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The responsibility of the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

INSTITUTION OF ENGINEERS & SHIPBUILDERS
IN SCOTLAND.
(INCORPORATED.)

THIRTY-FIRST SESSION, 1887-88.

Introductory Address,

By Mr **Alexander Carnegie Kirk**, President.

Read 25th October, 1887.

Gentlemen,

While I appreciate the honour you have done me, in this the jubilee year of our Gracious Queen, in appointing me President of the Institution of Engineers and Shipbuilders in Scotland, it is with grief that I take the place of one we all loved and respected, I mean the late Mr William Denny. In him the profession has lost one who had already done noble work, and who, had he been spared, would have done further work to the advancement of science in general, and of our profession in particular.

We have lost one whose researches in professional subjects will ever be referred to, and who ungrudgingly gave the public the results of his work.

It would be out of place in me to attempt to summarise all Mr Denny did. I will only refer to one brilliant piece of work from which we have all benefited, I mean his introduction of progressive speed trials, and his showing us how from these we could deduce in in each particular case a law, expressed graphically, connecting power and speed.

Taken in conjunction with the labours of the late Mr Froude, what Mr Denny did has gone far to give us a very complete, if somewhat empirical, solution of the difficult problem of finding the power required to drive a ship at any particular speed. Not only did he do this, but he placed the results of these investigations freely in our hands, and by his energy and power of lucid explanation he so firmly established the process, that probably few of us complete a ship without having her tried as Mr Denny showed us how to do.

He also successfully resisted the attempt of the Board of Trade to include the space used for water ballast under a double bottom. Had the Board's views been carried out, an admirable provision for safety would have been discouraged.

Amidst his other avocations, he also freely gave his time as one of the Committee to settle the vexed load-line question.

He has gone from us, and we have suffered a severe loss.

This year we naturally look back on the vast changes that have taken place during the 50 years of the reign of our Gracious Queen, which have just been completed.

Perhaps in no previous 50 years of the world's history have such extensive changes, social and political, taken place, and such enormous advances been made in science and in its applications. But perhaps of all these the most marked and far reaching are the enormous facilities that have been attained in locomotion, in the distribution of merchandise, in the rapid travelling of passengers, and the almost instantaneous transmission of thought both written and spoken, all of which come within the lines of our profession, and which unquestionably have had much to do with the changes political and social, which I referred to. With these latter, however, I am not concerned.

Looking back fifty years, the railway system was in its infancy, the electric telegraph was unknown, and still less the telephone, and the first steam ships had just shown that it was possible for them to cross the Atlantic.

When in September, 1830, the Liverpool and Manchester Railway was opened for public traffic, it formed an era in the progress of national advance, alike in the arts of peace and war, and a striking epoch in the progress of mechanical science. This great step was not made before its time. The world was in want of more facilities for transport, and as soon as it was made clear that the rail and locomotive was the right thing, the extension of the railway system progressed at once by rapid strides. Just fifty years ago, in 1837, the Grand Junction, and in the following year the London and Birmingham railways were opened, and now we have in Great Britain and Ireland alone, 19,169 miles open, representing a capital of £619,653,800, with total receipts of £69,592,000. Incredible as it would have seemed fifty years ago, the number of passengers in 1886 was 725,584,400.

But to give you a fuller idea of the importance of railways, we must look at a wider field.

In Europe there are open	70,049	miles.
,, Asia, - - -	14,621	,,
,, America, - -	155,424	,,
,, Africa, - - -	4,610	,,
,, Australasia, - -	7,971	,,
Altogether,	252,675	,,

or more than sufficient to reach from the earth to the moon.

As the subject of railways and of locomotives has been so ably handled by one of my predecessors a few years ago, having briefly sketched the progress of the last fifty years, I will at once pass to the development of the electric telegraph, of which invention this year is the jubilee.

We have seen the enormous development of the railway system, but had the railways been left to themselves without the help of the electric telegraph, no such development could have taken place. Even fifty years ago, with a comparatively small traffic, the difficulty of managing it and of extending it had become a serious question. Once a train had started, it was not known at other stations where that train was to be found on the road, and consequently large margins of time had to be allowed to prevent collision, and in fact the amount of traffic that could be conveyed on a pair of rails was very limited indeed.

Exactly fifty years ago, two scientific men Cook and Wheatstone, sent a telegraphic message from Euston Square to Camden Town and back. From that small experiment (as we should call it now), has grown the whole telegraphic system that has brought New York within speaking distance of London, and revolutionised the whole transmission of information throughout the world.

In that small experiment, Messrs Cooke and Wheatstone, by the combined movements of five needles, made up the whole alphabet.

The immediate effect of this experiment was to enable railway traffic to be enormously increased, and to be worked with comparative safety. But for the electric telegraph few of us would feel easy in travelling from Glasgow to London, and the saying would be very wide of the truth indeed, that the safest place you can be in is a railway carriage.

The Board of Trade returns for the years 1873 and 1883 show the following results, for which I think the more extended use of the electric telegraph in the latter year may claim its fair share of the credit due to the improvement in the safe working of railways:

	1873.	1883.
Number of passengers carried by railways in the United Kingdom, - - -	455,000,000	683,000,000
Number of passengers killed,	40	14
Number of passengers injured,	1,522	584

But the telegraph did not long remain as an assistant to the railways only. In 1846, the Electric Telegraph Company was formed, and in 1870 the complication and multiplication of companies had become so great, that although their competition had been of enormous assistance in developing the system, the inconvenience had become somewhat serious, and the Government of the day acquired the interests of all these companies, and concentrated them under the management of the post office.

That the public have taken full advantage of the electric telegraph is shown by the number of messages sent. Through the post offices of the United Kingdom alone, the number of messages last year was 51,500,000, or in round numbers, nearly 1,000,000 per week, and this number is steadily increasing.

When the first electric telegraph was established, the highest rate of speed was from four to five words per minute. Now, duplex and quaduplex telegraphy has been introduced, and it is a common thing for four distinct messages to be sent at the same time through a single wire, and 460 words per minute is done regularly, and thus the miraculous feat of transmitting words by telegraph has been increased about 100-fold in the last fifty years, and there is little doubt, rash as the prophecy may seem, that this speed of transmission will in the future be yet greatly exceeded.

Hitherto I have been speaking of telegraphs on land, but so flexible, so to speak, and adaptable to such varying conditions is the telegraph, that not only do we transmit messages from one place to another *on land*, but the whole ocean, I may say, is laid with telegraph lines, bringing all the world into instantaneous communication. To a country like ours with distant colonies, an empire in fact extending (though the parts are separated by wide extents of ocean) over the whole circumference of the globe, the submarine telegraph has been of inestimable value. None of the improved means of communication, neither railways, nor steamships have done so much to link together the different parts of this empire, and bring them into the most intimate communication with each other as these submarine cables have done.

I see from a statement of Mr Pender, who has done more perhaps than any one else to extend submarine telegraphy, that, while 20 years ago there were only something like 2000 miles of submarine cables, now there are 115,000 miles, and it has cost about £39,000,000 to put that amount of telegraph cable at the bottom of the sea.

The benefit to commerce has been enormous and the method of transacting it has been revolutionised. I see Mr Pender states that of 100,000,000 messages carried by submarine telegraphs $\frac{9}{10}$ths are for commercial purposes.

But science, although it was the parent and the continued improver of the electric telegraph, did not carry out this enormous work alone. The engineer has had his full share, and without his help these wondrous results could never have been attained. In fact, at the very commencement of the application of the electric telegraph to railways, the late Mr Stephenson put its working out into the hands of Mr E. Clark, who was then superintending the erection of the Britannia Bridge, and whose work on the subject I commend to every young student of engineering as one of the most practical and instructive books he can study. Then came the time when engineering had to do its share of the work, and well it was done, for in a few years the telegraph system was extended over the chief railways of the country in a substantial and systematic manner.

Nor have the labours of the engineer been less in the matter of the electric cable. A vast amount of talent has been expended by the engineer, working hand in hand with the electrician, in making these cables a success.

In 1850 the first attempt was made to lay a submarine telegraph cable, but from defects, largely of a mechanical kind, this did not last a year. But the experience gained, and the application of engineering in protecting the cable by wire laid on outside the guttapercha, formed the successful beginning of the extensive submarine system I alluded to.

I can only refer in passing to the amount of engineering work and invention involved in the machinery required for making these cables, and in the ships for laying them.

At the same time, electric science was working hand in hand, with marvellous results, devising apparatus by which the delicate currents through these enormous distances could be utilised, and I am proud to say that one of the most eminent labourers in that field was Sir William Thomson, one of our honorary members and a fellow townsman, whose invention of the mirror galvanometer made telegraphic communication between this country and America a success.

The third great place in promoting intercourse and revolutionising the world, alike in commerce and in war, falls to the steamship.

When Her Majesty ascended the throne, the first steamship had just crossed the Atlantic; the screw propeller had just been introduced; the first iron ship had been classed in Lloyd's; and the first steam war vessel constructed; and now there is neither sea nor ocean nor navigable river which is not traversed by steamers, nor warship built whose power of locomotion does not depend upon the steam engine.

True, steam navigation had been for years before that slowly developing; and I am proud to say that the Clyde, which was its cradle, maintains still its high position, although many and powerful competitors have sprung up all round.

In 1838 the "Great Western" reached New York after a passage of 18 days, but the first great practical establishment of Transatlantic steam navigation was the formation of the Cunard Company, in which Glasgow took a very prominent share.

Four steamers were built of wood by the best Clyde builders, and engined by the late Mr Napier, the first of which, the "Britannia," of 1154 tons, sailed from Liverpool to New York in 1840, making the passage in 14 days.

But the days of the wooden paddle steamers were numbered. The screw was to take the place of the paddle in all ocean-going steamers, and the iron ship was entirely to replace the wooden one, —to be itself in turn replaced by steel.

Nor was the marine steam engine stationary. Magnificent and stately as the old side lever paddle engines were, holding their ground at all events till 1861, when the last of the paddle engines for the Cunard Company was built by Mr Napier, other forms of paddle engines, more particularly the oscillating, competed for supremacy, and as soon as we got the iron ship (which is a rigid structure compared with its predecessor the wooden one) the oscillating engine almost entirely took the place of the side lever engine. But the greatest change in marine engines is due to the introduction of the screw propeller, which involved a quick running shaft placed near the bottom of the vessel, instead of as before with the paddle, a slow-going engine whose shaft was at the upper deck.

It is amusing to look back on the pertinacity with which engineers held to slow-going engines with the shaft raised up in the ship, in fact to the old paddle engines, but in order to adapt them to the screw propeller, introduced all the additional complication of wheel and pinion gear. However, this state of things did not last long.

The engine was quickly inverted, the cylinders placed at the top of the ship, and the shaft at the bottom. The engine was at the same time reduced to about a third of the size, the same power being got by running it about three times as quick.

This arrangement is to the present day recognised as the most fit and proper type of screw engine, and will unquestionably remain so, until some radical change in the propeller demands some radical change in the steam engine.

Still, something was much wanted to reduce the consumption of coal, which, looking at it from our present practice, was at that time enormous, and from Glasgow the much needed improvement came.

In 1854 the demand for a reduction in the coal consumed, and an increase in the cargo carried, began to make itself felt, and to meet this the compound engine was introduced on board ship on a practical scale by the late Charles Randolph and the late John Elder, who in the screw ship "Brandon," engined by them, showed that the coal consumption could be reduced from about 4½ lbs. to 3¼ lbs. per I.H.P. with a corresponding increase in cargo-carrying power.

From the nature of their trade on the Pacific Coast of South America, the Pacific Steam Navigation Company at once appreciated the importance of this, and it was largely due to the opportunity afforded by them in their ships, at first paddle and later screw, that the compound engine was gradually perfected, confidence established, and public attention drawn to its importance.

As usual, the early forms of the compound engine were the most complex. But experience speedily remedied this, and the simple two-cylinder receiver type of engine, working on two cranks at right angles to each other, supplanted all these earlier types, except in some of the largest engines, where owing to the great size required for the low pressure cylinder it was divided into two, thus giving three cylinders and three cranks.

The next great step was also made in Glasgow. The speaker had early observed that practically, even with the help of steam jackets, you could not conveniently or economically expand steam more than about 2½ times in one cylinder, and in 1874, having to design an engine for the s.s. "Propontis," belonging to Mr Dixon of Liverpool, which was supplied with steam of 160 lbs. pressure, generated in Rowan's water tube boilers, he made the engines with three cranks and three cylinders, in which the steam was expanded in three successive steps instead of in two. A very great step in economy was by this means gained.

Advantage was taken of the higher temperature got by the increased pressure of the steam, to expand it through the full range of temperature down to nearly that of the condenser, without introducing any abnormal range of temperature or variation of pressure in any one of the cylinders, securing the utmost smoothness of action combined with the utmost efficiency.

Most unfortunately, however, these boilers had in course of time to be removed and replaced by boilers of the ordinary type, and thus the adoption of the triple expansion engine was delayed for seven years.

In 1880, when Messrs George Thompson & Co., of Aberdeen, were about to inaugurate a steam fleet from London to Australia, the speaker placed before them the great advantages of coal economy on a long voyage such as theirs, and showed them that by the adoption of triple expansion a very notable saving and a notable increase of freight earning power could be effected, with the result that the well known ship "Aberdeen" was fitted with triple expansion engines, with boilers of the ordinary type. It was a bold step for them to take, but a wise one.

She made her first voyage to Australia without a hitch and with marked economy, for not only was there a saving on a voyage of 500 tons of coal compared with the best compound engines, but she carried 500 tons more cargo.

The importance of this step very quickly impressed shipowners, and now I can safely say that unless in a few exceptional cases, the triple expansion three-cylinder three-crank engine as fitted in the "Propontis" and "Aberdeen," has entirely displaced the ordinary compound engine.

As a step further in the same direction, also due to the Clyde, Mr Brock, a member of our Institution, has introduced quadruple expansion, that is the expansion of steam in four successive cylinders, to realise the full value of which we only want a steam boiler capable of sustaining higher pressure than those which we are making at present.

So far as we have gone the saving effected in the weight of steam used to produce a given power has reduced the total weight of the machinery, although the scantlings are heavier.

From what we have seen, not only has there been a reduction in space occupied, and in the weight of coal and machinery, but there has been a saving both in the weight and in the space occuiped by the machinery alone, and fewer men are required to work it.

The first to appreciate the importance of this as enabling a higher speed to be attained in warships was the Russian Imperial Admiralty, who ordered of Messrs R. Napier & Sons a set of engines of 12,600 horse-power, and soon after I was able to show to the British Admiralty that, by adopting triple-expansion engines in the belted cruisers "Australia" and "Galatea," an additional knot more speed could be got.

As to the future, without setting up as a prophet, I may, I think, venture to predict that it is in the boiler rather than in the engine that the next great step will be made.

What that step will be I dare not venture to foretell, but I would not have it be imagined, that because the water-tube boilers of the "Propontis" gave out after a time, that the water-tube boiler cannot be revived. More is known of the management and action of boilers than was known then, and those in charge have learned more, with the result that what was not then a success may contain the germs of success now. I commend the steam boiler to the attention of all my hearers.

In attaining the great speeds recently got in warships, the extension of the system of forced combustion has played a most important part. There, the object is occasionally to get the greatest power possible for a comparatively short period, economy of coal being then a secondary consideration. And to a great extent this applies to short run vessels, such as channel steamers. But though the conditions are so very different in an ordinary deep sea ship, trials are being made in the same direction with the view of reducing the machinery space and giving more paying space, to which we wish success.

It is not only in the construction of the hulls of ships, or of the engines that propel them, that improvements, during the period under review, have been made and economies effected. Very great improvements have been made in the machinery for loading and disloading, and enabling cargoes to be turned over with greater despatch. Manual labour has been supplanted by machinery to a large extent, although by no means to the extent that it may yet be. One man by the help of the steam engine can steer the largest ship; the anchor is raised by steam power; the cargo discharged and put on board by steam and hydraulic power; and coals are carried instead of fresh water. The effect of all this has been, not only to enable the ship to make more voyages, but to reduce the number of seamen very much.

I find in 1854 there were 4·36 persons employed per 100 tons, while in 1885 the numbers had been reduced to 2·76 persons. In fact, we should not be far from the mark in saying that the number of persons required to work a steam vessel is now just about half what it was at the beginning of Her Majesty's reign.

The following figures will show at once the importance to the British empire of shipping, and the enormous advance it has made within Her Majesty's reign. In 1840, which is about the nearest year to the commencement of her reign for which I can obtain statistics, I find that the total mercantile registered tonnage of the British empire was 3,311,538 tons, in 1877 it had increased to 8,133,837 tons, and in 1885 to 9,323,615 tons, an increase of 181·5 per cent in 45 years, and of 14·5 per cent. in the last eight years from 1877 to 1885. Compared with this the corresponding increase in all the rest of Europe was only 6·2 per cent., or from 7,472,905 tons in 1877 to 7,938,900 tons in 1885.

Coming now to steam tonnage, I find that in 1840 the total registered steam tonnage of the British empire amounted only to 95,807 tons. This had increased to 2,492,327 tons in 1878, and to 4,293,115 tons in 1885, thus increasing 43-fold in 45 years. The rate of increase from 1878 to 1885 is 72 per cent. It is interesting to compare with this the increase of steam tonnage for the rest of Europe during the same period. In 1878 it amounted to 1,063,092 tons, and in 1885 to 2,058,073, thus showing an increase of 93 per cent. This shows that foreign-owned steamships are increasing at a faster rate than British-owned steamships are.

Before I conclude, the following figures may be of interest as showing the importance of the shipbuilding industry.

I find that in the United Kingdom from 1858 to 1868 there was built—

3,480,882 tons of shipping,
1,317,750 tons being steamships, and
2,162,832 tons sailing ships.

From 1868 to 1878—

4,477,351 tons,
2,861,359 tons being steamships, and
1,615,992 tons being sailing ships.

From 1878 to 1886—

4,523,846 tons,
3,476,983 tons being steam ships, and
1,046,863 tons being sailing ships.

The history of warships is a very tempting subject and quite as revolutionary, but, time does not permit me to enter upon it.

Perhaps no business has been so much influenced by legislation, or had so much bestowed on it, as that of the shipowner and builder. During the period under review the evil effects of a vicious tonnage law, which had fostered ships the construction unstable and of bad proportions, were done away with, and a more rational system substituted, which by giving freedom to ship designers allowed the gradual introduction of ships of better proportions, better sailers, and safer. There was also much done for the welfare of passengers and crews. But addressing engineers—particularly engineers of the Clyde—it is the least thing I can do to recal to your memory the noble efforts made and time bestowed by them in attempts to stem the tide of official interference with the elementary principles of engineering that took possession of the Board of Trade about 1875 and 1876. It was fortunate for the steam shipping of this country that in all its leading features it was firmly established before legislation took the details of construction in hand, and it is fortunate that there still remains a class of ship, the machinery of which is outside their influence, and in which improvements may go on, of which the "Aberdeen" is a case in point, being not built under them. Whilst Sir Charles Adderley was President all the leading engineers of the Clyde, you will recollect, addressed a memorial to him remonstrating with him against the imposition of rules such as they were, and the crude absurdities of some. But although they have been since then amended in some points, I am sorry to say that they are being gradually enlarged in scope, embracing all sorts of details, till the marine engineer may be looked on as but a babe in swaddling clothes, for whom technical education may be reduced to a simple study of the rules of the Board of Trade and how to make the most of them. This state of things was certainly never intended by the Legislature and is much to be deplored. For instance, although safety and economy alike demanded it, the Board of Trade most obstinately opposed the introduction of spring-loaded safety valves on board ship, although they had then been in use in every railway station for some 40 years, and many of you will recollect the obstinate fight the Clyde engineers had to wage till at last the Board of Trade were compelled to give in and permit their use.

As an illustration, if time permitted, it would be an amusing relief to the heaviness of this address, to detail their perverse arrangements for testing bar steel, were it not that by that stupid perversity they make Board of Trade rivets about £1 per ton dearer than rivets made to Lloyds or the Admiralty tests.

That the enormities of this state of things are making themselves felt in higher quarters in the Board of Trade, may be inferred from some of the provisions in the draft of the Boiler Registry and Inspection Bill, which was read a second time in the House of Lords last session, and printed in order to be distributed among steam users during the recess.

This Bill was one of wide scope, and well worth the study of steam users. It would place under the Board of Trade all steam boilers whether afloat or on land, the only exceptions being those already under the Board of Trade, those in ships classed at Lloyds, locomotive boilers (mark this exception), and kitchen boilers, as also those employed in Her Majesty's service. But the point I referred more particularly to was that it is in this Bill proposed to hand over the making of rules for the guidance of the surveyors to a committee, composed of experts and representatives, scientific and practical, drawn from various sources.

True, the composition and method of the election of this Committee are by no means satisfactory, and the powers proposed to be given them are of much too limited a kind to permit of the Committee being efficient, or of ensuring that the objects of the Bill be secured without placing the manufacturers of the country at heavy disadvantage in the competition of the world. Still, the germ of a valuable improvement is there, and if properly worked out and developed, much improvement in the controlling body of the constructive department of the Board would be effected, but to do this engineers and shipowners must co-operate vigorously. The task will be by no means easy, but the vital interests of the country demand it.

Professor JAMES THOMSON moved a vote of thanks to the President for the admirable address he had favoured them with. He had given a *resumé* of the wonderful events through engineering invention and through engineering practice, on a very large scale, in many different ways, during the past fifty years. Many of those present were old enough to well recollect the whole of that period, and in the ordinary routine of their lives had observed the wonderful progress which was going on around them, yet they would all admit that it was profitable and interesting occasionally to take a review of the progress of the past. They had had a very interesting review of that period from the President, who was well qualified to give it having been himself effectively engaged in both the advancement of engineering invention and the execution of works on a very large scale. In connection with this vote of thanks for the address, he begged to thank the President for accepting the office he was so well able to fill.

The vote of thanks was heartily accorded.

The PRESIDENT asked the meeting to accept his thanks for the vote they had so cordially passed. He was happy to say that the Institution was at present in a very flourishing condition, and he hoped that the term of his presidency would be marked by the reading of interesting papers.

On the Indicator as Applied to Modern Steam Machinery.

By Mr W. Carlile Wallace.

Received and Read 25th October, 1887.

