stand round in the fog, sometimes up to their knees in water, and wait for things to clear, and reveal the effect of the blow. This is often disappointing, and for pneumatic cylinders the writer has seldom found conditions which would warrant the cost of the additional plant necessary.

It is a simple matter to construct a cylinder, or concrete caisson, which can be used, if necessary, either as an open or pneumatic caisson.

It is then possible to dredge, or pump out, the loose material, and put on the air-lock for taking out the gravel and boulders, or other difficult material met with.

If a lot of mud or silt covers the bottom, it is usually cheaper to dredge it out before landing the caisson than to excavate it from within the working chamber.

The pump illustrated on Plate No. 33 is valuable when there is a lot of overlying silt or mud. Operated by hydraulic jet with 125 pounds pressure, it will force up fairly large gravel when loosened up with the separate hydraulic jet shown on the diagram.

At the St. Louis Bridge, U.S.A., the piers of which were sunk by the pneumatic process, the sand pump was used to clear sand from the caissons. With a pump pipe bore of 3½ inches, and a water jet under a pressure of 150 lbs. per square inch, 20 cubic yards of sand per hour were raised 125 feet.

A jet of air has also been successfully used in the same way at the East River Suspension Bridge, New York, and at other places.

Plate No. 34 gives a view of a Bascule Bridge erected over the Wilson River at Telegraph Point. Space will not permit a lengthy description of the sinking of the caissons, which consisted of reinforced concrete shells, sunk by the open method.

MUD AND SAND PUMPS

USED IN OPEN CAISSON AND OTHER FOUNDATIONS

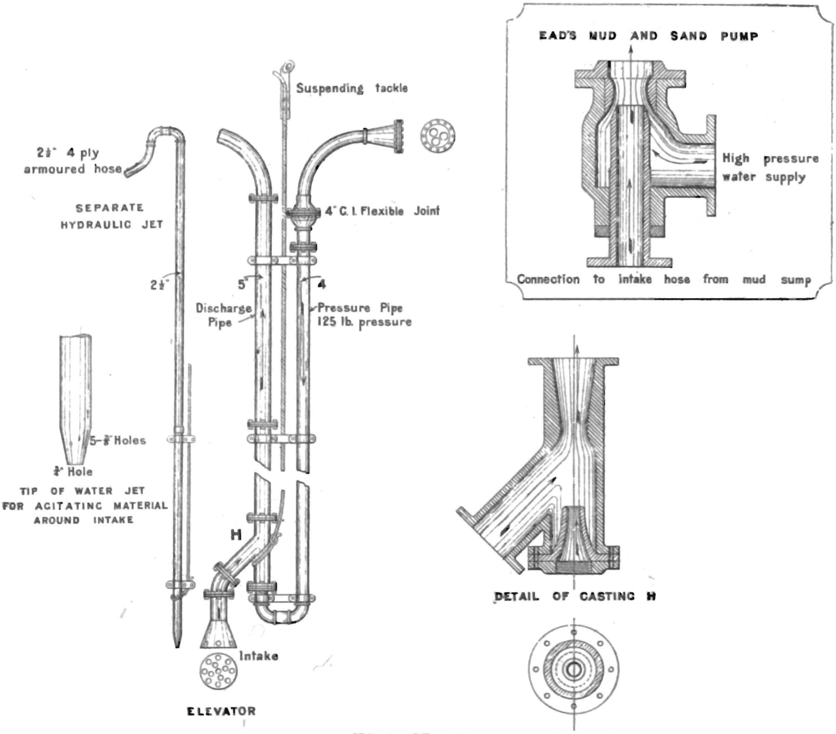


Plate No. 33

The work was carried out by day-labour under the direction of the writer, who employed some of the same divers trained at Kempsey for excavating the material.

It may be mentioned that the young Australian, with the capacity for erratic "stunts" previously referred to, nearly lost his life when depositing concrete in one of the larger river caissons through water. The accident occurred through his failure to comply with the instructions that any defect in the diving gear should be personally reported to the engineer in charge. One day he lost the pin which secures the helmet to the corselet, after turning the segmental screw attachment. The loss was not reported, and he went down without it. Standing on the bottom, he received the onion bags, loosely filled with concrete, which he had to stamp in around the cutting edge.

Sometimes the concrete bags landed on his helmet, and he would twist his muscular neck to shake them off. There came a time when a large bag, very loosely filled, clung to the helmet like a stingaree to a rock. The diver's repeated neck and head twistings released the segmental screw, and the helmet came off.

Fortunately the writer happened to be coming aboard the punt alongside, and noticed the diver's tender, who was sitting on the caisson edge with the life-line and air pipe, being jerked about, and nearly dragged into the open caisson. Calling to all hands on the punt, the life-line was promptly hauled in, and the diver came up, feet foremost, with a loose helmet dangling at the end of the air-pipe. The man's face was smothered in cement, and when the gear was cut away he was pretty far gone.

An example of Australian toughness was exhibited by this young diver who, when subjected to a rather rough first-aid treatment, swallowed a considerable portion of whisky, and although unaccustomed to the use of spirits, was, on recovery, able to walk unassisted to the camp, change, and resume duty in the diving dress well within an hour.

Another view of this Bascule Bridge under construction is given by Plate No. 35.

Plate No. 36 gives further details.

After this somewhat hurried bridge building journey around the State, Sydney is again reached, and this view of the Sydney Harbour Bridge—Plate No. 37—showing the Northern Railway Connections, is given as a fitting close to this paper.

The writer has long had the hope of seeing this much-needed connecting link in a general electrification scheme brought into actual existence, and even now is of the opinion that its construction will be forced upon us sooner than many anticipate.

In conclusion, the writer has to thank Mr. Bradfield for kindly permitting the use of some of his plates for illustrating the Metropolitan Railway Electrification Scheme, the extent of which is shown by Plate No. 38.

The writer's thanks are also due to Mr. T. B. Cooper, Under-Secretary for Public Works, for permission to use departmental plans, and for the courtesy extended in authorising the preparation of a considerable number of lantern slides, which were excellently made by Mr. Degotardi, Government Photographer.

Mr. J. G. Lancaster, and others of Mr. Bradfield's staff, kindly assisted in the preparation of the numerous diagrams illustrating the text, also in the compilation of statistical matter, and the computations required in the tables.

Discussion.

MR. BRADFIELD: Before discussing Mr. Burrow's excellent paper, I wish to thank you, Mr. President, and your Council, for your courtesy in asking me to be present to-night. The fact that there is a fair sprinkling of visitors to your Society to-night may be taken, I hope, as a happy augury that the labors of the Provisional Council now engaged in putting the finishing touches to a draft constitution for welding the Engineering Societies of Australia into one Institution will bear fruit.

Personally, I hope that this Society, and the Sydney University Engineering Society, will exercise a little judgment, and unite to form a combined civil and mechanical branch of the Institution.