In a very able paper read before the Institution of Civil Engineers* Professor Reynolds has pointed out the many faults of the Richards indicator, and his paper taken together with that of Mr Brightmore's and the very interesting and well-sustained discussion and correspondence carried on by some of the most eminent engineers on this and the other side of the Atlantic, is well worthy of the careful perusal of all those interested in the steam engine.

It is the purpose of this paper to show that engineers are fully alive to the imperfections of Richard's indicator, for high speeds at least; to consider what has been done by them and makers of indicators up to the present time towards getting rid of these faults by the production of more reliable instruments, and to point out in a general way the direction in which, in the author's opinion, improvements may still be made.

As stated by Professor Reynolds, there are two things necessary to secure an exact diagram.

1. That the pencil of the indicator shall, under every change of pressure, instantly move through a distance in exact proportion to the change of pressure in the cylinder of the engine.

2. That the paper on which the diagram is taken shall change its position in exact accordance with the change of position of the piston of the engine.

How these conditions are accomplished within certain limits is

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* See Proceedings of the Institution of Civil Engineers, Vol. LXXXIII.

too well known to require explanation, and what I wish to consider is the disturbing forces which militate against the attainment of these conditions. They may be divided under two heads. (1) Those that can be got rid of by careful manufacture and fixing of the indicator, and (2) those which can be only partially eliminated. To the first of these belong (in the pencil movement) inaccuracy of spring, pressure of steam in indicator barrel not corresponding with pressure in cylinder, and last, but not least, sticking of piston in indicator barrel. (In the drum movement) errors due to badly-designed reducing gears.

Under the second head we have (1) inertia of the piston of the indicator and parallel motion, (2) friction of the pencil, &c.; these two affect the motion of the pencil, while the three following affect the drum motion:—(1) Varying action of spring; (2) inertia of drum; (3) friction of drum.

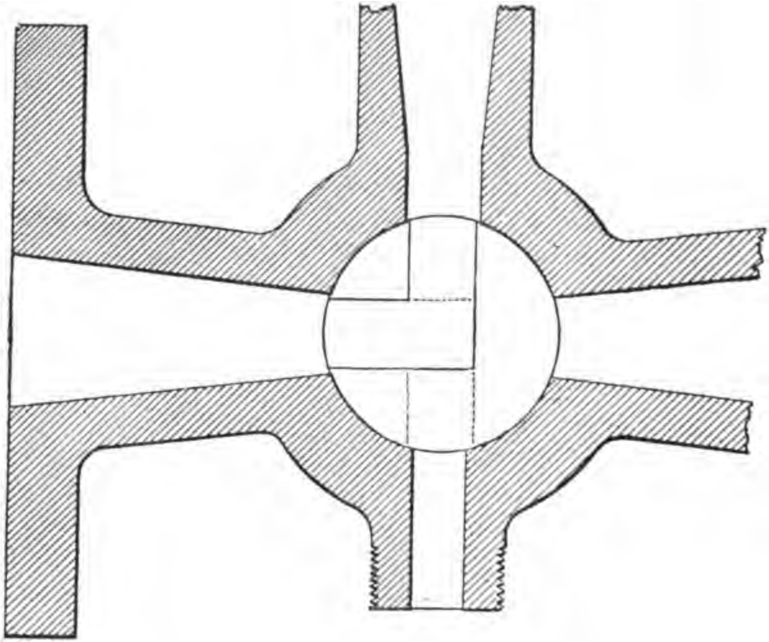
INACCURACY OF SPRINGS.

One of the first things to be done before using an indicator for any important work is to test carefully all the springs that will be required, and the manner of doing so in use by the author may seem rather rough as compared to some other methods; it has the advantage, however, that the spring is as nearly as possible under working conditions. The indicator with spring in place is connected up to a chamber, to which is led a steam pipe fitted with a reducing valve; to this chamber is also attached in the usual way a carefully tested Bourdon gauge and a drain cock to get rid of condensed water. Steam is admitted to the chamber, say, to 10 lbs., the cock opened to the indicator, and when the pressure on gauge is seen to be quite steady a line is drawn on a card (previously placed on the drum of the instrument) by drawing out the cord by hand, more steam is then admitted to the chamber, say, to 20 lbs. and another line drawn, and so on up to the required pressure, steam being then released from the cylinder in the usual way and the atmospheric line drawn. Several cards are thus taken off for each spring (starting at opposite ends of the scale), carefully marked and kept for reference. Each card is then very carefully measured by the scale of the spring, and any error is easily detected. From a number of springs tested in this way it has been noticed that if the pressure is rapidly increased or decreased, and the lines drawn in quick succession as the pointer of the gauge passes the selected points, there is a lagging behind of the spring, both in coming up and going down, to the extent of as much as one pound on the scale. This does not, the author believes, occur to any great extent in practice on account of the vibration, as a good shake usually puts matters right. One reason for adopting this means of testing springs was that it overcame the difficulty of testing the tubes used in the Kenyon indicator which could not have been done in any other way. With the exception of the peculiarity before mentioned, springs, as supplied by good makers, are usually correct.

PRESSURE IN INDICATOR CYLINDER NOT CORRESPONDING WITH PRESSURE IN ENGINE CYLINDER.

In marine engines of the inverted cylinder type, it would be most inconvenient to place the indicator directly on a hole bored into the cylinder below the piston; this method would also entail the use of two indicators for each cylinder if the diagrams were to be taken nearly simultaneously, which ought to be the case. For a quadruple expansion engine eight indicators would be required. To avoid this it is usual to have a three-way cock, similar to one on table, placed about midway between both ends of the cylinder to which pipes are led with as few bends as possible, and these when necessary should be very easy, the pipe for a screw engine not to be less than 1¼-inch bore and carefully lagged. If these precautions are taken, there will be no appreciable drop in the pressure, but cases have come under the author's notice when pipe ½-inch to ⅜-inch diameter have been used, and not even covered to prevent condensation, in which case the fall of pressure must have been very considerable. Under this heading we might consider the presence of water in the indicator pipes, either from condensation there or carried over from the cylinder; this, it is needless to say, will prevent a diagram being taken until it is got rid of, and for this purpose the three-way cock may be made as shown in Fig. 1,

Fig. 1.



with a hole in the lower side of the barrel, so that when the plug is turned, as shown by dotted lines, any water in the pipe leading from the cylinder is blown out. It can then be turned back as in Fig. 1, and the diagram taken before water has had time to collect in the pipe. The three-way cock, Fig. 2, has the advantage of an easy bend for the steam to follow, which is a decided improvement. It can also be arranged to blow through into the atmosphere, but in addition to this method of getting rid of the water, the indicator cock supplied with the instrument should be made as shown in Fig. 3. The plug is made to turn through 180° instead of 90°, as is the usual practice, and there is a mark on the handle to indicate the

Fig. 2.

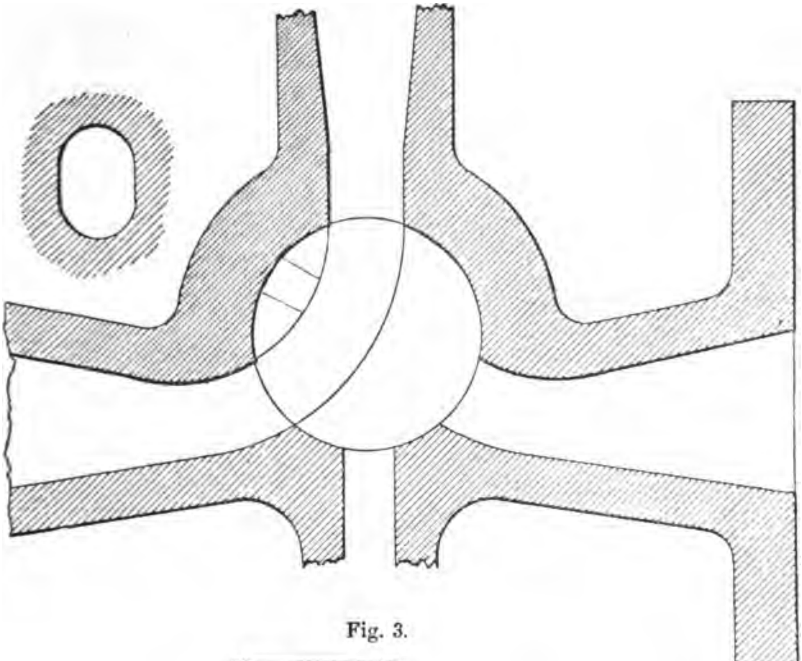
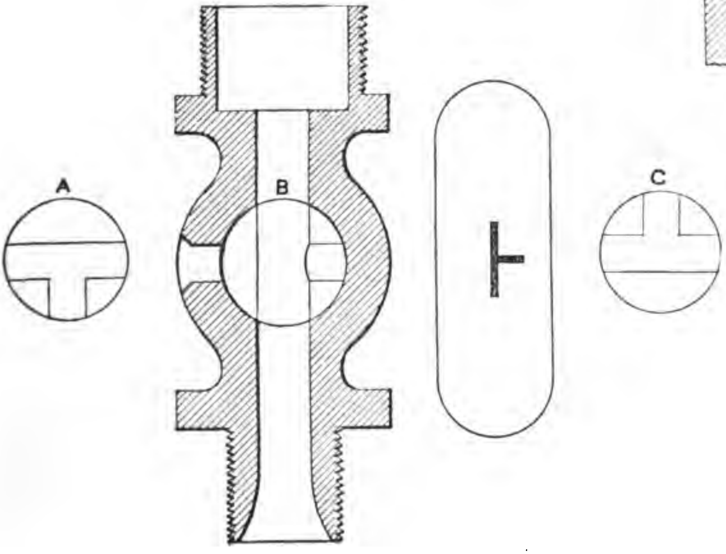


Fig. 3.



direction of the passage in it. When in position A, water is blown out of the pipes; when in position B, connection is made with the indicator; when in position C, the indicator is open to the atmosphere. Those who have not used this form of cock can hardly appreciate the advantages of it when much water is present in the cylinder. For three-way cock, Fig. 2, the author is indebted to the catalogue of the Crosby Steam Guage and Valve Company. The cock, Fig. 3, is copied from one on the table supplied with a Thomson indicator. The side hole is in this case too small to be of much use, so has been enlarged to $\frac{3}{16}$ths diameter.

PISTON STICKING IN THE INDICATOR CYLINDER.

This must not be confounded with the necessary friction of the piston in the indicator cylinder, which cannot be avoided. It is caused by friction of a most aggravated character. It may be said to be peculiar to high pressure given an indicator which will work perfectly on pressures up to 80 lbs. if proper precautions are taken, it may be quite useless for pressures over 100 lbs., the difficulty increasing as the pressure rises. The pencil draws the admission line quite correctly, but instead of falling as the pressure decreases, the piston remains fixed in the cylinder until the pull of the spring overcomes the friction, when it comes down with a jerk, making a series of steps until the pressure of the steam falls below a certain point when the pencil will again follow the true line. For a considerable time all efforts is overcome, this sticking of the piston with high pressures proved ineffectual, and we were forced to the conclusion that it was due to some unequal expansion of the metal in the piston and cylinder, due to the increased temperature of the steam, and with this idea the author had a cast-iron piston made, so that the greater the temperature of the steam the slacker it would become in the cylinder, owing to the difference of the rates of expansion between cast-iron and brass; but this did not seem to mend matters, so we adopted Kenyon's indicator for high pressures. But, continuing to experiment with the piston indicator, we found that when the spring was removed, the piston then moved quite freely in the cylinder even with high pressures. From this it appears that one of the principal causes of the sticking is due to unequal yielding of the spring, and consequent jamming of the piston against one or other side of the cylinder. To obviate this the author, in conjunction with Mr K. D. Noble, of Dumbarton, conceived the idea of making a loose joint between the lower end of the spring and the piston, which gave good results, not knowing at the time that this was one of the features of the Crosby indicator, this end being attained by a most beautiful arrangement, as will be seen by examining the piston and spring. But about this time an instrument was obtained from Messrs Schaffer & Budenberg, made under Thomson's patent, and especially adapted for high pressures which gave not the slightest trouble, rather to the writer's surprise, as the spring is rigidly fixed to the piston. The workmanship in the instrument is very good indeed, great care having been taken in its manufacture.

Latterly the author has obtained some very good diagrams at high pressures with Richard's indicators, supplied by Messrs M'Innes Bros., of Buchanan Street. Mr T. S. M'Innes, who thoroughly appreciated the difficulty, spared no pains to get good results with these instruments.

In trials made with the Crosby indicator on the H.P. cylinder of a quadruple expansion engine, with 170 lbs. boiler pressure, it gave the stepped diagrams already referred to, but this may have been due to the piston being too good a fit in the cylinder for such high pressure. It gave most beautiful diagrams when placed on the other cylinders. The piston of this instrument is of rather peculiar construction. The following description taken from the catalogue will explain it and the joint already referred to:—The "piston is made as light as possible, and is provided with steam chambers in the outer surface, on which the pressure of the steam acts and prevents the piston from touching the sides of the cylinder. The springs are made of the finest quality of steel wire, and are wound and tempered in the most careful manner. In form they are of a unique and ingenious design, which enables the strains to which they are subjected to be transmitted from the centre of the piston. Each spring is made of a single piece of wire wound from the middle into a double coil. This construction gives it all the advantages of a double spring. The two ends are confined to the head by screwing them into the four wings. The final adjustments for strength are made by screwing the spring in or out of the head until it is of exactly the right strength. This method does away with the necessity of grinding the wire to make the required adjustments, and consequently avoids the errors due to that practice so fatal to the accuracy of indicator springs. The foot of the spring, where lightness is of great importance, as this is the part of the spring that has the greatest movement, is simply a small steel bead brazed on the wire. This bead replaces the heavy brass head to which the lower end of the ordinary spring is soldered, and by this change the weight of the moving parts is very materially reduced where the reduction is most needed. The bead has its bearing in the centre of the piston, forming a ball and socket joint which allows the spring to move in every direction."

IMPERFECTLY CONSTRUCTED REDUCING GEAR.

So much has been written on this subject already that it is needless to enter on it in this paper, more especially as it is no part of the instrument itself, and the designer must to a great extent be guided in the arrangement by considerations which could not possibly be stated in general terms.

SECTION II.

We now come to consider those errors which may be greatly reduced by careful construction of the instrument, but can never be entirely eradicated, as they are due to fixed physical laws.

The first and most fruitful source of error (at high speeds at least) is the inertia of the indicator piston and its accompanying gear. This subject has been very fully treated, as far as the Richard's indicator is concerned, by Professor Reynolds in his valuable paper already referred to, in which he shows that the oscillation got up at the beginning of the stroke by the pencil being shot up on admission of the steam, and which is caused by the inertia of the moving parts, is the most serious thing we have to contend with. He farther states that when the number of oscillations in a revolution is less than a given amount they would seriously distort the diagram, unless the effect is neutralised by undue pencil pressure. This, it is almost unnecessary to state, is a most undesirable course to follow, and the only true way to meet the difficulty is so to modify the pencil gear that its inertia will be considerably reduced. It is stated by Mr Brightmore that the bar which carries the pencil in the Richard's motion has more influence on the oscillations than all the other parts put together; consequently the first thing to be done is to get rid of this bar, and this has now been done in all the newer forms of parallel motions in use, as will be seen by examining the instruments on the table, but besides this it is necessary to reduce the weight of all the parts as much as possible, and in this direction there is farther room for improvement. If we examine the Crosby indicator, which you will see from Table No. I., has (size of piston considered) the lightest parallel movement, we will find that the arm which carries the pencil might be much thinner, and the marking point (which owing to its position has so much influence on the oscillations) might be very much lighter. Applying the formula used by Professor Reynolds for finding the number of oscillations in a revolution to the Crosby motion, namely,

$$n = \frac{\frac{60}{N}}{2\pi\sqrt{\frac{W}{12aesg}}}$$

where n = number of oscillations in a revolution;

N = number of revolutions of engine;

$W = \Sigma\,(r^2 w)$ where Σ expresses the sum of all the quantities in the brackets;

e = scale of spring;

a = area of piston;

= ratio of motion of pencil to that of piston of indicator.

Table I.—Weights, &c., of Indicator Parts.

	1	2	3	4	5	6
	Elliott Richard's.	Elliott Dark's.	S. & B. Thomson's	Elliott High Speed Dark.	S. & B. High Speed. Thomson.	Crosby.
Weight in grains of piston and rod, -	403	350	480	297	180	234
,, ,, parallel motion, -	315	163	141	138	74	96
½ ,, ,, $\frac{1}{40}$ spring, -	230	230	257	75	94	70
	948	743	878	510	348	400
Ratio of pencil travel to piston travel, -	4 to 1	4 to 1	4 to 1	4 to 1	5 to 1	6 to 1
Area of piston in inches, - - -	·5	·5	·5	·5	·275	·5
Weight in grains of paper drum, - -	3027	3027	2187	1084	884	664
,, ,, drum carrier, - -	6960	6960	4894	1848	2142	800
	9987	9987	7081	2932	3026	1464
Diameter of drum, - - - -	2·05	2·05	2·01		1·59	1·52
Greatest travel of drum, - - -	5·25	5·27	5·375	3·5	4·25	4·062
Form of drum spring, - - - -	Volute	Volute	Volute	Volute	Volute	Spiral

One-third weight of Crosby spring is taken.

and substituting the altered values for W and s in the new motion, the number of oscillations would be about twice as many for a given speed as with the Richard's motion; or in other words, it would be possible with a given spring to take good diagrams at double the number of revolutions with the new indicator as could be done with old one; or in the case of an engine, the speed of which is not very high, it allows a lighter spring to be used which is often a great advantage. With Thomson's indicator the author found that at 180 revolutions and $\frac{1}{16}$ spring he got better diagrams than was possible with a Richard's indicator and $\frac{1}{32}$ spring, so that in every way it is of the utmost advantage to reduce as much as possible the inertia of the pencil gear. This might be accomplished to a degree much beyond anything that has been already done, by making the piston rod and radius links of the pencil motion of aluminium, and the pencil arm of thin tempered steel.

PENCIL FRICTION.

If the pencil is not to be used as a break to stop oscillation set up by inertia, as already described, the error due to its friction and that of the piston, &c., is not more than one per cent., as has been pointed out by Professor Reynolds. He further found that when the speed of the engine was such that the oscillations were less than 30 in a revolution, it was necessary to increase the pencil pressure which increased the error due to friction until, when the oscillations in a revolution were only 15, the pressure on pencil necessary to prevent distortion of diagram was so increased that the error was in some cases as much as five per cent. It is evident that the only true remedy for this is either to increase the strength of the spring, which often may be impossible if the pressure in the cylinder is low, or else have recourse to an indicator with lighter moving parts, and not attempt to take diagrams with an instrument unfitted for the work.

THE INERTIA OF THE DRUM.

This has not hitherto been fully investigated, as far as the author is aware; he has, therefore, gone into it carefully in conjunction with Dr Wallace, of Cardross, and has arrived at the following solution of the problem which he would place before the members of this Institution for their consideration, as, if correct, none of the instruments before you will meet its requirements, as may be seen by examining Table II.

Table II.

Weight in lbs. on Cord required to pull Drum from Stop to Stop against Spring.

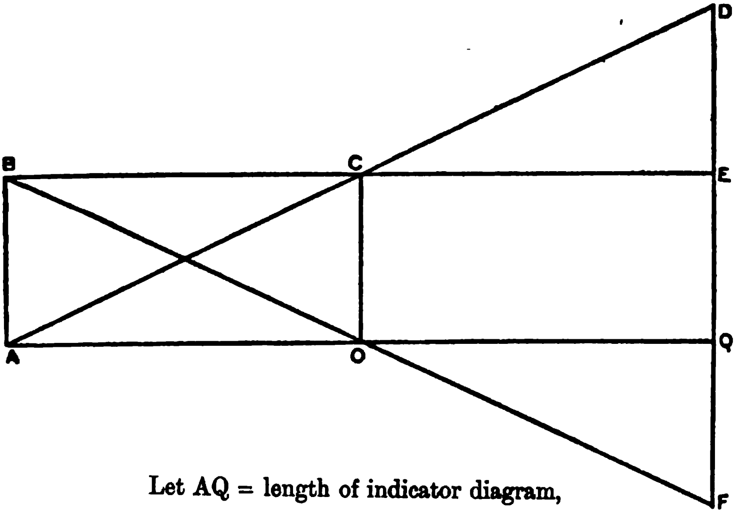
Load at Starting.	Load when Spring is pulled out.	Differences.	
3¾ lbs.	6¼ lbs.	2½ lbs.	Richard's not adjustable.
¾ lb. 2½ lbs. 4 "	3½ lbs. 4½ " 5 "	2¾ lbs. 2 " 1 "	Thomson large.
1 lb. 2 lbs. 3 "	5 lbs. 6 " 7 "	4 lbs. 4 " 4 "	Thomson high speed.
2 oz. ½ lb. 1 "	1 lb. 4 oz. 1 lb. 10 oz. 2 lbs.	1 lb. 2 oz. 1 lb. 2 oz. 1 lb.	Crosby.

The motion of the drum being derived from the piston, may be treated for practical purposes as harmonic. The angular acceleration, therefore, is equal to $\frac{4\pi^2 D}{T^2}$, when D indicates the angular displacement from the centre of the diagram, and T the period of an oscillation. Then the couple required to start the drum is $\frac{4\pi^2 I}{T^2}$ × half the length of diagram.* This couple varies as the angle

---

* $T = 2\pi\sqrt{\frac{D}{A}}$. Hence, $A = \frac{4\pi^2 D}{T^2}$. The couple acting at any point $= AI$, $D = \frac{\frac{1}{2}\text{ length of diagram}}{\text{radius of diagram}}$ at the beginning of the stroke. Hence the couple acting when the stroke begins is $\frac{4\pi^2 I}{T^2} \times \frac{\frac{1}{2}\text{ l. of diag.}}{R}$. It is convenient to estimate the couple in pounds acting at the circumference of the drum, which is got by substituting IR for I in the above formula. The R cancels out, and the expression in the text is obtained.

of displacement, and of course is zero when the drum passes the centre point, and of opposite sign through the last half of the semi-oscillation of the drum. The problem is to arrange the resistance of the drum spring so that its couple shall be opposite and equal to that of the moving drum, in all portions of the oscillation. If the spring be a spiral and is rigidly fixed to the drum the couple required to turn it varies inversely as the length of the diagram, counting from the right hand, and the couple moving the drum varies as half the length of the diagram measured from either side of the centre. It is, therefore, manifest that if the difference between the couples created by the spring when the drum begins and ends movement, is double the couple required to start the drum, the algebraic sum of the two couples will be a constant. This is shown by the diagram.



Let AQ = length of indicator diagram,
QD = couple of spring fully coiled,
AB = initial couple acting on drum ;

then ADQ = work done against spring,
ABO = positive work upon drum,
OQF = negative work done by drum.

It is evident that for a quarter of an oscillation the cord does work against the spring and upon the drum, which is represented by the rectangle BO. During the next quarter the drum and cord both do work against the spring, and the portion done by the cord is represented by the rectangle CQ. In the remaining half of the oscillation this is reversed. The following figures will give an idea of the couples to be dealt with at different engine speeds, taking the moment of inertia of the moving parts of the drum to be represented by 1 lb. acting at the circumference:—

Revolutions per minnte.	Lbs,
120 - - -	0·46
180 - - -	1·04
240 - - -	1·84
300 - -	2·87
360 - - -	4·16
480 - - -	7·36
600 - -	11·52

These figures are calculated for a 4½-inch diagram from the formula acceleration at circumference of drum $= \frac{\cdot 11523}{T^2}$. If the calculation is to be made for a 3-inch diagram, the formula becomes $\frac{\cdot 07703}{T^2}$.

The practical inference from these calculations is that the moving parts of the drum should be made as light as possible, and that the spring which actuates the drum should be so arranged that its stiffness can be increased. By thus making it possible to adopt the stiffness of the spring to the couple acting on the drum at any engine speed, it will be possible to secure a uniform tension on the cord, whether a diagram is taken from a slow or fast going engine.

FRICTION OF THE DRUM.

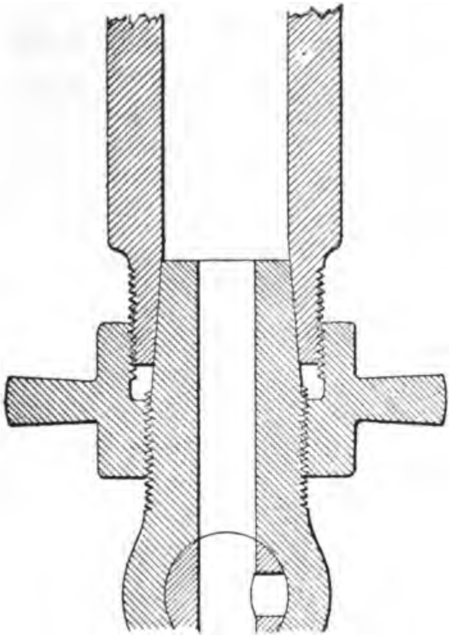
Professor Reynolds has shown that when the cord is long the effect of the drum friction in distorting the diagram is very serious, even at comparatively slow speeds, but as this distortion is due to the cord being stretched in overcoming the friction, it was much less apparent when wire was used. Although something may be done to reduce the drum friction, it is apparent that the only way to prevent distortion from this cause is to use a cord of as unyielding material as possible. From experiments made by the author, it was found that ordinary indicator cord well stretched and then laid aside for some time yielded ·0125 per foot for every pound weight applied, but that the same cord when subjected to a weight of 15 lbs. for an hour, and then tested, yielded only ·008 per foot for every pound applied. From this it is evident that cord should not be used longer than is necessary to go round the drum, and about nine inches to spare for adjustment of the hook, wire being used for the remainder of the lead. This has always been the author's practice, but the great difficulty with wire is its liability to get into kinks and bends, and if these are not fully pulled out by the initial pull on the drum spring, stretching will be the result. From experiments on the piece of steel wire which is now shown, No. 36 BWG, the author found that it stretched ·003 per foot for every pound of load. But wire like this would be far too likely to kink and get broken. To obviate this the author would suggest a cord having two or three such steel wires, copper-plated to prevent rusting, woven into it. Such a cord would be as pliable as this steel wire, and with ordinary care would have no tendency to kink. Even finer wires and more of them might be used so as to ensure sufficient pliability.

In quadruple tandem engines a source of error comes in which is most felt in the upper cylinders. I refer to the spunging or working of the engine itself, which in engines constructed with columns between the upper and lower cylinders is so marked as to be quite apparent to the eye. This tends to lengthen the diagram on the down stroke and shorten it on the up stroke, but to what extent there is no means of knowing.

In the course of this paper the author had occasion to mention the Kenyon indicator, in which instrument the cylinder and piston is replaced by a bent elliptical tube similar in principal to the Bourdon gauge. By this means we most effectually get over any difficulty of piston friction, but from a number of diagrams taken by this instrument, the author is of opinion that the tube is sluggish in its action; all sharp corners about the diagram being rounded off. In some instances, the diagram even having the appearance as if the valves were set with negative lead. In comparing several diagrams taken in rapid succession from the high pressure cylinders of a triple expansion engine, it was found that invariably the piston indicator gave from half a pound to a pound more mean pressure in 37 lbs. than the Kenyon instrument. It further appeared from experiment that a $\frac{1}{80}$ scale tube if correct when hot, was about 20 lbs. strong in 160 lbs. when cold, so that in using the instrument great care should be taken to have it thoroughly heated up before taking the diagram, and the atmospheric line should be drawn immediately on releasing the steam.

There are one or two small points of detail in the construction of indicators which call for attention. Though simple in themselves, they greatly affect the handiness of the instrument. In the first place the paper drum should be so turned to the operator that when the drum is against the stop the papers can be put on by the right hand. This, you will notice, is not the case with some of the indicators before you. Secondly, the paper clips should be about half-an-inch shorter than the drum and slightly turned out at their points. The author would prefer them both the same length. Attention to these points greatly facilitates the rapid placing of the paper. It is further suggested that the coupling at the bottom of the indicator might be constructed as shown in Fig. 4; the hollow cone being simply a continuation of the indicator cylinder, the entering cone and coupling nut being on the cock this would have the advantage that, on removing the indicator from the cock and taking out the piston, the cylinder could be cleaned much more easily than at present, it being most difficult to remove particles of grit from the bottom of the cylinder as now constructed. Not only does the indicator itself admit of improvement but, as may be seen

Fig. 4.



by examining those now supplied by Messrs Elliott Bros., of London, the cases may be improved also. The side of the case is hinged to fold back, and the indicator is attached to this side by its coupling, so that when the side is folded back, the indicator stands clear of the box and is securely held in an upright position most convenient for overhauling.

No paper on the indicator would be quite complete that did not make some reference to the use of the planimeter as the most accurate and convenient methods of calculating diagrams. With the smaller form of the instrument, the reading on the scale gave the area of the diagram, and to get the mean pressure it was necessary to divide by the length of the diagram in inches, and multiply the result by the scale. With the improved instrument which is now placed before you, and which is Amsler's proportional planimeter, fitted with a point on the top of the bar, and another on the slide, it is only necessary to set the points to the length of the diagram by moving the slide along the bar, place the instrument in position and go round the diagram in the usual way, that is, in the direction of the hands of a watch. The reading then gives the mean height of the diagram in the 400th of an inch, taking the smallest division read by the Vernier scale as unity. The scales of springs are usually some multiple of four, so that it becomes a very simple matter to arrive at the mean pressure.

Let R = reading, S = scale of spring, MP = mean pressure; then

$$MP = R\,\frac{S}{400}.$$

$\frac{S}{400}$ can be calculated for any scale, and a record kept of it. The following are some examples:—

For $\frac{1}{10}$ scale $\frac{S}{400}$ = ·025.
$\frac{1}{20}$ = ·05.
$\frac{1}{40}$ = ·10.
$\frac{1}{80}$ = ·20.
$\frac{1}{100}$ = ·25.

From this it will be seen that the instrument saves a great deal of calculation; and, used in conjunction with Fuller's slide rule, enables diagrams to be worked out in a few minutes. The planimeter in this form was first brought under the author's notice by Mr Davison, a well-known member of this Institution.

The **President** said that as the paper which they had just heard read embraced a great deal of detail, in which many of them were much interested, they must defer the discussion until next meeting. In the meantime, if any gentleman who could not be present at next meeting had anything to say on the paper, the meeting would now hear him.

There being no remarks,

The President said he hoped every one interested in the subject of the paper would be present at the next meeting.

November 22nd, 1887.

No remarks being made on this paper, the discussion was closed, and on the motion of the President, a vote of thanks was awarded the author of the paper.

On an Improved Riveting Machine.

By Mr Hugh Smith.

(SEE PLATES I. AND II.)

Received and Read 22nd November, 1887.

MARINE boilers are now made to work at a very much higher pressure than what was the practice only a few years back, and this has necessitated the introduction of new tools for their manufacture. Very heavy and large hydraulic riveting machines are now used, and it is a new principle in these machines for first closing the plates, and then staving and forming the rivets, that I am about to describe. The novelty of this machine is that it first closes the plates with a pressure equal to or greater than the pressure used for staving and forming the rivet, as may be considered best, and that this pressure is next gradually transferred, wholly or partially, to stave and form the rivet: that is to say, each ton of pressure which goes on to stave the rivet is relieved from the plate closer.

Fig. 1, Plate I., represents a section through the head of a boiler riveting machine, designed for the purpose of first thoroughly closing the plates, and then staving and forming the rivets. B is the plate-closing cylinder and C is a piston working in it, and fixed to the main casting of machine. E is the riveting cylinder, and the piston F, is cast in one piece with the slide GG, and slides in this riveting cylinder. The plate-closing snap K, is actuated by an outside slide DD, which is screwed into the end of the casting of cylinders at S. The small cylinder A, is for the purpose of saving of power, and M is the push-back cylinder. In working this machine the pressure water is first admitted into small cylinder A, which forces forward the cylinder and slides until the plate-closing snap K, strikes the plates. The plate-closing cylinder B, has meanwhile had free communication with the water in a tank placed about 10 feet above the level of this cylinder, causing it to get filled with water on account of the pressure due to the 10 feet of height and on account of the vacuum created at B when the cylinder is forced forward by small ram. The cylinder B, is now shut off from communication with this tank and opened to the pressure water, which causes the whole pressure from the cylinder to come on plate-closer K, and thus to close the plates with the desired pressure. Cylinder E is now opened to the pressure water, and this forces forward the piston F, which acting through the slide GG, staves the rivet by means of the snap H. When the pressure water enters the cylinder E, the pressure in this cylinder will be only sufficient to overcome the friction and cause the piston and slide to travel forward, and this pressure will remain thus until it meets with a resistance to cause it to rise. It will meet with this resistance when the snap comes up on the rivet and the pressure in the cylinder will only rise in proportion as the rivet resists it. The back pressure of the cylinder E will thus also be equal to resistance of the rivet, and this pressure will come off the pressure which is holding or closing the plates, owing to the cylinders being in one piece. The cylinder E may be made the same size as the cylinder B, and in that case when the riveting snap comes up to the solid metal the whole pressure will be relieved from the plate-closer and transferred to the rivet. By making the cylinder B, or plate-closing cylinder larger than the riveting cylinder, a certain amount of pressure is left on the plates after the rivet is closed, this amount being due to the difference of areas. The amount of pressure on the rivet very often used in the machines for heavy marine boiler work is 130 tons, and supposing the 130 tons to be on the plate-closing snap, the amount of pressure necessary to stave and form a head on the heaviest rivet when moderately heated is about 50 to 60 tons, and thus when the rivet was completely formed there would still be a pressure of from 70 to 80 tons on the plate-closer, which would be either wholly or partially transferred to give a final squeeze to the rivet. The speed at which the rivet can be put in with this machine is quite as fast as can be done with an ordinary machine, the small cylinder A, pushing up the plate-closing snap to the plates much faster than if you were admitting the pressure water direct from accumulator to the large plate-closing cylinder B. The amount of power or pressure water required for working this machine is less than that required by ordinary machines, because the point of snap requires to be about 2 inches clear of the point of rivet to give a good working clearance, and in an ordinary machine this would be made to travel forward by admitting pressure water to a large cylinder, but in the machine before us the small cylinder A, as already described pushes forward the snap, filling the larger cylinder with water from a tank, and water being practically incompressible the amount of pressure water required is only as much as overcomes the spring of the machine. Also the distance from the point of snap H, to point of snap K, can be regulated to suit the projection of the rivet through the plates, thus only using pressure water when work is required to be done. The advantage of thus thoroughly closing the plates is to prevent washers or rings forming between the plates, and also for the purpose of reducing the caulking to a minimum. The weakest part of the shell of a boiler is through the rivets on account of the section of plates being reduced, and having the plates thoroughly closed must so increase the friction between the plates as to make the boiler stronger at this part than could be got if the plates are not thoroughly closed. Another important feature of the plate-closer is that if the boiler is not hanging in the proper position with respect to the machine, it is at once brought round to that position, and the pressure on the plates causes the boiler to stand square, and also the rivet, ready for the riveting snap to come up. It is also a great advantage to have the boiler held fast when the riveting snap comes up on rivet, as in a machine without a plate-closer the rivet has a tendency to bend when the snap strikes the point of it, which causes the boiler to swing a little and very often makes the rivet one-sided, besides the objectionable vibration which takes place when the snap comes hard up to the boiler. In riveting two rings together the usual mode adopted is to put in a few rivets round the circumference at a pitch of about 15 inches and then withdraw all the service bolts and proceed with the rest of the riveting. The application of a plate-closing riveter for riveting the keels of ships would, I think, be very advantageous as there is some difficulty in getting these plates to lie closely up to the keel. Also in large girders where the top and bottom flanges are composed of a number of plates riveted together in order to get the necessary strength, there is great difficulty with an ordinary riveter, in getting the plates as close as could be desired, and the strength of the girders would be materially increased by using a plate-closing machine.

Fig. 2, Plate I., is a section of a machine similar to Fig. 1, but the pressure is taken direct from the centre of the cylinder and not overhung as in the case of the flush-topped machine.

Fig. 1, Plate II., is a section through a riveter of the portable type, and although a little different in construction from Fig. 1, Plate I., it is exactly the same in principle, except that the small ram for pushing forward the plate-closer is not applied on account of it being unsuitable for a portable machine. The method of suspending and working this machine is shown at Fig. 2, Plate II., along with the arrangement of crane, hoist, and walking pipes. The machine is shown riveting the shell of a boiler to the end plate, the end plate being flanged outwards, and also riveting a furnace to the end plate. One method adopted for allowing all the riveting in a double-ended boiler to be done by machines is to flange one end with the outside flange inwards, and the furnace holes outwards The end is riveted to the shell by the fixed machine, and the furnaces are put in and riveted in their place by the portable riveter, as shown at Fig. 2, Plate II. The other end has the outside flange and the furnace holes all flanged outwards, the end being riveted to the shell, and the furnaces riveted in their place, as shown at Figs. 1 and 2, Plate II. The combustion chamber may have the flanges outside and be riveted by the portable riveter if desired.

For the purpose of altering the power to suit the various classes of riveting, the simplest method is to have an accumulator arranged so that any portion of the weights may be carried on an iron framing specially constructed for the purpose, and thus relieving their weight from acting on the ram the water can be reduced to any pesired pressure. In cases where large accumulators are already in use I have varied the power by using three cylinders for plate-closing, and three cylinders for riveting, thus getting three powers for plate-closing, and three powers for riveting.

In the after discussion,

Mr THOMAS A. ARROL said he had done a good deal of work with hydraulic riveters, although he had not had so much experience with them as a famed namesake. He did not quite understand whether Mr Smith claimed the "closer" as his own original idea, or merely that he had brought the idea to a practical use, for he had known of it for at least the last ten or eleven years. Mr Tweddell brought out the idea, but he did not know whether it had or had not proved very useful in boiler-making, although he believed it would be more useful in that than in bridge-building. He could not remember what were the details of arrangements according to Mr Tweddell's ideas, but the same principle was aimed at, and he felt sure was obtained. He did not think it was advisable to vary the pressure on a riveting snap as it came up to its work. He could see there was a practical difficulty, for to his mind the pressure on the snap was greater at the time that it was effecting its greater pressure. He could imagine if the pressure snap were relieved there might be a tendency for the rivet to spring, and the metal to keep open. He thought for bridge work the machine would produce a theoretical fineness that was quite unnecessary, because in such work they were under different conditions from what they were in boiler-making, and he conceived that the difficulties in getting plate joints together in boiler work were now getting fewer and fewer. From his own experience he could say that it was quite possible to close a ¾-inch angle and two 1-inch plates. He thought that with flat surfaces properly bolted together it should be good. The crane arrangement he had used for the past ten years. In the angle joint arrangement there might be a difference although he did not know. The arrangement for saving water might do so, but from his own experience with a 1000 ton press, they applied side rams to bring forward the large cylinder to the work, and as the main pistons were lifted up they saved a great deal of water. He thought the saving of water in that small valve was nothing, if they could get the ram forward quicker. Before going more fully into this matter he would like to compare some drawings of Mr Tweddell's that he had with those diagrams of Mr Smith, so as to refresh his memory. He was afraid they were not making much progress in their scientific arrangements for the making of boilers or the building of bridges.

Mr GEORGE RUSSELL said he had had very little experience with hydraulic machine tools, except for riveting comparatively thin plates; but he thought the plan explained in the paper was a very ingenious one for saving power. No doubt the idea was not quite new of closing the plates and holding them close until the rivet head was formed. One of the managers of Messrs Caird & Co., designed a machine for that over 15 years ago. He had not observed whether it was stated in the paper the diameter of the rivets. It would be of great interest if Mr Smith could also give them the amount of power required for closing the plates, and forming the head of the rivets of various sizes. They were entitled to thank Mr Smith for bringing the paper before them, and for the many details it contained, although they might not be quite novel, as Mr Arrol had said. The President, he had no doubt, could tell them a good deal about hydraulic work, for he had made experiments with some special machines himself.

Mr MOLLISON remarked that Mr Smith had put a good deal of stress upon the closing part of the machine. His experience in boiler making led him to the conclusion that they must not place too much dependence upon the closing of work after it went to the machine—the work must be fairly fitted before it went to the machine. The greatest difficulty he had experienced lately in riveting joints was to get rid of the scale on the rivets. This scale accumulated in heating, and went into the holes with the rivets, preventing a good job being made, as he had found on having occasion to take out some rivets, that they came out quite easily. The great point was to get the work thoroughly fitted before going to the riveter, and having the scale well knocked off the rivets.

Mr JAMES ROWAN said he could bear out what Mr Mollison had said with regard to boiler-riveting, which was really the opinion of marine engineers generally, that they must see to their careful fitting together, and that they could not lay any stress upon the closing of them. He believed that the caulking of heavy riveted joints was rather the exception than the rule. The ordinary hydraulic riveter was a mere cylinder, and was as simple a machine as could be made. They had got to fit the plates so carefully together that he believed that even before they were riveted they were quite water-tight. It was not the pressure upon the rivets that had to be depended upon, for if they were made too short then the holes would not be filled, and if they were made too long the holes would be filled, but then there would be a large barb left. Rivets, when heated in an ordinary furnace, had always a scale on them, and that should be removed carefully. He had been informed that rivets heated by the Lucigen light had not the same scale left upon them; but where there was scale going into the hole with the rivet, it being cold caused leakage in the joint. He really thought that Mr Smith's patent was a bit of refinement that none of the boiler-makers had found much use for, and he thought that every one would agree that the simpler their working tools were the better, and that the introduction of this machine into their workshops would be of no practical use, and yield them no proper return.

Mr Hugh Smith said with regard to the oldness of plate closing machines, no doubt plate closing by machinery had been attempted long ago. But the question is—How was it done? Was it of service to improve the riveting or not? By the application of his patent machine they could get the whole power of the machine to close the plates; and it was pretty much admitted by boilermakers that to get the plates thoroughly closed required more power than to make the heads of the rivets. They made a rivet head 1¼-inch with about 60 tons pressure quite effectually, but they would not make tight boilers if they had only 60 tons pressure. It was found that those 1¼-inch rivets required about 130 tons to close them thoroughly and make a good job. Now, with his patent machine they could get the whole power applied to close the plates before they closed the rivets, which prevented washers from forming between the plates. There were plenty of good riveting machines in the country, but the object of the engineer now-a-days was to make something better than existed, something more automatic, and that the work might be thoroughly done. He believed his machine was a step in that direction. As he explained in his paper, the bringing of the plates close brought the boiler into position, and it prepared the rivet for the snap coming up properly to it. Frequently the boiler was found swinging about, and when the snap came up the rivet was not fairly hit. It was required that the boiler should be standing square to the snap, and that the head of the rivet should be pressed hard in, so that the plates might be thoroughly closed. Surely these were great advantages in making a boiler. In the case of Mr Tweddell's machine, he could only get on the plate closer the pressure that he took off the riveting snap, and when he allowed that to go on the rivet, he had to let the plate closer go.

The President said that according to the rules of the Institution, the discussion must be adjourned till the next evening, and therefore he thought it would be better for Mr Smith to reply to any of the remarks made afterwards, as he would have an opportunity of doing so at the end of the discussion.

Mr **Smith** cordially agreed, and the discussion was accordingly adjourned.

In the discussion of this paper, on the 20th December, 1887,

The **President** said that he observed that Mr Smith was not present, but if any one had anything further to say on the subject, he was sure the meeting would be pleased to hear it.

Mr **Thomas A. Arrol** remarked that at last meeting he had said that it appeared to him that Mr Smith's patent machine was very similar in principle to those that Mr Tweddell had brought out previously, but at that time he was not prepared to speak very definitely on the subject. Since then he had been looking into the matter, and he now held more confidently to the statement he had then made than he was then prepared to do. He was of opinion that Mr Smith's patent was a very close following after that of Mr Tweddell, which was brought out fully four years before Mr Smith took his patent. At all events, Mr Smith and Mr Tweddell held the same principle and sought to obtain the same objects. He would not, probably, have said anything further on the subject if Mr Smith had owned at the time he had drawn his attention to the matter, as he had done afterwards, that he was only following in the footsteps of other engineers; but he might state that, at the meeting at Cardiff, in 1874, of the Institute of Mechanical Engineers, Sir Frederick Bramwell mentioned that he had seen a plate-closing machine in the year 1841. Mr Tweddell, he had no doubt, had received an impetus towards perfecting his machine from what Sir Frederick had stated, and subsequently brought it into use. Seeing that Mr Smith was not present, he would not prosecute the matter further; but in his remarks after reading the paper Mr Smith made the following state ment:—"In the case of Mr Tweddell's machine, he could only get on the plate-closer the pressure that he took off the riveting snap, and when he allowed that to go on the rivet, he had to let the plate-closer go." He had no doubt that all the gentlemen who had seen Mr Tweddell's machine would say that was quite an erroneous statement. In his machine Mr Tweddell had a pressure of 150 tons. Of this he used 60 tons pressure for closing the plates, and 90 tons for closing the rivet up. As the rivet snap came up the water escaped from the plate-closer. On referring to Mr Smith's diagrams it was evident that he could have no excess pressure at the closing at all, as his cylinders were both of the same diameter. He did not think he need say more. There were differences, perhaps ingenious differences, between Mr Smith's and Mr Tweddell's machines; but he thought the latter should have the credit of being the first to apply hydraulic pressure to a plate-closing machine.

The PRESIDENT said they must thank Mr Smith for his paper on this very important subject. Whether it be new or not new, at all events the Institution have had much advantage both from the paper and from the discussion. How far "closers" were of any real value was a matter that he would express no opinion upon, as he had never used one.

The vote of thanks was cordially passed.

The following additional remarks have been received :—

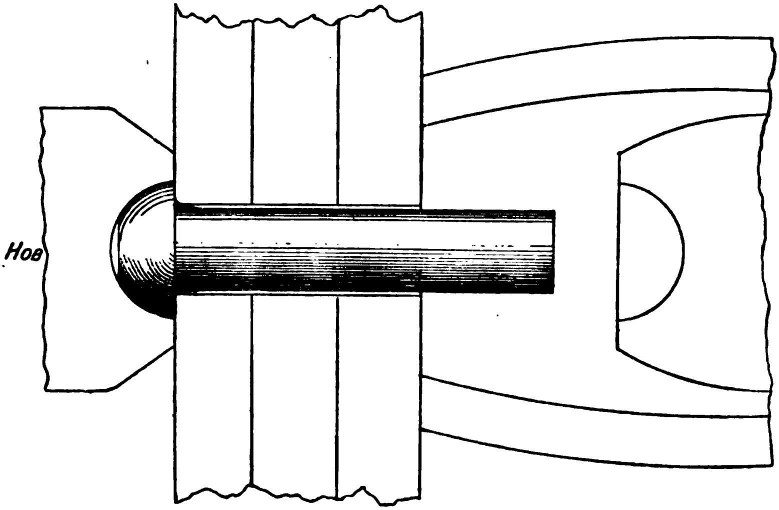
Mr William Crockatt writes :—

The experience of Alexander Stephen & Sons with a plate-closer may be of interest. About two and a half years ago, they laid down a 100-ton Tweddell riveter, fitted with plate closing apparatus. The work done by this machine on a heavy boiler shell, appeared to be highly satisfactory, until some of the rivets were casually tapped with a hammer, when it was found that a few of them were slack in the holes.

On investigating the matter the reason was apparent, and the defect was seen to be inherent to the principle of the closer.

When the rivet is put into the hole, and the closer brought on to the plates, as shown in Fig. 1, the resistance comes in the first place on the head of the rivet. This has the effect of pushing any surplus metal that may be in the head into the hole; and as the point of the rivet is not held, the shank is not compressed and does not fill the hole. Also, if the head should not exactly fit the cup in the hob to begin with, there may be a vacancy left in the cup, as shown in Fig. 1, when the closer has squeezed the plates against the hob.

Fig 1

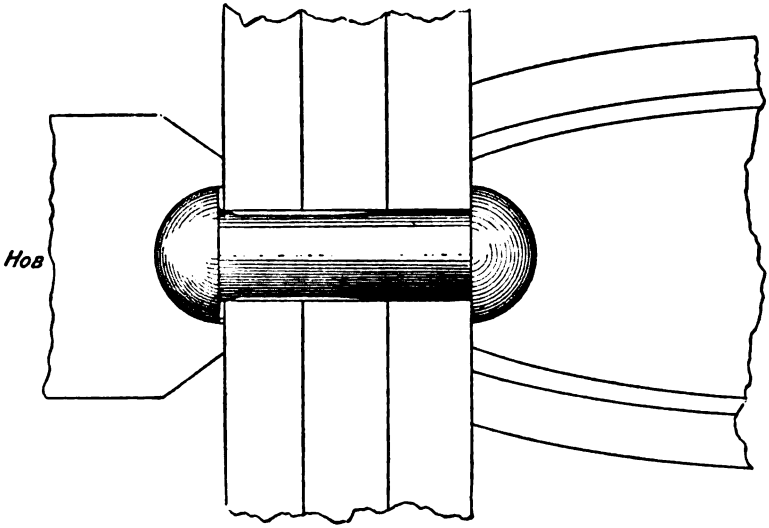


When the rivet-closing snap is now brought on to the rivet, as shown in Fig. 2, there being no surplus metal in the head to be squeezed, the compression all takes place from the point, the result with a long rivet being that only about half of the shank next the point fills the hole tightly, the end next the head not filling the hole completely. Further, when the head of the rivet does not fill the cup in the hob, the rivet is—while being closed—forced on end slightly, leaving it slack endways.

When doing work with the closer, we had a number of rivets to cut out, and ultimately discarded it. To make it efficient would require the addition of a moveable closer on the hob side, which, of course, would complicate the machine enormously.

These objections to the closer apply, of course, only to its use with heavy plates. With plates up to say $\frac{3}{4}$-inch thick it may do very well. But after all, there should be no occasion, with good work, to require to close the plates while riveting.

FIG 2



Mr Alexander Turnbull also writes:—

I think that to disparage the using of plate-closing appliances is quite a mistake, not only with regard to boiler-work, but to all riveted structures where it is desirable to have the greatest possible cohesive and frictional strength.

The degree of accuracy now obtained in plate bending is surprising, the curved surfaces being found frequently to be better fitted than ordinary flat surfaces, and while it may be admitted that incidental and exceptional cases may occur where an all round water-tight joint is obtained, it cannot for a moment be granted that such accurate fitting generally occurs in ordinary practice; and even were it so, in view of capillary attraction, a water-tight joint in its ordinary acceptation cannot be regarded as perfect fitting, or such that the use of a plate-closer could not improve matters, and it is questionable whether in the future more accurate fitting from black plates can be obtained than at present, because, as we know, the slightest difference in hardness or homogeneity in any part of the plate will prevent accurate bending, or perfect fitting, so that if this desirable object is to be attained, it seems that the only course open is to have the contact surfaces of the plates machined in their cylindrical form, and fitted to each other male and female with a slight taper.

In ordinary work prepared for riveting, it is not a very uncommon thing to find, both in flat and curved plates, that the surfaces of the plates are at several places $\frac{1}{16}$th of an inch distant from each other, and were riveting to proceed from any such point, washers or films of metal between the plates is almost certain to be formed while the rivet is being staved, and which is more detrimental to the closing of plates in which the holes are drilled than where the holes are punched, the latter providing as they do a receptacle for the protruding metal, and unless these washers or films of metal are forced into the plates by the combined force of the riveting-machine, and that exerted by the rivet in cooling, calking must necessarily follow-

Again, in cases where the rivet in cooling has succeeded in drawing the plates together, it will not be infrequently found that the rivet has been drawn, and does not fill the hole, also that the force exerted by said rivet in holding the plates together is much less than that of a similar rivet where the plates were closed previous to riveting.

Usually, riveting proceeds from a point where the plates are in contact, so that the contractile force of each rivet is relied upon to act as a plate-closer for each succeeding rivet, and while it is admitted that by so doing there is less likelihood of washers being formed between the plates, such a method cannot be regarded in any other light than than of a "makeshift," and one in which the structure is robbed of a considerable amount of its proper strength, and therefore, I conclude that a practical plate-closing adjunct to a riveting machine is conducive to the securing of the strongest possible riveted structures.

The appliance before us seems to have been got up with much care and thought, and appears to be a practical machine, but in this machine, like all others, there is nothing like a thorough practical test and of some duration being applied to it. The saving of power appears to be obtained in a simple way. I would, however, suggest for Mr Smith's consideration, whether it would not be desirable to dispense with the small auxiliary cylinder, and bring forward the plate-closer to its work by using the water at low pressure acting in the closer cylinder, by so doing the machine would be simplified, and a further saving of power would be effected, because the quantity of water at high pressure used would be only that due to staving and forming the head of rivet. Possibly the suggested arrangement might be accomplished by using a threeway bock.

I trust Mr Smith will be successful, believing, as I do, that he is on the right track.

Mr Smith being unable to be present at meeting of 20th December, communicated his reply to discussion on 18th January, 1888, as follows:—

Mr Thomas A. Arrol stated that my patent machine was similar in principle to Mr Tweddell's. After considering my patent, he states he was further confirmed in that view. I hold that the principle of my machine is totally different from Mr Tweddell's—it is described in my paper, and I need not repeat it—producing a very different effect, viz.: That we get the full power of the machine to close the plates, whereas Mr Tweddell's only gets a portion of the power of the machine. I previously stated what Mr Tweddell's machine did, and Mr Arrol condemns that statement as erroneous, but immediately afterwards confirms my statement by repeating the very same, viz.: That with Mr Tweddell's machine, with a power of 150 tons, he used 60 tons on the plate closer, which was taken off the 150, leaving 90 tons for closing the rivet; and if he allowed the whole 150 tons to go on the rivet, he must let go the plate-closer. This is precisely what I stated.

Mr William Crockatt states his experience with Mr Tweddell's riveter, that when using the plate-closer the rivets were found to be slack in the holes. He accounts for this by the inherent principle of the plate-closer. This may be the case with a defective plate-closer or defective working. I have found in working my machine with the plate-closer that the rivets are so tight that they do not require to be caulked. The plates require no caulking inside the boiler, and a very slight amount of caulking outside. This is the best proof of the utility of the plate-closer. He also objects to the plate-closer being used when doing heavy plates, but he approves of it when doing light plates. This appears to be the defect of Mr Tweddell's machine, that for heavy plates his plate-closer has not sufficient power, which agrees with what I stated in my paper.

Mr Alexander Turnbull appears to me to have thoroughly grasped the subject before us, and appreciates the principle of bringing the plates close by a machine before staving the rivets; and also the other very important point I referred to in my paper, viz.: The increase of the strength of all iron structures by the close contact of the plates. He recommends me to consider a mode of bringing forward the plate-closer by a low water pressure. I may state that I had this under consideration before maturing my machine, but found that the amount of additional machinery would be very much increased. I have found this part of the machine to work most satisfactorily with the tank placed about 10 to 20 feet above the machine.

Mr Turnbull approves of a practical test of the machine with which I quite agree. I have sent out three very large machines, one of them has riveted a number of marine boilers, and the parties state that they are thoroughly satisfied with the great improvement in closing the plates, the boilers being nearly tight without caulking, requiring only a very little caulking outside, and no rivets being caulked. The second machine has also done its work to the perfect satisfaction of the firm who have it in use. The third machine, which was sent abroad, I expect is at work, and have not yet heard definitely regarding it.

On Copper and Copper Castings.

By Mr George C. Thomson, F.C.S.

Received and Read 22nd November, 1887.

The object of the present paper is to bring before your notice a few samples of castings made by Mr R. Murray's new process, and to point out their suitability for various purposes connected with the arts and manufactures, more especially that known under the head of Engineering. It may be well, in the first place, to give a few particulars about copper, and the influence of various impurities thereon, before touching upon the effect of heat on copper and the copper alloys. Copper is a metal well-known by its fine, rich, red colour and general indifference to oxidation or rusting, also by its great ductility and malleability. It takes its name from Cyprus, from whence the Romans obtained it, and its Latin name is *cuprum*. Copper is one of the few metals found native in masses; but the most of all the copper of commerce is obtained from the oxides, carbonates, and sulphides of copper ores, and the Spanish copper is almost entirely obtained by the wet process from iron pyrites containing from two to four per cent. of copper. It is very widely spread in nature, being found in various minerals, soils, seaweed, blood of various animals, the liver and kidneys, feathers of birds, and flour, hay, straw, meat, eggs, cheese, &c. In the ores wrought by the dry process, or smelting, the percentage of copper varies from 15 to 88 per cent. according to the ore. The specific gravity of the best commercial copper, according to Rankine, is hammered 8·9, rolled 8·8, cast 8·6; and the melting point is about 2012° F., while cast-iron is just about the same, or 1967° F., wrought-iron 2822° F., steel 2507° F. These must be taken as approximate, as there is no exact way of determining these high temperatures. It melts at a lower temperature than fine gold, 2282° F. and $\frac{9}{10}$ = 2084° F., and higher than silver, 1904° F., both of which metals it resembles in a variety of ways. Messrs Abel & Field (Chem. Soc. Journ. xiv., p. 280) gave the following as general results:—

Arsenic and silver almost invariably present in copper.

Bismuth very general, in fact always present save when carbonates have been used as ores as in Australian and Russian coppers.

Antimony not so frequent as generally supposed, bismuth being often mistaken for it, both being precipitated by water from acid solutions.

Lead of rare occurrence in cake copper, but almost invariably present when manufactured into sheet and rod.

Iron like sulphur though in unrefined copper mostly removed by refining process.

Messrs Abel & Field.

COPPER.	Silver.	Arsenic.	Antimony.	Bismuth.	Lead.	Tin.	Iron.
Chili (29 samples), Bar and Blister,	present in all	traces in 16 ·02 to ·50 in 8	traces in 8 ·20 to ·50 in 2	traces in 19	none	none	·43 to 1·64
Spanish (8 samples),	in 6	3·31 to 0·25	·70 in 1	traces in 3 0·04 in 1	traces in 2	none	·21 to ·35 in 2
English Best, Select (16 samples),	traces in 2 0·02 to ·07	trace in 1 ·01 to ·31	traces in 6 ·02 to ·07 in 6	traces in 3 ·02 to ·17	none	none	traces in all
Sheet Copper (9 samples),	·02 to ·07	trace in 1 ·06 to ·14	traces in 5 ·01 to ·02 in 2	trace in 1 ·04 to ·18	·05 to ·40	none	traces in 8
Bolt " (2 "),	traces in 2	·07 to ·01	none	·02	·13 to ·22	traces	traces

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*
Copper,*	99·61	—	99·31	99·94	99·80	99·92	98·99	99·5
Lead,	trace	—	·21	—	·04	·07	—	—
Iron,	·02	—	·02	trace	·11	·02	—	—
Nickel,	—	—	·28	—	—	—	trace	0·1
Tin,	0·27	—	—	—	—	—	—	—
Silver,	trace	trace	·10	0·06	·06	trace	—	—
Antimony,	—	—	—	—	—	—	1·01	0·4

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* Prof. Kerl, page 164, "Metallhüttenkunde."

a Norwegian block copper.
b From Altenfjord in Norway.
c From Reichelsdorf.
d—f From Dillenberg top, middle, and lower veins.
g From Stefanshütte, can be smithed without breaking at the corners, and for rolling out in fine sheets.
h From Phœnixhütte, can be smithed to different shapes easily.

Refined copper from Mansfeld, according to Steinbeck, June, 1868.

Copper,	99·28	per cent.
Silver,	·02	„
Nickel,	·32	„
Iron,	·06	„
Lead,	·12	„
	100·00	

(From Wagner's "Handbook of Chemical Technology.")

From the fact that the copper refiner tests the quality of copper by forging a *hot* sample, it must be inferred that the effect of impurities is more perceptible at a high than low temperature upon the malleability and tenacity. Impurities in copper are As, S, Sb, Sn, Bi, Pb, Ag, Fe, Ni.

Arsenic gives both hardness and toughness to copper.

Sulphur makes it redshort, as also ·6 per cent. zinc and ·25 per cent. tin.

Antimony and nickel seem to have a bad effect on copper, and do not stand hammering.

Tin gives it hardness and lowers the ductility $\frac{1}{1000}$ while increasing the tenacity.

Bismuth is bad, making it both red and coldshort.

Lead ·1 to 0·3 per cent., but ·1 per cent. good for rolling and hammering, but not for drawing in brass wire.

Iron the same, but in a less degree.

Silver and gold do no harm to copper—*but better when separate* In fact the purer the copper, the better for working. When rubbed, or heated, copper has a peculiar and disagreeable smell—is hardened by hammering or wiredrawing, but annealed by heating to redness and cooling slowly or quickly in water. Copper expands on solidifying. Being desirous of determining whether there was any expansive action observable in copper at the time of setting, the following experiment was made:—A copper bar, cast in open sand, with a piece of iron at each end so made up that any expansion could be measured or noticed. The mould measured to begin with 23⅞ inches. It was found that the bar expanded on setting fully $\frac{1}{32}$ of an inch, and when cold measured $23\frac{7}{16}$ inches. Shrunk ¼ inch bare per foot. When it contains red oxide it melts at a lower temperature than when pure, but does not form so thick a liquid, it also solidifies more slowly. When the proportion of oxide is large it does not expand on solidifying; the expansion is prevented by addition of 1 per cent. of potassium, zinc, or lead.

Dr David Watson, in a paper on the "Constituents of Commercial Copper," &c. (Journ. Soc. Chem. Ind., p. 153, 1883), states that it is never pure as ordinarily prepared, and that suboxide of copper is an essential constituent, and good copper may contain from 1 to 2½ per cent. Lead is not an essential constituent but is invariably present in toughened copper, and it is not unusual to find as much as ¼ per cent. Arsenic he considers a natural constituent seldom absent, and in toughened copper is present in appreciable quantities; ½ per cent. is not unusual. Its presence gives toughness and the lead helps the working of the copper. The colour on the surface is to some extent an indication of the quality, but is not to be entirely depended upon.

The beautiful rosy tint on very fine Japanese copper indicates a larger percentage of lead than in ordinary copper, and is produced by casting the metal in water and not exposing it to the influence of the atmosphere till it is practically cold."

Passing now to the effect of heat on copper and its alloys great differences in the tenacity and ductility at various temperatures is found. This is well shown by the experiments made at Portsmouth Dockyard, and published in *Industries* of 1st July last. The object of making these experiments was to see whether gun-metal would be more or less suitable than cast-iron for making such articles as stop and safety valve boxes, which might be subjected to high temperature either from superheated steam or proximity to hot uptakes or funnels.

The method adopted for heating the specimens was that of using an oil bath near the machine for breaking them. They were suspended in the oil out of contact with the vessel containing it and the dies for gripping them were heated similarly; the process of fixing and breaking took about one minute, and care was taken to prevent as far as possible loss of heat by radiation and conduction. The recorded temperatures are those of oil when specimens were taken out. In case of gunmetal three or more tests were made at each temperature, and the results are the mean, save in a few cases where metal was defective. All the specimens of each composition were run from the same pot in the same manner—viz., in a horizontal position, with a head of 2½ inches, except those in Nos. 1 and 2, purposely cast separately.

	No. 1.	No. 2.
Copper, -	87·75	87·75
Tin, -	9·75	9·75
Lead, -	2·5	2·5

All varieties of gunmetal suffer gradual but not serious loss of strength and ductility up to a certain temperature, at which within a few degrees the strength falls to about half original, and ductility is wholly gone.

At temperatures above this point up to 500° F. there is little if any further loss of strength. The precise temperature of this great change takes place though uniform in specimens cast from same pot, varies about 100° in same composition cast at different temperatures, or some varying conditions in the foundry process.

The precise temperature of change in No. 1 series was about 370°

F., and in No. 2 a little over 250° F. Whatever the cause, the fact is certain. This point was so important that it was repeatedly tested by experiments at same temperature, both sorts being heated at same time in same bath.

Phosphor bronze, the only metal in the series which, from strength and hardness, could be used as a substitute, was less affected by the heat, and at 500° F. retained more than ⅔rd of the strength and ⅓rd of its ductility.

Rolled muntz metal rods about ⅛th in strength, but the ductility was doubled at 250° F. when it fell to same as at atmospheric temperature, but rose again to double at 500° F. Rolled copper bars lose gradually to 450° F. and at 500° F. have lost about ⅐th of their strength, but more than doubled the ductility.

The rolled muntz metal and copper can be used for securing bolts with safety.

Wrought-iron and Yorkshire manufactured increase in strength up to 500° F., but lose slightly in ductility up to 300° F., where an increase begins and continues up to 500° F., where it is still less than at ordinary temperature of atmosphere.

Open hearth steel was not affected in strength up to 500° F., although its ductility was reduced by more than half.

Breaking strain of cast bar at atmos. temp. = 9·1 tons per square inch, 21 per cent. elong.

Gunmetal (composition in parts, 16 Cu, 2 Sn, ¼ Pick Scrap) = 13·9 tons per sq. in., 17 per cent., elong.

(Tested at Parkhead in presence of Lloyd's Surveyor.)

Analysis, 9th June, 1887, of copper Y piece sent to Messrs J. & G. Thomson, Clydebank, by R. Tatlock :—

Copper,	99·25	per cent.
Tin,	·25	„
Lead,	·20	„
Arsenic,	·30	„
Antimony,	—	„
Phosphorus,	Traces	„
Zinc,	—	
	100·00	

Steam 150 lbs., water 400 lbs. (tested to this by Messrs Thomson); 5 bolts in flanges, ½ inch diameter; 2″ × 1½″ × 1½″ bore of branches.

	Tenacity.	Modulus of Elasticity.	Tenacity.
Cast Copper,	19,000 lbs.		19,000 to 26,000 lbs.
Sheet „	30,000 „		
Bolts „	36,000 „		ordinary 33,000; pure wrought 36,000 lbs.
Wire „	60,000 „	17,000,000	60,000 lbs.
	(Rankine.)		(Anderson.)

Results of Experiments made at Woolwich, to ascertain the Tensile Strength of Copper. (Anderson, "Strength of Materials," p. 81.)
Length of Specimen under Test, 2 inches.

Breaking Weight in tons per square inch of section.	Specific Gravity.	Remarks.
15·39 14·78 14·89 11·79	8·688	Cast Copper (very pure).
15·75 16·25 15·9 16·25		Specimens cut from virgin copper bolts. The bolts were 2½, 2, 1, and ¾ ins. dia. respectively, and the diams. of the specimens cut from the bolts, 1, 1, ·6, ·6 ins.

These results on cast copper indicate a better quality of copper than the average.

Cast Copper,		about 10	tons per sq.	inch	ultimate strain.
Forged „		15	„	„	„
Rolled „		16	„	„	„
„ „	with 2% phosphor,	20	„	„	„

Pure copper drawn into wire, about 28 tons before and 18 tons after annealing.

Average strength of sheet copper, 13½ tons; and for calculations may be assumed to be 30,000 lbs. per square inch.

(Seaton, "Manual of Engineering," page 404.)

These experiments confirm and show with accuracy the effect of considerable degrees of heat on copper alloys and other materials, facts which have been known to brassfounders and made use of by them daily in breaking up castings with ease, and which every observant engineer has also noted.

The fact of this change in heating brass, &c., and the failure of a friend, a copper smelter, to cast copper cylinders in sand and get them solid, led me to believe the difficulty could be overcome if proper means were adopted. On speaking of this belief to Mr Murray, the patentee of the process by which the castings before you have been made, he, in common with others, at first believed it to be impossible to cast copper in sand, but ultimately he came to be of my opinion, with the result you see before you; and when I showed the first castings to marine engineers I was informed that my views were correct and corroborated by the Government experiments which were not at that time quite finished. With steam pressures from 125 to 185 lbs. per square inch, corresponding to temperatures from above 350° to 380° Fah., it became a serious question what is the strength and ductility of ordinary gun-metal castings. To help the difficulty the thickness was increased by many engineers, but this does not get rid of the difficulty. Therefore a metal or alloy was needed which had a higher melting point than brass, and as copper pipes were in use, the use of copper casting naturally suggested itself. From the samples you will see the suitability for various purposes. To make any of the pieces shown from sheet copper necessitates brazing and a very considerable amount of work, which by casting are avoided. The uncertainties of brazing and the risk of overheating or burning the copper is exemplified in the investigation into the sad accident on board the s.s. "Elbe," by which 10 men lost their lives through the bursting of a copper steam pipe.

Professor Thurston, in his report to the "United States Board appointed to test iron, steel, and other metals" on the copper tin alloys, mentions the difficulty of obtaining solid castings of copper, tin, and their alloys, when using dry sand moulds on account of irregular surfaces and blowholes, and that recourse was had to cast-iron moulds. When cold the results were bad, but on heating mould to a little less than the melting point of the alloy or metal cast, results were good, the moulds were vertical. Copper bar No. 1 was bad, being spongy and full of blowholes, so bar No. 30 was cast in a cold iron mould at a dazzling white heat, and the fracture showed a homogeneous and compact metal, entirely free from blowholes and with fine but very distinctly defined lines of cooling perpendicular to each edge.

Average Results of Tests of Copper, rejecting those marked defective, and Average of all Tests of Tin. (Thurston, "Copper and Tin Alloys," page 387.)

	Transverse Tests.				**Tensile Tests.**			
						Tenacity per sq. in. of		
	Breaking load.	**Modulus of Rupture.**	**Elastic limit-parts of breaking load.**	**Modulus of Elasticity.**	**Elongation-parts of original length.**	**Original section.**	**Fractional section.**	**Elastic limit-parts of breaking load.**
Cast Copper,	765	24,357	·232	10 076,756	·0628	23,118	26,817	·491
Cast Tin,	130	4,150	·270	6,185,210	·3551	3,130	—	·476

Torsional Tests.

	Maximum Torsional Moment.	**Torsional Moment at Elastic limit.**	**Elastic limit-parts of breaking load.**	**Extension of ext. fibre.**	**Resilience.**
Cast Copper	118·06	41·79	·354	0·2630	244·54
Cast Tin,	12·95	5·07	·392	2·5502	156·97

Compressive Tests. (Thurston, "Copper and Tin Alloys," pp. 367 and 336.)

	Load per square inch causing a compression of			Maximum Load per square inch.	Total Compression produced by max.load. Parts of original length.	Crushing Strength per square inch.	Remarks.
	5 %	10 %	20 %				
	lbs.	lbs.	lbs.	lbs.		lbs.	
Cast copper,	34,000	42,000	58,000	71,709	·3210	42,000	flattnd.
,,	30,000	36,000	50,000	104,303	·5154	36,000	,,
,,	30,000	37,000	50,000	91,266	·4814	37,000	,,
,,	35,000	48,000	65,000	97,785	·4122	48,000	,,
Average,	32,250	40,750	55,750	91,266	·4325	40,750	,,
Cast Tin,	6,030	6,400	6,519	7,497	·4445	6,400	,,

Analysis of Turnings from Four Bars of Copper :—

	No. 1.	No. 30	No. 53.	No. 57.
Silver, - - -	0·035	0·014	·015	0·063
Iron, - - -	·020	·014	·035	·014
Zinc, - - -	·014	·057	·016	—
Lead, - - -	Trace	Trace	—	Trace
Bismuth, - -	—	—	—	—
Arsenic, - - -	—	—	—	—
Antimony, - -	—	—	—	—
Suboxide of Copper, -	12·086	3·580	6·730	1·620
Metallic Copper, -	87·900	96·330	93·200	98·330
Insoluble Matter, -	—	—	—	0·005
	100·055	99·995	99·996	100·032

The suboxide of copper was considered the cause of the brittleness and sponginess in No. 1 specimen.

Mr Alfred Riche in "Compts Rendus," vol. 55, 1862, page 561, says :—

"Pure copper is possessed of the property of being permeable to liquids, so that it can take up a small portion of water, &c.; but copper melted, than cast at a high temperature, does not possess this quality, and does not exist in copper reheated in the air as under the ordinary conditions of working this metal. The question has often been raised as to whether copper allies itself to iron—experiments as under were carried out to determine this:—

"1st,—Heated in a temperature sufficient to melt cast-iron.
Copper, 90; cast-iron, 10.
Ingot obtained contained at highest part iron uncombined.
2nd,—Heated very hot and held for some time in fusion.
Copper, 90; iron rivets, 10.
The ingot obtained furnished on analysis—Top, 1·600 iron; bottom, ·365 iron.
3rd,—Heated very hot, and kept melted some time.
Copper, 96; iron rivets, 6.
Metal appeared very homogeneous. Its density at the different points gave 8·881 and 8·876.
Is easily forged, stretches, and coils upon itself.
It rolls with such facility, that without annealing, a bar of it can be reduced from 9 mm. to 1 mm.
Tenacity exceeds that of copper.
Examined with magnifying glass; the plates 1 mm. thick showed some grey spots at certain places, but analysis gave no material difference between them and other portions. There was found—Iron, 5·383; 5·285; 5·236.
Substance made very hot in crucible, gives a button, in which there remains only—Iron, 0·167 per cent.
This metal is not homogeneous, for after being reheated at a very high temperature, for 3½ hours, the solidified ingot gave on analysis—Iron, per cent., 6·5 top; 4·0 bottom.
It is not permeable to liquids.

> Iron destroys softness and porosity, and considerably increases tenacity and hardness, without affecting its malleability."

To those who are interested in this subject, I heartily recommend a perusal of this report, as it contains a mass of useful information.

After considering the weakness of the alloys under heat, it is surely better to use a material for casting wherever practicable that is scarcely affected by heat.

In the after discussion,

Mr P. STEWART asked as to what weight those castings referred to by Mr Thomson could be made, and if the process was applicable to pipes of 10 or 12 inches diameter?

Mr THOMSON could not say; but he was getting models made of funnel-tops of 23 inches, largest diameter for 11 inch pipe, and they would weigh about 50 or 60 lbs.

Mr GEO. RUSSELL asked whether it was proposed to core the castings in the ordinary way? The only objection he saw was that in coring those big pipes, if the core shifted even a little it would affect the strength very much unless they were made excessively thick, to allow for irregularities inseparable from castings with cores. Copper being so expensive, the thickness of metal must be uniform on economical grounds.

Mr MITCHELL asked whether it was proposed to cast pipes of the same section of metal as was required in the case of ordinary brazed pipes?

Mr LOBNITZ said they could get solid drawn copper pipes up to six inches, and he did not see any reason why they could not make them bigger than that—even 12 or 15 inches. He did not know whether it was practicable to make such a pipe.

Mr P. STEWART said that at present they were laying down plant in Birmingham to make solid drawn pipes of 12 inches diameter.

Mr LOBNITZ said there were lap-welded iron tubes ½-inch thick, 12 inches diameter, made to stand 1000 lbs. pressure, and pipes 15 inches in diameter, made of manganese steel not more than seven-sixteenths thick, to stand the pressure of 100 atmospheres. He did not believe in brazed copper pipes at all for high steam pressures.

Mr THOMSON asked if those test pieces of wrought copper were broken in the oil; and he further asked how the joints were made in the pipes referred to by Mr Lobnitz—were they flanged or screwed?

Mr LOBNITZ replied that they were made with flanges, screwed on.

Mr THOMSON said he did not think there could be any more difficulty with regard to cores with copper than with cast-iron. The copper ran as freely as the cast-iron. The shrinkage of copper is barely a quarter of an inch to the foot. That was not more than a great many of the copper alloys in use. He thought that in casting large pipes it might be done the ordinary way, same as was done with iron pipes, and in thicknesses that were desired. In regard to cast pipes, for his own part he would not so make them if they could get drawn pipes 12 inches in diameter. Then with regard to the iron pipes that Mr Lobnitz had referred to. He had had pipes 12 and 18 inches in diameter welded with flanges from Messrs Galloway in Manchester. He did not know what pressure they would stand, but they were not required to stand more than 50 or 60 lbs. to the square inch, and were merely used for lightness. Then the joints were simply of india-rubber. There were a good many bolts. The castings he showed were all made in green sand, and he had experienced no difficulty in keeping their thickness all the same. It depended altogether on the patterns.

Mr W. J. MILLAR (the Secretary) said with reference to the expansion of copper, there was considerable physical interest attaching to it. In some experiments carried out by Mr Angus Murray and himself, at the Anderston Foundry, they had tried to ascertain whether cast-iron expanded in setting. On the suggestion of Mr Murray, they had placed the mould in the open sand, and put marks, so that they had every facility for observing any change in the molten metal. The metal was run into bars and watched carefully; there was, however, no sign of expansion in the iron on setting. It was stated in some books that the sharpness of an iron casting was due to expansion on setting; but so far as their experiments went, there was no expansion discernible; the shrinkage, however, was quite marked. The bars referred to were about three feet long, so that they had every opportunity of observing if any expansion had taken place. He would like to ask Mr Thomson if he attributed the sharpness of the copper castings on the table to expansion at setting?

Mr THOMSON said he would rather not give a decided opinion on this point. He believed, however, that the expansion of copper at setting had nothing to do with the sharpness of the castings, but that the great fluidity of the metal, together with the pressure due to the head of metal, was quite sufficient to account for it, and the same was the case with iron, he believed.

Mr ALEX. FINDLAY said that in casting plate-bending rolls up to 16 or 17 tons in weight, they had to feed these for six hours, and to add 10 to 15 cwt. of metal to make up for the shrinkage, and if they did not feed them for five or six hours there would be failure. Those were virtually test bars, 32 inches in diameter and 10 feet 6 inches long. He would like to ask Mr Thomson if in casting tee pieces he made them three-eighths thick, while the tee made of wrought copper was of the usual thickness, what would be the comparison of the strength; for if they had to make the copper castings stronger he did not know where the economy would come in. Could Mr Thomson inform them how the price would stand the one with the other?

Mr THOMSON replied that he had never intended to cast long pipes in copper, though he believed it could be done comparatively easily. It was principally to substitute copper castings for special pieces requiring a good deal of work and brazing if made of sheet copper, and to reduce the weight where brass pieces were used in addition to the greater safety under high temperatures, as it was known that brass lost half its strength and became quite brittle at ordinary steam pressures. Were long copper pipes to be cast the conditions would be quite different from the case of casting a large roll of the dimensions stated by Mr Findlay. For his own part he would prefer to use solid drawn pipes, and it was only a question of power and plant to get them of any size wanted.

Mr LOBNITZ said that some years ago he had found that he could cast brass tee pieces of double the thickness cheaper than work them from the copper sheet. The wages made all the difference.

The PRESIDENT said that he hoped Mr Thomson would furnish them at next meeting with some further details of the strength of cast copper pipes compared with wrought copper pipes. He hoped this subject of making copper pipes would be carried a little further. It had been a matter that had been before engineers for some time, and he thought the practical coppersmiths might give their views, not only with regard to how copper pipes can be well made, but also how copper pipes could be spoiled, which was quite as important a matter as the making of them.

The discussion was then adjourned till next general meeting. (See page 70.)

On Experiments on the Strength of Copper Steam Pipes, made at Lancefield.

By Mr NISBET SINCLAIR.

(SEE PLATES III., IV., V., AND IX.)

Received and Read 22nd November, 1887.

I WAS instructed by Mr Kirk, our President, to have a series of tests made to ascertain the strength of Copper Steam Pipes, and, as much attention is being bestowed on this subject, owing to the unfortunate accident on board the "Elbe," the results may be of interest to this Institution.

The tests were made from plates and pipes obtained from a leading coppersmith in town, and the strips cut from them were tested at different temperatures up to the highest temperature of steam at present in use.

The testing machine was a simple lever machine, the pieces being tested in a vertical position, and those pieces which were not tested cold had the required temperature produced and maintained during the process of testing, by suspending them in a bath of hot oil, as shown in Plate III.

Of course, in testing the pieces in this way, it was necessary to have those strips that were cut from pipes straightened, and this was done carefully by the coppersmith.

Three sets of tests were made:—

A Series—On pieces cut from two flat plates, brazed together for the purpose of these experiments in the same way as copper pipes are usually done.

B Series—On pieces cut from a high pressure steam pipe, 14 inches bore, not prepared for this purpose, and which had been thrown aside without any flanges having been put on.

C Series—On pieces cut from a high pressure steam bend pipe, 9 inches bore, not prepared for this purpose, and which had been thrown aside without any flanges having been put on. A flange was brazed on each end of this pipe, specially for these experiments.

The positions in the plates and pipes of the various test pieces, and the treatment to which they were subjected previous to testing are indicated on Plate IV.

Table No. I. gives in detail the results of the tests.

I do not propose to add any remarks further than to express the hope that in view of the importance of the subject, others may be induced to bring forward additional results of tests, or other experience bearing on this matter, and that a discussion of real interest and value may be the issue.

On the suggestion of the PRESIDENT, the discussion of these two papers was taken together, on the 20th December, 1887. The authors of the papers being invited to make any additional remarks that they might desire,

Mr NISBET SINCLAIR read the following supplementary paper:—

I have now to present a short analysis of the experiments on copper and brazing at different temperatures, made at Lancefield. The various tests enumerated in Table No. I. are classified in Table No. II., with the following results:—

Classification.

The only two tests of copper joints made at 150° show no reduction of strength from that at the ordinary temperature of the atmosphere, and they are classed as "cold." All the other tests

STS.—SYNOPSIS OF RESU

Ultimate Stress in Tons

Joints.						
Broken			Material beyond joint.			
Inside edge.						
ld.	Hot.	Ho Col		No. of Test.	Hot.	Hot. Cold.
	9·6		625	11 12	12·1 11·19 } 11·645	·796

above the temperature of the atmosphere, though varying from 330° to 410°, are classed generally as "hot."

Effect of Flattening Test Pieces.

A comparison of the A series, in which two flat plates were brazed, with the other tests, shows that the process of flattening the cylindrical strips after brazing to make them suitable for the testing machine, had no sensible effect on the strength, whether the copper was flattened while slightly heated or cold.

Effect of Temperature.

A temperature of 370° to 390° reduced the mean strength to 80 per cent. of the cold strength, the pieces of copper and the brazing, from whatever part of the pipe they were taken, being affected in about the same degree.

Effect of Planishing.

Planishing cold increased the strength per square inch somewhat under all conditions, whether solid, jointed, hot, or cold.

Solid pieces—	
Cold,	About ¾ per cent.
Hot,	A mean of about 5 per cent.
Joints (which all broke at the inside edge)—	
Cold,	Mean, 17½ per cent.
Hot,	„ 11½ per cent.

Of course this means addition to strength per square inch, and does not all represent increased strength to the pipe.

No record was kept of the thickness before and after hammering, but no doubt the thickness would be lessened somewhat by the hammering, though not to the extent of the increase in strength, so that there should be a gain in strength by the process.

The Parts Adjoining Flanges.

The parts adjoining the flanges, which were re-heated to a red heat for a length of 5 inches in brazing on the flanges, do not show in the solid portions beyond the joints any diminution in the mean strength, but on the whole a more equal distribution of strength—that is, the material was *annealed.*

The few pieces which broke through the joint in C series, whether hot or cold, were all from the neighbourhood of the flanges. The three hot ones, which show very low strength, had probably been weakened by being re-heated while the flange was being brazed, and in one joint piece the weakness might also be due to its being part of a "cramp."

The Joints.

A series shows the unusual proportion of breaks through joints of 5 in 8 tests. The copper in these cases slipped off, and the brazing metal seemed as if it had been pared off and curled up separately.

But these joints are not sensibly weaker than others. A few pounds either way would probably have determined whether the break would have occurred through the joint or at some other section.

The joint pieces generally show a strength compared with the solid plate under similar conditions of temperature as follows:—

	Max.	Min.	Mean.	
Those breaking through the joint—				
Cold,	Constant.		75	per cent.
Hot,	97	62	78·5	,,
Those breaking at edges of joint—				
Cold,	92·5	76	83·5	,,
Hot,	94	82	86	,,
Planished joint compared with planished plate—				
Cold,	-	-	93	,,
Hot,	-	-	97	,,
"Peaked" joint—				
Cold,	100·7	80·8	93·5	,,
Hot,	-	-	101·3	,,

Plate in Neighbourhood of Joints.

The solid plate immediately adjoining the edges of joints is weakest, 24 out of 37 joints having given way there. Out of these

24 there broke at the inside edge as many as 15, showing that that edge is most frequently the weakest section in the circumference of the pipe.

Elasticity.

The observations noted regarding elasticity seem somewhat irregular, and that independent of temperature, but the mean result is that in the solid copper samples extension begins to be visible at 10,200 lbs. per square inch.

The elastic limit is more clearly defined, and shows that it preserves a fairly constant relation to the ultimate stress, the mean result showing permanent set beginning at 63 per cent. of the ultimate stress.

Extension and Contraction of Area.

It does not seem desirable to trust to these figures for fair comparison. The lengths of the test pieces and the sizes of their sections are so varied, and, in the case of the joints, the extension and contraction are so local that the results are too erratic to be regarded as of much value.

Comparison with Mr Kirkaldy's "Elbe" Tests.

The above deductions are based in some instances on a very limited number of tests, and they cannot therefore be accepted as giving more than a suggestion of what may be the normal condition of things.

An accumulation of tests is necessary to form a reliable basis for opinion, and with this view Mr Kirkaldy's tests of the "Elbe" steam pipe have been put in the same terms as the Lancefield tests and set down *in situ* on a copy of his diagram, and a synopsis added, so that the two sets of experiments may be easily compared.

The following is a comparison of the strength of the various parts with the mean strength of the plate beyond the influence of joints or flanges, as found by the "Elbe" and Lancefield experiments :—

		Max.	Min.	Mean.	
				"Elbe."	Lance-field.
Joint pieces—					
Broken through joints, -	E	94·8	75·2	82·7	
	L	78·4	70·38		74·6
Broken at edges of joint,	E	102·7	98·8	100·8	
	L	95·4	74·8		85·18
Back of flanges—					
Edges of joints, - -	E	91·9	67·3	80·7	
	L	92·45	74·83		84·63
Beyond joints, - -	E	100·6	97·	98·8	
	L	104·2	95·5		100·14
Beyond flanges, longitudinal tests—					
Centre of test ½ inch from edge,		102·7	86·8	97·9	no tests.
" " 1⅛ " "		106·4	86·8	100·8	
" " 1¾ " "		108·3	91·9	103·7	
Beyond edges and flanges—	E	109·3	51·4	100	
	L	102·5	93·82		100

These tests are all cold, and the two sets are fairly consistent. The joints and the material immediately adjoining them seem somewhat stronger in the "Elbe" tests than in the "Lancefield" ones; but, on the other hand, there is less variation in the strength of the material in the Lancefield tests than in those of the "Elbe" pipes.

Corroboration of the Temperature Results.

To add to the temperature results the Portsmouth Dockyard experiments exhibited by Mr Thomson at last meeting have been set down in graphic form (see Plate V.). The curve of copper rod tests shows 25·75 tons at 55°, and 23 tons at 370°, or 89·3 per cent. of the cold strength. That is not greatly different from 82·25 per cent., as found by the Lancefield tests.

Effect of "Blistering."

A flat joint was made under instructions to "blister it and make a bad job." The piece showed blisters extending about one inch

ABLE No. III.

tension per cent.	Elastic stress per sq. in of least original section. Lbs.	El St — Ult St
in 2 inches	23669	
·05 „ 3·335 „		
·14 „ 3·335 „		
·5 „ 2 „	16910	
·02 „ 4·5 „		
·02 „ 4·5 „		
·6 in 3·75 inches	22866	
·26 „ „	20906	
·4 „ „	14474	

from the outside edge of the joint and parallel to it, but extending over the joint at one end.

The tests from this piece form D series in Table No. III.

The brazing seemed to be destroyed just at the edge nearest the blistering, the remainder being perfect except where the blistering extended over the joint; in that case the brazing metal had been melted out and decomposed, the copper rising in large "blisters."

All the joint pieces broke through the joints, the strength being—

When "blisters" extended over joint, 59½ per cent of solid unhurt plate.

When "blisters" extended only to 1 inch from joint, 70½ per cent. of solid unhurt plate.

Mr Kirkaldy found that the *solid* pieces he heated to blistering temperature broke at 88·7 per cent. of the mean strength of solid unhurt plate.

Influence of Direction of Rolling.

From the same sheet two pieces were detached by making a chisel line along one side and bending them from side to side till they broke along the line.

One piece was broken in this manner in the direction in which the plate had been rolled, the other across the direction of rolling. The breaks showed appearances like lamination, the laminæ being silky and granular alternately, and irregular in thickness and in the disposition of the silky and granular layers.

These pieces were tested in both directions, with the result, shown in the table, that the copper had a high tensile strength, and was the same in both directions.

These tests form E series in Table No. III.

Strength of Brazing Metal.

The peculiar formation of the curves of the Portsmouth tests are worthy of attention. The alloys of copper in which tin is present particularly show as a *distinctive* feature a sudden drop in strength, each alloy at its own temperature. Generally speaking, the more the tin the earlier in the ascending scale of temperature is the drop (an exception occurs in No. 1, which has a large relative percentage of tin, and has a temperature of 370° at the drop), while alloys in which zinc predominates over the tin show the strength maintained to a higher temperature, and in the alloy "Muntz metal," of zinc and copper alone, the strength is maintained without the drop through the range of the table.

No experiments have been made at Lancefield specially on the behaviour of brazing metal, which, it is understood, is composed of

Spelter,	49·15
Copper,	50·85
	100·00

But, if one may infer from the behaviour of the alloys in the table, and from the behaviour of the joints so far as tested hot, probably no drop in strength would occur within the range of 500°, and its strength would be somewhere between that of "Muntz metal" and "phosphor bronze," or probably not greatly different from copper itself (which, it will be observed, shows remarkable immunity from sudden changes of this kind up to at least 500°).

There can, however, be little doubt that over a coppersmith's fire the brazing metal would be decomposed long before the copper would be perceptibly injured, and that hence we have to depend entirely on the carefulness of the coppersmith for having joints solidly filled with brazing metal. Nothing on the outside indicates whether they are so or not, and a hydraulic test only shows that the cold breaking point has just been reached.

General Conclusions.

The whole investigation may be summed up in a few words.

Copper is a very reliable material at all temperatures within the present limits of practice in steam machinery.

It may be used indifferently with or across the grain.

The copper may be blistered so long as the brazing is left, and still 70 per cent. of strength may remain.

Unplanished pipes have a strength cold in the neighbourhood of brazed joints of 75 per cent. of the plate from which the pipe is made.

When heated to 390°, the strength of the whole pipe is 80 per cent. of the cold strength.

Or, it has in the neighbourhood of the joint, at 390°, 60 per cent. of the strength of the cold copper of which the pipe is made.

Planishing brings up the strength of the joint to within about 5 per cent. of the body of the pipe, so that a planished pipe should have at 390° a strength of 76 per cent. of the cold unworked sheet.

The weakness in the neighbourhood of flanges *might* still exist to the extent of 20 per cent.

But we must be governed in calculating the strength of a pipe, not by the mean of such experiments, but by the weakest that would be passed by a fair tradesman as a sound job, and put thus—*the strength of ordinary pipes cannot be taken as more than 60 per cent. of the strength of the copper the pipe is made of.*

If solid drawn pipes are possessed of the strength of rolled copper, a manifest reduction of thickness combined with increased safety will be got by their use, and if the present ratio between the costs of providing and fitting on board brazed and solid drawn pipes is maintained, the difference in weight should make solid drawn pipes as practicable commercially as they seem, on the surface, to be desirable mechanically.

Mr Geo. C. Thomson said that he had only to add that being desirous of testing the behaviour of copper castings while hot, a Y piece with 2-inch and 1½-inch bores was heated to a bright red, but at this heat the flanges could not be knocked off with a hammer; on heating to a strong white heat the flanges were knocked off pretty easily, and the metal appeared quite brittle. The body of the Y piece was allowed to cool down considerably, when it was struck several times with a hammer, but with no effect save making the round pipe oval. Brass castings at this heat would have flown in splinters in all directions on being struck with a hammer. (The remains of the broken Y piece were exhibited on the table.) The Y piece of the same size, which was shown at last meeting, was analysed by Mr Iuglis, Chemist to the Tharsis Sulphur and Copper Company, with the following result:—

Copper,	99·20	per cent.
Arsenic,	0·54	„
Antimony,	0·16	„
Bismuth,	0·01	„

He was indebted to Mr Peter Stewart for this analysis. The Y piece was then sent down to Lancefield Engine Works to be tested, and he was indebted to Mr A. C. Kirk, the President, for the following results:—With a water pressure of $\frac{3}{4}$-ton per square inch, there was no change of form observed. At 1-ton per square inch, a small spray of water was observed to issue from a leak fair in the fork. Upon examination, no hole or crack could be observed, even with a glass. A $\frac{1}{4}$-inch hole was bored at the place with a view to make it tight there, and subject it to further pressure. When the hole was bored a crack could be seen in the side of the hole just at the junction of the two halves of the casting. A plug was put in, but only seemed to act as a wedge and widen the crack, and the piece would not then stand anything like the pressure before applied. The Y piece was then sawn right through the middle, and the one half sawn as you see it,* and two pieces were cut out and tested with the following result:—

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* The samples of copper castings shown included a sheet bent cold into a tube, thickness $\frac{1}{24}$th of an inch, name plates in relief from $\frac{1}{16}$th inch thick, picture panels, Y and T pieces and funnel top from $\frac{1}{8}$th and $\frac{3}{16}$ths inch in thickness, the whole having a clean sharp finish direct from the sand. They can be cast in any thickness from $\frac{1}{8}$th inch and upwards as required.

Results of Tests of Pieces cut from a Cast Copper Y piece, 2 inches and 1⅛ inch bore.

No. of Test.	Description.	Temperature when broken.	Original dimensions.			Ultimate stress.			
			Size at point of fracture.	Area at		Total.	Per sq. in. of least original section.	Per sq. in. at point of fracture.	Tons per sq. in.
				Least section.	Point of fracture.				
90	Cut from leg of Y piece.	atm.	·77 × ·223 in.	·17196	·17196	4228	—	24587	10·976
91		,,	·76 × ·18 ,,	·1368	·1368	3528	—	25789	11·51

No. of Test.	Area at fracture.	Contraction of area per cent	Extension per cent.	Elastic stress per sq. in. of least original section.	E.S. / U.S.	Load in lbs. per sq. in. on least original section at which extension was first visible.	Remarks.
90	·108	37·2	21·9 in 1·89 ins.	13026	·53	13026	short grained, open, with gilded spots.
91	·099	27·6	12·22 in 1·67 ,,	10029	·38	5731	,, ,, ,,

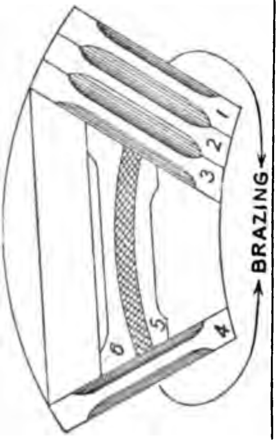
The greater tenacity of the piece marked 91, is probably due to having been slightly hammered before testing. An examination of the pieces will show the peculiar way the metal has flown, the break shows the cleavage of the copper crystals on their different lines, and the play of the light gives the appearance described in the remarks. The crack at the fork was probably caused by the metal being poured at the junction of the two flanges, and when the casting cooled the contraction being unequal caused a crack. However, the metal is now poured at one flange, thus getting rid of this source of weakness. The thickness of metal in the Y piece is $\frac{3}{16}$ths of an inch. There is also a funnel-top casting on the table, which will show the adaptability of copper for casting purposes. On the different results obtained by analysis he would not touch at present. Mr Robert Murray, the patentee of this process, had written as follows :—"I send you herewith a casting in copper from the 6-inch funnel-top pattern, it is much heavier than it ought to be, but with proper plant and the alteration made on the pattern that I explained to you, the weight will be corrected, and it will be possible to make it in half the time as at present—say 1½ hours. After the results of the two independent analyses are made known, it will surely be conceded that the castings are what we claim them to be—commercially pure copper. Arsenic, phosphorus, or bismuth, I have never seen or handled to my knowledge. Antimony, I only know alloyed with lead (type metal). Of the value of the analysis you can form an opinion when I tell you that both castings were made from Rio Tinto ingots. The effect of adding 1 per cent. of either tin, lead, or zinc, or as has been suggested, melting the copper in a dirty crucible, is to seriously affect the fluidity of the metal. When the crucible is taken from the furnace and skimmed, a thick scum gathers on the surface of the metal, and after casting, a skin of metal adheres to the sides of the crucible : whereas in my plan the metal remains clear till the moment of solidifying, and leaves the crucible perfectly clean. It may interest you to know that on referring to my note-book, I find that in the two years ending July last, I had made 137 separate experiments with copper, allied with 11 nonmetallic substances, 7 of these were proved to be inactive, the remaining 4 had a more or less important action on the copper either separately or combined. With No. 1 the picture panels were cast; the pipes with Nos. 1 and 4. I now find that by combining Nos. 1 and 3, I can save over 30 per cent. time in melting, a rather important consideration; the funnel-top was cast so, and the result is excellent both as regards toughness and solidity. I am convinced that experimenters have failed in the past by keeping too strictly on conventional lines. Thurston failed so, both in his method of manipulating the metal and his manner of casting it. In reviewing the results of his experiments, he says, 'the subject is too important to be lost sight of, and the solution will probably be found in the use of a flux' (I quote from memory). Why a flux? his own analysis shows that he was practically working with pure copper."

Mr **James Mollison** said that since last meeting he had carried ont a number of tests, on behalf of Lloyd's Register, of copper sheets as used in the manufacture of steam pipes, and also of pieces cut from a large pipe which was brazed and finished. These tests were made at the ordinary temperature of the atmosphere, and also at high temperatures, the results of which are appended. He (Mr Mollison) also tested a large steam pipe to destruction, the particulars of which are summed up in the annexed diagram; and with reference thereto observed that with care in the workmanship a brazed joint could be made equal to about 75 per cent. of the strength of the solid material, and would give, as in this case, a very large margin of safety, equal to about nine times the working pressure for which the pipe was intended—viz., 150 lbs. per square inch. He remarked that neither this pipe nor the other pieces tested were made specially with a view to being tested in this way.

Tests of Pieces of Copper cut from a large Steam Pipe, and from plain Sheets as used in the construction of Pipes.

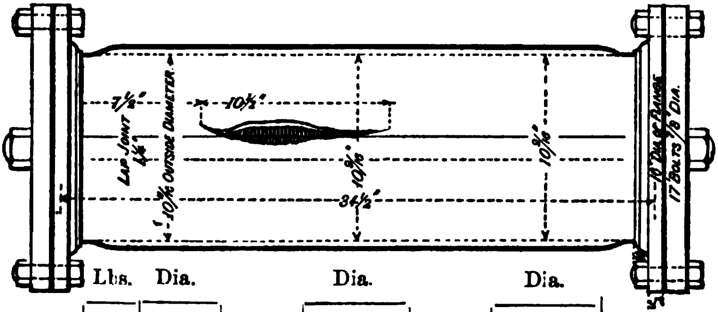
By Mr James Mollison, of Lloyd's.

Description.	Wire Gauge.	Dimensions.			Ultimate Stress.		Extension in 8 inches.	Remarks.
		Thickness.	Brdh.	Area.	Total.	Square Inch.		
		In.	In.	In.	Tons.	Tons.	P. cent.	
Plain sheets, -	7	·18	1·48	·266	3·98	14·84	38 5	Sheets as delivered to coppersmith
,, ,, -	8	·17	1·45	·246	3·88	15·77	39	
,, ,, -	10	·14	1 47	·205	3·	14·63	36	
,, ,, -	12	·11	1·46	·16	2·44	15·25	36	
,, ,, -		·33	1·49	·491	6·66	13 56	29	
						14·81	35·7	Averages.
Brazed and hammered,	4	·21	1·48	·31	4·6			Broke through braze.
,, ,,	5	·21	1·48	·31	4·6	14·83	21	Broke at edge of braze.
,, ,,	6	·19	1·49	·283	4·	14·13	17	Broke at edge of braze.
,, ,,	7	·17	1·47	·259	3·46	13·35	5	Broke at edge of braze.
,, ,,	8	·16	1·47	·235	3 6	15 31	17	Broke 2 in. from edge of braze
,, ,,	10	·12	1·46	·175	2·6	14·85	11	Broke at edge of braze.
,, ,,	12	·1	1·49	·149	2·13	14·29	12	Broke at edge of braze.
						14·49	13·83	Averages.
Brazed, not hammered	4	·22	1·47	·323	3·7	11·45	13	Broke through braze.
,, ,,	5	·21	1·47	·308	4·4	14·28	21	Broke at edge of braze.
,, ,,	6	·19	1 5	·285	4 05	14·21	21	Broke through braze.
,, ,,	7	·18	1·46	·262	3·73	14 23	17	Broke ¼ in. from edge of braze.
,, ,,	8	·17	1·5	·255	3·15	12·35	9	Broke at edge of braze.
,, ,,	10	·14	1·49	·208	2·77	13·31	17	Broke at edge of braze.
,, ,,	12	·11	1·49	·163	2·36	14·47	22	Broke at edge of braze.
						13·47	17·14	Averages.
	1	·32	1·6	·512	6·17	12·05	11	Broke at edge of braze.
	2	·3	1·57	·417	5·15	10·93	8	Broke at edge of braze.
	3	·31	1 54	·477	4·9	10·27	6	Broke at edge of braze.
	4	·37	1·52	·562	6·85	12·18	16	Broke at edge of braze.
	5	·31	1·53	·474	3·5	7·37	5	
	6	·37	1 5	·555	6·45	11·7	15	
						10·645	10·16	Averages.
								Temperature—
	A	·375	1·03	·386	4·55	11·78	29	330°
	B	·375	1·03	·386	4 0	10 36	18	540°
	4	·24	1·03	·247	2·66	10 76	27	670°
	5	·2	1 03	·206	2·3	11·11	27	580°
	6	·195	1 03	·2	2·3	11 50	25	530°
						11·1	25·2	Average.



Sketch of Copper Steam Pipe, tested to destruction.

Pipe 10 in. bore, made with two sheets and two lap joints, brazed; thickness of copper, No. 2 W.G. = ·276 inches; 1380 lbs. bursting strain = 11·11 tons per square inch of section; copper at break showed a fine silky fracture; reduced thickness at break = ·2187 inches; stay through centre, 1½ inch diameter.



Lbs.	Dia.	Dia.	Dia.
700	$10\frac{3}{4}$ ins.	$10\frac{19}{32}$ ins.	$10\frac{19}{32}$ ins.
800	$10\frac{13}{16}$,,	$10\frac{5}{8}$,,	$10\frac{5}{8}$,,
900	$10\frac{7}{8}$,,	$10\frac{11}{16}$,,	$10\frac{3}{4}$,,
1000	11 ,,	$10\frac{3}{4}$,,	$10\frac{7}{8}$,,
1100	$11\frac{1}{16}$,,	$10\frac{7}{8}$,,	11 ,,
1200	$11\frac{3}{16}$,,	11 ,,	$11\frac{1}{16}$,,
1300	$11\frac{3}{8}$,,	11 ,,	$11\frac{1}{4}$,,
1380	Burst at this pressure.		

The **President** remarked that as a great deal depended on good workmanship in this matter, nothing would be more acceptable to this Institution than the expressed opinions of practical coppersmiths. He was certain they could cast light upon the subject, and therefore the members would all be very thankful to them if they would give their views on it.

Mr **Andrew Thorburn** said he thought that the tests that had been gone into had been somewhat exhaustive, both those of Mr Sinclair and Mr Mollison; but he thought perhaps that they ought to go a great deal further. He might mention that there were not many kinds of copper to be bought. There was only about 10s a ton of difference between the prices of the various manufacturers. In working copper the coppersmith might, out of a considerable number, only find one sheet showing signs of weakness. It might show cracks, and in knocking out right in the centre of the sheet it usually gave way, often as a long reed. Others showed little holes. The coppersmith returned those imperfect sheets to the maker, who always averred that it was bad workmanship was the cause. That was the practical difficulty the coppersmith had to contend with, and the information would be most valuable if some one could tell them what caused those cracks and holes. They could not tell the wholesale merchant the causes, and hence he always said the sheets had been burned or otherwise improperly treated, although the bits that were said to be burned had been furthest from the fire, and those nearest to the fire were all right. They had often observed that the pipe gave way at the back edge of the seam. This was probably owing to that part being the first influenced by the brazing, a gutter being formed by the wash of solder, though the copper was not necessarily overheated. This could easily be detected by looking inside the pipe. The weakness at the same edge could also be caused by deficiency in lap.

Mr JOHN CAMPBELL rose to corroborate what Mr Thorburn had said with regard to bad copper. He would be glad to show any of the members a bad sheet, to see if they could throw any light upon the formation of the cracks in it. He had seen, in a quantity of copper received from a firm that was admittedly one of the best makers, three or four such sheets which were very faulty. When returned to them of course they said that they had been overheated. With regard to the brazing of copper pipes, he thought it depended a great deal on the coppersmith to see that a proper job was made· The gentleman from Lloyd's made a statement with regard to copper test-pieces, and he might state that some of them were done in his firm's works. These were given to an apprentice, and he was not given to understand that they were for express testing. They were made into copper pipes, cut up the back, and straightened out, and they proved very satisfactory with regard to the brazing.

In testing, most of the pieces gave way at the joints, and only one at the brazing, a circumstance which might occur with any one. He had observed also that heat affected copper considerably. The grain changed from a silky to a granular form, and of course with a strong heat of steam pressure the margin of safety would require to be greater.

Mr CLARKE said, as representing one of the large copper manufacturing firms, although not possessing practical knowledge, he might be permitted to make a remark. In reply to the gentleman who had just spoken, he might say that when any of the coppersmiths returned sheets as bad copper there were always two sides to a question of that kind. But the point with him was not so much with regard to sheets of copper as with seamless copper pipes, with which he had been associated all his business life. From last evening's discussion on this subject he observed that some of the members wished to know whether they could get large seamless pipes. Now, his firm, the Broughton Copper Company, had been making, for some years past, 14 inches seamless pipes, and all sizes up to that diameter; and they had recently covered hydraulic rams for the Victoria Graving Dock Company with seamless drawn copper tubes 26 feet long × 10 inches diameter × $\frac{3}{16}$ths thick. Now, he claimed for these pipes a considerable advantage over brazed copper pipes, for this reason:—In the manufacturing of these pipes they cast the original shell under a pressure of five tons per square inch, with the object of driving out all the blow-holes, which were apt to be present in ordinary cast copper. Now, sheet copper suffered from this, that if there were blow-holes in the centre of the copper from which the sheets were made the rolling tended to cover up all defects; but when a pipe was subjected to the severe test of drawing cold, if there were blow-holes in the copper the tube would probably give way in the centre. The difficulty of using large seamless pipes was that they could not bend them when they got to 10 and 12 inches diameter, and also because they cost 7d or 8d per lb. more for a 12-inch tube than they had to pay for a similar pipe when brazed. But if they could do with a decreased thickness, then, perhaps, the one would counterbalance the other. If a great increase in the demand for large drawn pipes occurred, no doubt they would become cheaper.

The **President** asked if Mr Clarke could furnish the Institution with the strength of those copper pipes that the firm he represented made, as that would be a piece of most valuable information. If he could get the record of any experiments to show the strength of the pipes, it could be published in the Transactions.

Mr **Clarke** believed he would be able to do so. He had written to his principals on the subject already, and had a reply that morning to the effect that the shortness of time before this meeting had prevented them sending the information desired, but that if time were given, they would furnish it.

Mr **Arthur Mechan** said he was sorry that he had not had the privilege of hearing the paper read, but from what he had heard it must have been a very interesting paper. He looked on what Mr Thorburn had said as a very fair and straightforward statement. He had almost overtaken everything that he (Mr Mechan) could say in reference to brass and copper pipes. Mr Thorburn had had considerably more experience than he. In reference to solid drawn copper pipes, he had found that in working small sizes sometimes a reed or split was found in them which could not be detected until after they were bent. With regard to large sizes of copper pipes, the difficulty of bending them was great. He did not think that could be done but with hydraulic power, and it must be remembered that when they bent a very large pipe they thinned the back, and consequently weakened it. Mr Thorburn had not mentioned with regard to the seams springing open in brazing. He had observed that in working copper sometimes the workmen allowed the seam to open so that the solder went in between the two laps of the copper, and thickened it so much that if he hammered it he cracked the pipe immediately behind the lap joint. That was done by men who were careless in keeping the seam close when the metal was running, which would be passed without noticing it by the employer, and not found out until a high pressure of steam immediately put it to the test.

In reference to the working of the pipe, which had been shown by the paper, that the hammering of the pipe showed a considerable increase of tensile strength. He was a little afraid that Mr Thomson's tee piece would not be able to stand the hammering or the pressure that the seamed pipe would do. No one had mentioned the Delta metal. His firm had made several articles of it. They had made a good many torpedo shells for some of the Governments. The tensile strain was from 20 to 24 tons per square inch. They found that it was no more difficult than any mild steel to work, and he had thought to use it for steam pipes. One difficulty was that it melted at a low temperature, and required great care in brazing when hot. It worked like a piece of putty, and the more it was forged the stronger it got. They had had so much difficulty in brazing it that they had had to use jewellers' silver solder. He thought they had tried about a dozen different samples of solder, but none of them could be got to run before the metal would run, and so they were compelled to use the silver solder. He believed Delta metal would add to the strength of the pipes. It was very much stronger than copper. He thought if the engineers would try it, it might be of great use.

Mr CARLILE WALLACE said he trusted this discussion would be carried on into the next meeting of the Institution. At present the firm with which he was connected were engaged in carrying out tests on copper pipes, but they had not got sufficient information yet to make any definite statement. He noticed that both Mr Sinclair and Mr Mollison had found from tests they had made that hammering increased the strength of copper pipes, and he would say that in one instance that came under his notice, the test-pieces having been cut from a 12-inch discharge pipe about No. 11 B.W.G., the strength and extension were increased, the latter very considerably, by heating to redness and then allowing to cool slowly. All these experiments were carried out by Mr Robinson, who, he had no doubt, would be very glad to give them information on the subject.

Mr LESLIE ROBINSON said the pipe he had been testing was very much thinner than that used by Mr Sinclair. It was No. 11 gauge, 12 inches bore, and it was cut from the end of a pipe supplied to them by a Greenock firm. He had cut eight pieces out, and merely flattened them carefully with a wooden mallet, and the pieces that were heated and cooled rose slightly in the ultimate strength; the pieces, when unheated, broke with 5 per cent. extension, and when heated broke with 37 per cent. extension. Possibly those gave different results from what was found by Mr Sinclair and Mr Mollison, because the specimens were thinner. He would like to get at the exact effect of planishing. He thought if they could get some results of the planishing it would be very instructive; for if they could raise the strength of their pipes by heating them and then cooling them it would be a valuable discovery; but they must make more experiments before that could be established. Another matter that interested them all was the nature of the fracture of the "Elbe" pipe, which presented a good deal of discolouration in the fracture. He thought that a most important point to which the coppersmiths would have to give attention was the working of the copper when heated. They would observe that the strength was reduced from about 30 to 34 per cent. in most of the experiments—that was taking the copper longitudinally; but he thought that the difficulty was that when copper was heated over a fire it became very pliable and very easily cracked, while the rest of the copper would remain unaltered. He thought that that would explain the breaking in the "Elbe" pipe—that the copper was injured while heated, that it was cracked though not seen, it was filed over and the people did not notice it. Another point he noticed in Mr Sinclair's paper, on Plate IV., in regard to the heating, from experiment No. 32 onwards. He seemed to have taken all the "heated ones" in the one joint, thus assuming that both joints of the pipe were of the same strength. If any gentleman present had experience in the working of copper under heat, and the jointing of the pipes, it would be very interesting to the members of the Institution if he would give any information as to the heating of the copper rather than the difference of the actual testing under heat.

Mr THORBURN, in answer to the last gentleman who spoke, said that some really good copper would not stand working hot, but worked well cold, by simply annealing it; while other coppers could be worked hot with impunity. Sheets had broken with their own weight, leaving the bit in grab, showing a black grain, which seemed purely local, as other parts of the same sheet were quite good.

Mr P. STEWART said he could add very little to what had been already stated in the course of the discussion. He had no experience in the treatment of copper sheets, and was glad to get the information given. Naturally no one cared to admit that faulty copper was turned out, but it was correct all the same that occasionally sheets unexpectedly failed while being worked, and from causes that he believed refiners were perfectly familiar with. Coppersmiths, however, had no monopoly of the difficulties connected with the treatment of the metal. It had to be very carefully dealt with even when smelting and refining, and it was only by experience, coupled with the most rigid chemical and mechanical tests, at all stages, that uniformity of quality could be maintained. Confirming the opinions expressed as to the benefit derived from planishing, he directed attention to a number of specimens showing the effects of refining and hammering on ordinary tough copper. Much depended on the skill and care of the refiner in determining the stage or "pitch" at which copper should be laded, in view of the purpose for which it is required, and also in regard to the lading itself, so that sound copper may be produced, such as will bear the treatment of hammering, rolling, or drawing. He would prefer solid drawn tubes, wherever they could be conveniently employed, to those with brazed seams; and any one familiar with the working the metal received, in making solid tubes, would readily understand this preference. He believed that the best makes of solid tubes would be found to weigh rather heavier than those made from sheets, the density of the metal being somewhat greater. Mr Stewart sketched on the black board and described several processes by which seamless tubes are produced.*

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* The process patented by Mr James Robertson, late of Glasgow, converts solid copper billets, about 30 inches long, and from 4 to 7 inches diameter,

Mr **Warden** thought that the rolling of copper billets accounted for the reed that Mr Mechan had referred to.

The **President** said that the discussion would now be adjourned till next meeting, when if any gentleman had additional facts, or deductions from facts, to lay before the Institution for their general information, they would be pleased to hear them. He trusted that

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into seamless tubes with great facility. In practice, a hole 1¼-inch diameter is bored right through the billet by drills from either end. The billet is then lightly skimmed in a lathe, to clean the surface, after which it is enclosed in a cast-steel "container," made in halves, and bored out to suit the particular size of billet. This "container" rests on a stout bed-plate, and remains stationary, while a pear shaped mandril, attached to a revolving hydraulic ram, is entered at one end of the hole in the billet. A flexible tube inserted in the other end of the hole, supplies lubricant. On pressure being applied to the revolving ram, which carries the mandril, the metal of the billet gradually flows back in the container, in front of the mandril, and in a few minutes the mandril pierces the elongated billet, leaving a shell, having the original outside diameter, but with a hole, corresponding to the size of the mandril. After annealing, this shell is ready either for drawing hot in rolls, or cold on the usual draw benches. The temperature of the shell or mandril never exceeds 120° Fah., and the only waste occurring in the process is the 1¼-inch hole through the centre of the billet, and the surface cleaning. This hole, however, is only a convenience, and is not an essential, for very frequently tubes are pierced out of the solid. It being only a question of a little more power and somewhat longer time. Another process begins with oval slabs of copper, about 24 inches by 10½ inches, and 2½ inches thick, which are rolled hot in the direction of the shortest diameter, till they become circular discs about 30 inches diameter. After annealing, these discs by means of suitable dies and mandrils, in a powerful hydraulic press, are cold worked, successively into basins, conical domes, and ultimately into parallel tubes, having one end closed. On punching out this close end, a shell about five feet long remains, for finishing on the draw benches. With the exception of the close end, all the metal of the original oval cake is in the shell. In a third process hollow billets are laded, having elliptical cores—there being difficulty in producing solid castings with circular cores. These billets are hot rolled flat, therey closing up the core opening and equalising the thickness of the metal. They are then passed hot through rolls, having a plug mandril between, which draw and open the flattened tubes out into circular shells of equal thickness for drawing into tubes.

Mr Clarke and Mr Robinson would be able to furnish them with data of experiments.

In the resumed discussion on these papers, on the 24th January, 1888,

Mr S. SMILLIE said he thought it would be of interest to them to know that in the preparing of copper for rolling into sheets, it was smelted three times—first, from the ore; and the second smelting was to separate the copper from foreign ingredients, such as iron, silver, etc. In that second process the copper absorbed an amount of oxygen, which was very pernicious to the quality of the copper, and hence it had to be smelted a third time, when the surface of the metal was covered with charcoal, in order to get rid of the oxygen which was a source of weakness in the metal. If puddled too little the oxygen was not sufficiently eradicated, and if puddled too much, then the copper absorbed carbon, which damaged its quality. The copper was then cast into square blocks, and rolled the one way and then across, in order that the fibre of the copper might be thoroughly interwoven, and so the sheet be quite reliable. There were two other points of great practical importance of which he would like to remind them—underheating and overheating copper. A sheet, if not properly annealed, was underheated. For instance, if a sheet of copper was brought to a black heat and allowed to cool gradually, it would be found to be almost as brittle as cast-metal; but if it were afterwards annealed properly, it would be restored to its original qualities. Whereas overheating completely destroyed the ductility of sheet copper. The proper method of planishing straight pipes was to hammer them by the steam-hammer, which quickly showed any defects that existed, and if there was the least weakness in seam, it would strip up at once. He found when copper was very red that it was not good, because there was too much oxide in it; and if it appeared too black, they might depend upon it that carbon had got into it. He believed that in copper they had a good and reliable metal, well suited for steam pipes.

Mr Sinclair, on being asked by the President to reply on the discussion, said that the large solid-drawn copper pipes on the table had been sent by the Broughton Copper Company, of Salford, to Lancefield, and had been tested there by Mr Kirk's instructions. The pipes were each 10 inches bore, 18 inches long, and ¼ inch thick. One was annealed, the other unannealed. A strip about 2 inches broad was cut from one end of each pipe and tested for behaviour under tensile strain. The results are given in detail in Series F, Table IV., of Lancefield tests, and show the high ultimate stresses of about 18½ and 15⅓ tons per square inch respectively. The results of all the experiments presented during the discussion, so far as these have gone, point to solid-drawn copper pipes as nearest one's ideal, and it appears that only a greater demand is necessary to bring down the price of them to such a point that their everyday use may be possible. He would like to add that the coppersmiths, and especially he would mention Mr Thorburn, have been very enthusiastic and courteous in explaining their processes and giving every information and help in their power to make the tests as fairly representative of everyday practice as possible.

The President said that the paper brought forward by Mr Sinclair was intended merely to show the strength of ordinary samples of the copper steam pipes which they were every day using. He thought the "Elbe" disaster need not frighten them from the use of copper pipes, or cause them to do as he heard that a certain engineer in Liverpool advised—to hoop copper pipes with iron. He had no such idea. The present brazed pipes were thoroughly reliable if made with ordinary tradesmanlike skill, and the factor of safety of the pipes that his firm had been using, and other people had employed, as the result of experience, had been quite sufficient. They would observe from the results of the experiments given in the tables that it was not in the brazed joints that the copper gave way. Of course, if the copper was burned that spoiled it, but inde-

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pendent of the burning the copper was thinned by the melted spelter. He thought the result of the whole matter, taking Lloyds' and the Board of Trade's experiments along with those given in the paper, was that pipes when of fair workmanship had 75 per cent. of the strength of the copper sheets of which they were made, and while they were working with 150 lbs. of steam pressure, they had from 60 to 62 per cent. of the strength of the sheet copper. Mr Clarke, the agent of the Broughton Copper Company, had very handsomely sent them specimens of solid-drawn pipes, and they were, he must say, very remarkable ones. Unfortunately, as Mr Sinclair had pointed out, they were sold at a prohibitory price at present, and that very likely they would be reduced when a demand for them sprung up; but if those pipes were adopted he thought it would be found that they might be from 60 to 66 per cent. of the thickness and weight of the ordinary brazed pipes; and of course if only 60 to 66 per cent. of the ordinary brazed pipes they could afford to pay more per pound for them.

Mr **Matthew Taylor Brown** wished to point out that Mr Mechan had rather understated the tensile strength of sheet Delta metal, as would be seen from the following record of test. The test piece was cut from a sheet supplied to a Glasgow firm in the ordinary course of business, and was sent to the Steel Company of Scotland, who made the test, and their report is dated Hallside, 2nd August, 1887 :—

Breadth of Test Piece, - - ·49 inches.
Thickness „ - - ·19 „
Area „ - - ·0931

Stress per square inch at first perceptible extension = 5·9 tons.
„ „ first perceptible set, - = 12·3 „
„ „ ultimate, - - - - = 30·3 „
The extension was - - - - - - - 18·74 per cent.
Reduction of area at point of fracture, - = 12·3 „

The test piece was cut across the direction of rolling. These figures are under rather than over the average results usually obtained, but on comparing these figures with those given for copper sheet, it would be seen that there was a very large margin in favour of Delta metal, which would allow of much lighter pipes being used. Regarding solid drawn tubes, the largest hitherto supplied in Delta metal had been five inches outside diameter ·275 inches thickness of metal, and they were used for a working pressure of 150 atmospheres, or say 2200 lbs. per square inch.

Mr George C. Thomson said, in answer to Mr Findlay's remarks regarding the relative cost of Copper *v.* Brass Castings:—The copper castings would come out cheaper than the brass castings if the brass castings were made from the constituent metals, but where scrap brass was employed the copper castings would be the more costly of the two, present prices being of course taken as the basis of comparison. At the same time it must be kept in remembrance that brass was not reliable at degrees of heat, such as are common in the compound and triple expansion engines at present in use. Referring to Mr A. Mechan's opinion that the castings would not stand the hammering or pressure that a seamed pipe would do, he said it appeared from Mr Sinclair's experiments that the strength of ordinary seamed pipes could not be taken as more than two-thirds of the strength of the copper of which the pipe was made. Allowing the average strength of copper plates to be 15 tons per square inch, and that of copper castings to be 10 tons per square inch, the castings would be equal to the built pipes as far as strength went, and have the advantage of being more quickly and easily made than the bends and special pieces of built copper pipes. The castings, of course, required to be a little thicker than the plates to meet the difficulties inherent in all casting processes, but the difference was nothing compared with what it would be in brass or any other of the copper alloys. In answer to Mr Thorburn, the difficulty of working some kinds of copper hot and others cold, would likely be found in the small percentage of impurities present in all commercial copper, and while a small proportion of arsenic or lead rather favoured the working, the presence of bismuth, sulphur, antimony, and nickel were decidedly unfavourable. The careful and exhaustive experiments carried out by Mr Sinclair were well worth the attention of engineers, and he trusted it would not be long ere experiments on some other of the alloys in use were carried out to show their strength and ductility at various temperatures up to 500° Fahrenheit, similar to those carried out at Portsmouth Dockyard and Lancefield Engine Works.

On the motion of the PRESIDENT, a vote of thanks was awarded to Mr George C. Thomson and Mr Nisbet Sinclair for their papers.

On the Construction of the Glasgow City and District Railway.

By Mr Robert Simpson, C.E., B.Sc.

(SEE PLATES VI., VII., AND VIII.)

Received and held as Read 20th December, 1887.

THIS railway was promoted for the purpose of connecting the Stobcross Branch of the North British Railway Company, on the West of Glasgow, with their College Station, on the East, and by this means to enable the trains from Airdrie, Coatbridge, Hamilton, &c., to be brought into Queen Street Station, and the Vale of Leven and Helensburgh trains to be run over the Stobcross branch through Partick, thus relieving the Queen Street incline. The railway would also form the completing link of the circle passing through Bellgrove, Springburn, Maryhill, Great Western Road, and Partick.

After receiving the sanction of Parliament, session 1882, the working plans were at once prepared, and the work was let in two contracts, the western portion, extending from Stobcross to West Campbell Street, to Mr James Young, and the eastern portion, extending from West Campbell Street to College, to Messrs Charles Brand & Son. Operations were started in March, 1883, and the railway was opened for traffic in March, 1886.

Railway No. 1 is 2·365 miles long, having stations at Finnieston, Charing Cross, Queen Street, and College. Railway No. 2 is a spur connecting the Stobcross branch with the Helensburgh line, and, as it was simply a work of ordinary cutting and tunnelling, it will not be necessary to describe it here. The contractors were Messrs Hugh Kennedy & Sons, Partick.

The purposes served by the railway will be seen at once by reference to any map, which shows the railways and stations in the Glasgow district. Over 200 passenger trains pass over Railway No. 1 in a day, and it will be thus seen that it affords a frequent and direct means of communication between the east and west ends of the city.

By May, 1883, operations were fully started at 9 points:—

1. On the extreme east of the line at College, excavating trenches and building retaining walls proceeding westwards.
2. At Montrose Street, sinking shaft for tunnel.
3. On the east side of Queen Street Goods Station, excavating trenches, building abutments, and putting on girders and flooring, proceeding westwards.
4. In West Regent Street, between Hope Street and Wellington Street, sinking shaft for tunnel.
5. At West Nile Street, building tunnel on the cut and cover system, proceeding westwards.
6. At Blythswood Square, sinking shaft for tunnel.
7. At Holland Street, sinking shaft for tunnel.
8. At the west end of Kent Road, driving sheet piling along both sides of the street, proceeding eastwards.
9. On the extreme west of the line, excavating trenches, and building retaining walls, proceeding eastwards.

Later on, in July, 1883, the contractor started cut and cover at High Street, going westwards, and in September and October, he sunk shafts for tunnelling in Hengler's Circus, in John Street, and in Frederick Street. In June, 1884, when the western half of Elmbank Crescent had been removed, Mr Young started to build the retaining walls for Charing Cross Station.

When operations were in full swing, therefore, the work was being carried on at 22 different points:—

Building retaining walls at Stobcross, Charing Cross, Queen Street (East and West), and College, 5.

Cut and cover at Kent Road, West Regent Street, and High Street, 3.

Tunnelling from Holland Street, Blythswood Square, West Regent Street, Circus, Frederick Street, John Street, and Montrose Street shafts, each two tunnel faces except Frederick Street, 13.

Abutments and ironwork for Queen Street Station, 1.

As will be seen by referring to the accompanying section, Plate VI., the material through which the railway has been made is very varied in character. Methods had therefore to be adopted in constructing the tunnel to suit the material, and for the purposes of description these different portions of the work may be divided up as follows:—

1. Kent Road covered way. 700 yards. Wholly in running sand, resting on rock about formation level.
2. Charing Cross wide tunnel for station. 102 yards. In boulder clay, resting on rock about platform level.
3. West Regent Street tunnel (part). 393 yards. In rock, with boulder clay a little above the springing of the arch.
4. West Regent Street tunnel (part). 125 yards. Wholly in rock.
5. West Regent Street tunnel (part). 20 yards. Wholly in boulder clay. Mr James Young's contract.
6. West Regent Street tunnel (part). 271 yards. Wholly in boulder clay. Messrs Charles Brand & Son's contract.
7. West Regent Street covered way. 159 yards. In soft mud, with brick clay above.
8. Section from West Nile Street to Buchanan Street. 100 yards. Wholly in rock.

9. Section on east side of Buchanan Street. 28 yards. In rock up to crown of arch. Underpinning buildings.
10. Tunnel from Frederick Street to George Street. 500 yards. In sandstone and shale.
11. Covered way from George Street to High Street. 174 yards. Mostly in mud and clay, part founded on rock.
12. Queen Street Station. 134 yards. In rock and forced material, formerly an old quarry.
13. Retaining walls, mostly in sand and mud. (Charing Cross Station in boulder clay.) 1314 yards.
14. Bridges at St. Vincent Crescent, Dumbarton Road, Dundas Street, and Hanover Street 110 yards. In sand, mud, or sandstone.

KENT ROAD COVERED WAY.

This portion of the work extends from Dumbarton Road bridge to Charing Cross Station. Length, 700 yards. The bores which had been put down showed that the subsoil consisted of sand and mud down to about formation level, at which level the solid rock commenced. Now, as there are large and heavy buildings on both sides of the street, it will be seen that in order to keep these buildings from being injured special precautions would require to be taken in the construction of the covered way. The system of construction ultimately adopted depends on the fact that when pure water only is drained from running sand the sand does not diminish in bulk. The difficulty to be overcome, therefore, was to keep the sand from draining away with the water. This was effectually done, and no damage was done to property in this portion of the work, with the exception of the case about to be mentioned.

Before Kent Road covered way was started an attempt was made to build the abutments for Dumbarton Road bridge, and for this purpose a trench was excavated on the north side of Kent Road, between Dumbarton Road and Alexander Street. When this trench, which was timbered in the ordinary way, was sunk 12 feet, water began to come in, and when down 17 feet, or within 5 feet of formation level, the water and sand came pouring in so fast that operations had to be abandoned. This was rendered all the more necessary owing to the fact of the property on the north side of the street beginning to crack, due to the withdrawal of the sand with the water. This work was re-started when the covered way was completed up to the trench, and was done with the utmost facility, the sand having become perfectly dry.

For the construction of the covered way the first thing done was to drive two rows of 6-inch sheet piles, one on each side of the street, 35 feet apart. These piles were nearly all driven down to the rock, the length varying from 20 feet at Dumbarton Road to 30 feet at Charing Cross.

The street was next excavated between the piles to the shape of the top of the proposed arch, as shown by Fig. 1, Plate VII., in plan, and Fig. 2, Plate VII., in section, the depth to the top of the arch varying from 2 feet 3 inches at the Dumbarton Road end to 10 feet at the North Street end. The sides of the excavation from Clairmont Street to North Street were put down to the level at which the water stood in the sand—13 feet at Clairmont Street and 16 feet 3 inches at North Street.

This was done in 15 feet lengths, each length as it was excavated being filled with concrete to the form of the arch, as shown in Fig. 3, Plate VII., the concrete being made 2 feet 3 inches thick at the crown of the arch and 6 feet at the sides. The material excavated from each length made up the length which had just been concreted, and the surplus was carted away. The street was then restored over the portion made up, and the barricade shifted along a length.

The concrete was made of 5 parts of stones and broken bricks in equal proportions, 1 of sharp sand, and 1 of Portland cement.

The barricade for the piling occupied a space 100 feet by 40 feet, and was never more than three weeks opposite any one point. The one for the excavation and concreting enclosed a space of 120 feet by 40 feet, and was never more than a month opposite any one point.

The second barricade followed up the first one, there being generally a distance of about 230 yards between them.

While these surface operations were going on a 4 feet drain was being constructed from the Clyde up Finnieston and Clairmont Streets. When this drain reached Kent Road a pit was sunk, at the junction of Clairmont Street with Kent Road, to the level of the drain, with which it was connected, the drain being about 8 feet below formation level at this point. In order to prevent any sand being taken away with the water, the water was first drained into a sump and then transferred to the drain by a syphon. In a short time the sand round the pit became dry, the water afterwards continuing to run over the top of the rock directly into the drain.

The concrete arch having become thoroughly set, a heading was started away from the pit towards the east, shown in section in Fig. 4, Plate VII. As this heading was driven ahead the sand at the sides dried down to the level of the floor, the water flowing to the pit at Clairmont Street. The fireclay pipes, shown at the sides of the heading, were put in to convey the sewage from a main drain running under the concrete arch. This drain was taken down as the heading advanced, and while one of the pipes was being carried forward the sewage ran through the pipes on the other side of the heading.

The heading having advanced considerably, the next operation consisted in driving down small sheet piles under the concrete arch, 9 feet apart, as shown in Fig. 5, Plate VII. The sand was then excavated between the piles. The was done gradually, so as to give time for the sand outside the outer rows of piles to dry. It was found that by this means, as the excavation of the gullet was carried deeper, the water in the sand took a natural slope—something like 1 in 5—and never caused the wet sand in the gullet to boil up from below. Any sand that came through into the gullet came from between the two rows of piles, and as this deficiency was always immediately made up, it will be seen that it was impossible for any subsidence to take place outside the outer row of piles.

When the sides had become perfectly dry they were excavated, and the concrete arch was supported by 9-inch timbers, as shown in Fig. 6, Plate VII. This timbering we do not suppose to have been strictly necessary, as every second pile had been notched near the top to give the concrete arch a catch, but it was thought advisable for the sake of absolute safety.

The hollows in the rock having been filled with concrete, the side walls were then bricked, the covered way now presenting the appearance shown in Fig. 7, Plate VII. The excavation of the sides and the bricking of the side walls were done in 18 feet lengths, the bricklayers starting immediately after the length was excavated. It took on an average about twenty hours to brick the walls for one length.

The last operation consisted in bricking the arch, and the completed tunnel is shown in Fig. 8, Plate VII. The bricking of the side walls is shown in plan by Fig. 11, Plate VII., and in section by Fig. 12, Plate VII.; and the bricking of the arch by Fig. 13 Plate VII.

The different stages of the work were carried on from four pits, about 60 yards apart. When the heading had advanced about that distance from the Clairmont Street pit, a second pit was sunk (space having been left in the concrete arch), and the heading was carried on from the second pit, the Clairmont Street pit being used for the raising of the sand excavated from the gullet. The heading still advancing, a third pit was sunk still further on, and the sand excavated was raised from this pit, the second pit being used for the gullet, and the Clairmont Street pit to raise the sand excavated from the sides and lower the bricks, cement, &c., required for the side walls. Afterwards a fourth pit was sunk still further to the east, and used to carry on the heading, while the third pit was used for the gullet, the second for the sides, and the Clairmont Street pit for bricking the arch. Then when the arch was finished up to the second pit, the Clairmont Street pit was closed, the crane being shifted to the front and a new pit sunk for carrying on the heading, and so on, the whole of the operations going on at once. We thus see that the time taken to complete an 18 feet length of covered way was in reality the time taken to excavate and build the sides—viz., about three days.

The work from Clairmont Street to Dumbarton Road was all done from the Clairmont Street pit. In this case the sand dried sufficiently fast to enable the whole length to be excavated at once.

Three forms of arch were adopted in Kent Road. From Dumbarton Road to Clairmont Street, where there was little cover, the form adopted is shown by Fig. 9, Plate VII. The section of the covered way from Clairmont Street to Elderslie Street, is shown by Fig. 8, Plate VII. At Elderslie Street, however, the concrete arch had to be raised to avoid interfering with the main drain during surface operations, and for this reason the height of the arch was increased in the portion from Elderslie Street to North Street. The section is shown by Fig. 10, Plate VII. When the side walls came to be built, the drains from the houses were all led down the sides, as shown in Fig. 8, Plate VII., and afterwards connected with the drain in the centre of the tunnel.

As the heading was advancing more quickly than the concrete arch, it was found necessary to open up the street at Belgrave Street, and carry on the concreting in both directions from that point. This was started on 9th June, 1884, and in this way the sand was never excavated from below the concrete till the arch had had time to become thoroughly set. The following table shows the time taken to complete the various portions of the work:—

Section from Clairmont Street to North Street—590 yards.

	When started.	When finished.	No. of yards in first month.	No. of yards in last month.	Average No. of yds. p. month.
Piling, 700 yds.	26th May, 1883	11th Oct., 1884	60	43	58
Concrete arch,	3rd April, 1884	7th Nov., 1884	50	41	43
Heading, -	22nd Apr., 1884	17th Feb., 1885	70	85	80
Gullet, -	2nd May, 1884	2nd Mar., 1885	43	92	73
Side walls,	13th May, 1884	18th Apr., 1885	18	100	53
Arch, -	16th Aug., 1884	20th Apr., 1885	40	100	72

Section from Clairmont Street to Dumbarton Road—110 yards.

	When started.	When finished.	Average No. of yards per month.
Concrete arch,	3rd April, 1884,	20th May, 1884,	73
Tunnel, -	28th May, 1884,	7th Oct., 1884,	25

The following table shows the distances between the various stages of the work:—

Between the piling and the concreting up to 9th June, 1884, when the section at Belgrave Street was started, - - - - - - -	240 yards.
Do. after that, - - - - - -	53 „
Between the concrete arch and the heading, - -	85 „
Between the heading and the gullet, - - -	34 „
Between the gullet and the side walls, - -	50 „
Between the side walls and the arch, - - -	82 „

There was thus an average of 166 yards of concrete roof left unsupported except at the sides. From Elderslie Street to North

Street the whole of the concrete arch was put in before the heading reached Elderslie Street.

The piling was done only in the day time, no night shift, in order to avoid disturbing the residents. It did not go on regularly, having been stopped for about 4½ months, from various causes. An average of 2⅓th piles were driven on each side of the street in a day, each pile consisting of three pieces, 12 inches by 6 inches, fastened together. The other portions of the work were carried on in day and night shifts, the concreting and bricking going on steadily, but the excavation of the heading and the gullet being sometimes stopped, the heading for two-and-a-half months altogether and the gullet for two months.

HOLLAND STREET AND BLYTHSWOOD SQUARE SHAFTS.

The tunnel was started from the Holland Street shaft on 2nd July, 1883, and was carried on in both directions, reaching Pitt Street on 25th March, 1884. Distance, 122 yards, through freestone with boulder clay on an average about 5 feet above the springing of the arch. On the west a commencement was made to widen out the tunnel for Charing Cross Station on 22nd December, 1883, and the tunnel was finished to Charing Cross Station on 9th August, 1884. The distance from the shaft to the wide tunnel was 114 yards; in freestone with boulder clay above. The length of the wide tunnel is 102 yards; in boulder clay above platform level.

This tunnel being, therefore, for the most part, through solid freestone, with boulder clay above, the work was done in two stages, the first of which consisted in excavating the boulder clay and rock down to within 9 feet of formation level (Fig. 14, Plate VII.), and building the arch (Fig. 15, Plate VII.). The second operation consisted in shearing the sides (Fig. 16, Plate VIII.), and quarrying out the rock down to formation level (Fig. 17, Plate VIII.). This description applies both to the tunnel through rock with boulder clay above the springing of the arch and to the tunnel wholly in rock, near Blythswood shaft, and shown completed in Fig. 18, Plate VIII.

The tunnel from Blythswood shaft was started on 20th August, 1883, and finished at West Campbell Street, on 4th July, 1884; distance 112 yards, partly in solid freestone and partly in boulder clay. On the west the junction with the Holland Street tunnel was completed on 18th December, 1884; distance 190 yards, in freestone and boulder clay.

This tunnelling was all done in 15 feet lengths, except the wide tunnel, which was done in 12 feet lengths in order to lessen the risk of subsidence to the surface. Where the roof consisted of boulder clay, it was supported by from nine to thirteen 12-inch bars, but in rock only five bars were put in.

As the work approached West Campbell Street, the rock began to dip down very quickly, and finally it disappeared, leaving the tunnel wholly in boulder clay. In this case trenches were cut for the side walls, which were founded on concrete (Fig. 20, Plate VIII.). The remaining portion was afterwards removed. The same method of construction was employed for the wide tunnel (Fig. 19, Plate VIII.), only in this case the side walls were founded on rock.

A shaft was sunk between Holland Street and Elmbank Street, about the same time as the Holland Street shaft, and after five lengths of tunnel had been bricked, it was used for the raising of freestone quarried in the second stage of working. The quarrying out of the rock was begun in November, 1883, and carried on in both directions. On the west it was all out by March, 1884, distance 63 yards, but on the east it was April, 1885, before it was all out, the excavation having been stopped at Pitt Street from September, 1884, till January, 1885. Distance from Elmbank shaft to end of rock 455 yards. The boulder clay was all removed from the wide tunnel in December, 1884, by means of an incline up to the ground cleared for Charing Cross Station. The quarrying out of the rock advanced at the rate of about 30 yards a month, there being about 27 cubic yards to the running yard.

The following statement shows the rates of progress of the other portions of the work:—

Wide tunnel—in boulder clay and founded on rock—12 yards per month; or 152 hours to each length, $\frac{5}{7}$ of that to the excavation and $\frac{2}{7}$ to the bricking.

Tunnel in rock with boulder clay above the springing of the arch—15 yards per month; 152 hours to each length; $\frac{5}{7}$ to excavation and $\frac{2}{7}$ to bricking.

Tunnel wholly in rock—10 yards per month; 228 hours to each length; $\frac{6}{7}$ to excavation and $\frac{1}{7}$ to bricking.

Tunnel wholly in boulder clay—15 yards per month; 152 hours to each length; $\frac{2}{3}$ to excavation and $\frac{1}{3}$ to bricking.

The excavation includes the setting of the bars, &c., and also the setting of the centres, which was done by the miners.

The material drawn from the various shafts was carted to Stobcross, tipped into waggons there, and thence taken by rail to make up the banking required for the Hyndland branch. The remainder was deposited near Great Western Road.

WEST REGENT STREET EAST SHAFT.

The tunnelling done from this shaft was wholly in boulder clay, with occasional pockets of sand. It was started on 3rd September, 1883, and finished on the west at West Campbell Street, on 24th December, 1884, length 150 yards. On the east the junction with the tunnel from the circus was effected on 18th October, 1884, length 121 yards. The tunnelling was done in the ordinary way in 12 feet lengths, the roof being supported by 13 bars and props resting on a sill 10 feet above formation level. This sill was supported on a second sill at formation level, and kept in its place by two raking beams 37 feet long. The timbering required for this method of tunnelling in boulder clay is much more than for the method previously described.

After the tunnel was completed, 34 concrete inverts were put in, 15 feet apart centre to centre, 6 feet wide, and 2½ feet thick (Fig. 21, Plate VIII.). This extended for 167 yards; the remainder, 104 yards, being founded on rock. Near Hope Street there was a sudden transition from boulder clay to soft black shale, brought in no doubt by a large fault.

In tunnelling through the boulder clay, it was found impossible to keep the surface from subsiding a little. The result was that the buildings on both sides of the street were more or less affected by this portion of the work, considerable sums having to be paid for structural damages.

The tunnel was carried forward at the rate of 11 yards a month, as compared with 15 yards by the method of excavation in two stages. Each length, therefore, took 166 hours—¾ to excavation and ¼ to bricking. No blasting was allowed in the boulder clay.

WEST REGENT STREET COVERED WAY.

For 54 yards west from West Nile Street the railway went through thin mud with brick clay above, the clay extending downwards for about 20 feet below the surface of the street. The remainder of the covered way, 105 yards, was through boulder clay, with brick clay above. The mode of construction was the same as that adopted in Kent Road, with the exception that instead of working with a heading and a gullet the whole length was excavated at once under the concrete arch, which was supported by timber in the usual way. This timbering, consisting of fifteen 9-inch bars and uprights resting on the upper sill, was considered necessary owing to the great pressure of the clay above on the concrete arch.

Before operations were started, a 4-feet drain was begun at Gordon Street, connecting with the Gordon Street main sewer, run by a flat gradient up West Nile Street, carried under formation, and joined to the existing sewer on the upper side of the tunnel by a quick incline.

Piling was started midway between Renfield Street and West Nile Street on 23rd Mary, 1883, and concreting on 9th June. This was done in 15 feet lengths, and as the piles were put down with the crane used for the excavation, &c., each length was concreted before the piling for the next was started. The concrete arch was completed to West Nile Street by October, 1883, and then a shaft was sunk inside the Circus, and tunnelling carried forward under the arch. On 14th April, 1884, piling was re-started opposite the Coal Exchange, and carried towards the west, the concreting being finished between Renfield Street and Hope Street at the end of August, 1884. To get across Renfield Street, piles were driven between the tramway rails during the night, and the causeway and rails were lifted on a Sunday, and then supported on timbers resting on the piles. Having now got the street supported, it was easy to excavate between the piles under the street and form the concrete arch. When this was finished the timbers were removed and the street restored on a following Sunday. The tunnelling in the meantime was being carried rapidly forward, the junction with the West Regent Street tunnel being effected on 18th October, 1884. Distance, 204 yards ; 45 in rock.

As the subsoil consisted of good stiff clay, the street was excavated nearly to the top of the arch, about 10 feet down, before piling. Fig. 22, Plate VIII., shows a section of the covered way constructed in mud, where a concrete invert was put in. The following table shows the rates at which the work was done :—

Excavation of street, piling, and concreting—19 yards per month ; 60 hours to each length, $\frac{3}{5}$ to excavation and $\frac{2}{5}$ to piling and concreting.

Tunnelling (with invert)—15 yards a month ; 152 hours to each length, $\frac{1}{2}$ to excavation and $\frac{1}{2}$ to concreting and bricking.

Tunnelling (without invert)—15 yards a month ; 152 hours to each length, $\frac{4}{7}$ to excavation and $\frac{3}{7}$ to bricking.

Where no invert was required the material was much harder and more difficult to excavate, and therefore the excavation occupied more time than in the case where the invert was put in, the material in the latter case consisting of dried mud. In the former case the side walls were founded on rock. An average of four piles, each 30 ft. long, and consisting of three pieces, were driven per day of 10 hours with the one crane.

The average depth of the street excavation was about 14 feet. No buildings were injured on either side of the street.

WEST NILE STREET TO BUCHANAN STREET TUNNEL.

This portion of the tunnel was almost wholly in freestone. The rock in the first place was excavated to within 9 feet of formation level, the remainder being quarried out when the bricking was finished. It was done in 12 feet lengths to start with, but where under the houses on both sides of Buchanan Street the lengths were reduced to 6 feet, in order to minimise the risk of subsidence. On the west side of the street the extrados of the arch was within 2 feet of the founds, and although the walls of the houses were not underpinned, no damage was done. On the east side, however, where the top of the rock was soft, and where it began to dip down, underpinning had to be resorted to. The work of tunnelling was carried on from the shaft inside the Circus, the face on the west side being started on 26th September, 1883, and the last length in the rock being finished on 11th December, 1883; distance, 45 yards. The east face was started on 2nd June, 1884, and the tunnel was finished on 12th March, 1885; distance, 83 yards. The tunnel in this case gradually widens out to 35 feet at the beginning of Queen Street Station.

The timbering consisted of 18-inch logs placed one on each side of the walls of the buildings, with short 12-inch logs placed across them about 4 feet apart, and on which the walls rested. The longitudinal logs were supported on 12-inch piles resting on the rock below. The arrangement is shown in plan in Fig. 23, Plate VIII., and in section in Fig. 24, Plate VIII.

When the rock was excavated, portions being left for the piles to rest on, the arch was built round the piles, and the sides made up with concrete. The spaces between the cross logs were then built up, the logs withdrawn, and the walls underbuilt. Lastly, the piles were sawn in two from below and withdrawn, and the holes bricked up. The completed tunnel is shown by Fig. 25, Plate VIII. The section (Fig. 24, Plate VIII.) is taken through the east building line of Buchanan Street.

The tunnel in rock, where the houses were not underpinned, advanced at the rate of 11 yards a month, each length taking about 166 hours; $\frac{2}{3}$ to excavation and $\frac{1}{3}$ to bricking. Where the houses had to be underpinned, the rate of advance was 7 yards a month, or 130 hours to each 6 feet length; $\frac{11}{13}$ to excavation and underpinning and $\frac{2}{13}$ to bricking and concreting.

FREDERICK STREET TO GEORGE STREET TUNNEL.

This portion of the tunnelling was mostly through sandstone and shale. The work was done from three shafts—Montrose Street, John Street, and Frederick Street. The Montrose Street tunnel was started on 20th July, 1883, the junction with the John Street tunnel being completed on 9th August, 1884; distance, 82 yards; and with the High Street face on 2nd April, 1885; distance, 248 yards. The John Street tunnel was started on 26th December, 1883, and finished on the east on 9th August, 1884; distance, 52 yards; and on the west on 3d October, 1884; distance, 70 yards. The Frederick Street tunnel was started on 22d October, 1883, and stopped on the east on 16th May, 1884; distance, 48 yards.

From Frederick Street to John Street the top of the rock was on an average about 6 feet below the top of the arch, and as the rock was overlaid by a little boulder clay, with soft muddy clay and stones above that, there was very considerable subsidence of the surface. The result was that all the houses between these two streets had to be taken down. The pressure from the soft material above was so great that bars of extra thickness had to be used (crown bar 2 feet diameter), and many of them could not be drawn forward.

This portion of the tunnelling was done in the ordinary way in lengths of 12 feet. From Montrose Street eastwards it was done in 18 feet lengths. From Frederick Street to John Street, where the cover was soft, and from John Street to Montrose Street, where there is only an average of about 2 feet of rock above the arch, 6 rings of brick were put in (Fig. 26, Plate VIII.); but from Montrose Street east, where there is an average of 12 feet of solid rock above the arch, only 4 rings were put in (Fig. 27, Plate VIII.). The timbering required for the latter section was very light, sometimes as few as five bars being used. No houses were injured by this portion of the work.

For the tunnel from Frederick Street to Montrose Street the rate of advance was 7 yards a month; or 261 hours to each length, $\frac{5}{7}$ to excavation, and $\frac{2}{7}$ to bricking. For the tunnel from Montrose Street eastwards the rate was 13 yards a month, or 211 hours to each 18 feet length, $\frac{5}{7}$ to excavation and $\frac{2}{7}$ to bricking.

HIGH STREET COVERED WAY.

This portion of the work, extending from High Street to the north side of George Street, was started on 2nd July, 1883, and the junction with the Montrose Street tunnel was effected on 2nd April, 1885; distance, 174 yards. It was partly in clay and partly in mud, sometimes with a little rock cutting at the bottom. For 140 yards the work was done entirely in the open in the usual manner. Two rows of sheet piles, 35 feet apart, were driven, and the material excavated from between them down to formation level, the piles being held apart by 12-inch struts. The brickwork was then finished, the haunches of the arch filled with concrete, and the whole covered with a foot of puddle clay. The completed section is shown by Fig. 28, Plate VIII. For the first 120 yards, where the foundation was mostly on rock, it was done in 30 feet lengths, part of the material excavated from each length being used to restore the length just completed, and the remainder carted away. On the west side of High Street a hole had been left in the crown of the arch, and through this hole the surplus material was shot into the waggons below, and from there conveyed away by rail.

On the east side of George Street, the rock disappeared below formation level, and was not got again for 23 yards. For this distance, therefore, a concrete invert was put in. Before this was done, however, arrangements had to be made for carrying on the work under George Street. In order to have the street cleared as quickly as possible the concrete arch was resorted to, piling being done between the tram rails at night. The arch was completed under one set of rails and the street restored before the other line was touched, and in this manner the traffic was kept going. This arch was put in for 35 yards, and occupied two months.

For a certain portion of this distance the rock was so far below formation that the piles could not be put down to it. While excavating under the arch, therefore, special precautions had to be taken in order to prevent the whole thing, arch and piles, from sinking down in the soft mud. It was taken in short lengths, and when each was excavated down to formation, two 6 feet brick cylinders were built, one on each side near the piles, and weighted with pig-iron to make them sink. As the cylinders sank down more brickwork was added, and when they reached the solid the mud was excavated from the inside, which was filled with concrete. On these the concrete arch was supported. The invert was then easily formed, and the bricking of the walls and arch completed. The section is shown by Fig. 29, Plate VIII.

The covered way, without arch or invert, advanced at the rate of 12 yards a month, the average depth to formation being 30 feet. Each 30 feet length took about 380 hours, ¾ to excavation and ¼ to bricking and concreting.

The covered way with invert, the concrete arch being supposed to be completed, advanced at the rate of 3½ yards a month; about 520 hours to each 12 feet length, $\frac{14}{15}$ to excavation, building cylinders, and putting in invert, and $\frac{1}{15}$ to bricking.

Where the foundation was on rock, the arch being completed, the rate of advance was 10 yards a month; 182 hours to each 12 feet length, ⅗ to excavation and ⅖ to bricking.

The material drawn from all the shafts in the east contract was carted to High Street, there tipped into waggons, and thence taken by rail to Shettleston, where it was deposited.

The tunnelling was fortunately carried out almost without accident, and it was hoped there would have been a clear record as regards loss of life. Unfortunately, at the very last length of the tunnel, and almost the last yard, a man, working under an old concrete foundation, neglected to prop a hanging bit of concrete, and it came away and killed him.

DRAINAGE OF TUNNEL.

All the water from the tunnel is carried off by two built drains, each 4 feet in diameter; on the west by the Clairmont Street drain, 8 feet below formation level, and on the east by the West Nile Street drain, 5 feet below formation level. The first of these sewers drains the railway from Stobcross to Charing Cross, and the second from Charing Cross to College. On the west of the Clairmont Street drain, the open cutting is drained by a 9-inch pipe, which runs into a 2 feet 6 inch built sewer at the beginning of the covered way. On the east we have first of all 108 yards of a 4 feet built drain, then 146 yards of a 3 feet drain, then 68 yards of a 2 feet 6 inch drain, and lastly 147 yards of 15-inch pipes, connecting with a 9-inch pipe from Charing Cross Station. These drains, in the centre of the 6-foot way, were made gradually larger going from east to west owing to the great number of drains, 86 in all, from the houses and street gratings, which are led down the walls of the tunnel and connected with the central drain as shown in Fig. 8, Plate VII. The built sewers were all cut out of the solid rock, and covered with an arch of 9 inches brickwork. Main drains in Elderslie Street, North Street, Buchanan Street, and High Street, were carried across the railway in 4 feet malleable-iron troughs lined with brick.

Twelve-inch spigot and faucet fireclay pipes are laid the whole way from Charing Cross to the West Nile Street drain. On the east, Queen Street Station is drained by a 2 feet built drain covered with flat stones, and the rest of the tunnel by 12-inch fireclay pipes.

QUEEN STREET STATION.

Queen Street low level station is nearly at right angles to the high level station, and 18 feet below it. The work of construction was done in sections or bays, each bay in the Goods Station consisting of a loading table and the roadway on the east, and in the passenger station of half a platform and the line of rails next it. Each bay was completely restored before the next was started, and the work was done without interrupting the traffic of the station. The length of the bays in the Goods Station varied from 34 feet to 46 feet, and the breadth was about 110 feet. In the passenger station the average length was about 45 ft,, and the breadth 110 ft. There were 11 bays altogether, and the time taken for the whole of the work was exactly two years, from 25th May, 1883, till 25th May, 1885. The average time to complete a bay was about two months.

The method of construction was as follows:—Trenches were excavated for the abutments, and also a pit for the centre column, the trenches being about 9 feet wide, and the pit 10 feet square. Where there was no rock the walls were founded on 2 feet of concrete, and the centre column on a block of concrete 10 feet sqaare by 3 feet thick. On the concrete was put a block of granite 4 feet 3 inches square by 2 feet thick, on which the sole of the column rests. The walls having been completed and the column placed in position, the girders were thrown across, span 48 feet, the iron flooring completed, and the platform and rails restored. The material was afterwards removed from below when the waggons could be brought right through from College.

In order to get the girders placed under the large columns supporting the roof of the upper station, four piles 12 inches square, were driven down, one at each corner of the found on which the column rested. When these piles had been driven down to the hard, an iron superstructure, consisting of rolled beams and angle irons was erected. An iron casting was then fitted on to the top of the column, and the whole thing raised by means of hydraulic jacks resting on the iron framing. The column was thus left hanging in the air, and in this position it was easily cut and the girder placed beneath.

The total cost of the undertaking was as follows:—

Parliamentary, arbitration, and law expenses,	£53,478
Construction, claims for damages in connection therewith and engineering,	404,708
Property, £398,304, but deducting estimated value of surplus property, £149,727, there is left,	248,577
Total cost,	£706,763

The total length of railway made was 3·123 miles, and if we deduct Railway No. 2, and the part of the City line in the open, extending altogether to 1·365 miles, and costing £118,600, we have a length of 1·758 miles of City underground line, costing £588,163, or at the rate of fully £334,000 per mile.

In opening the discussion on this paper on the 24th January, 1888,

The PRESIDENT said they had had brought before them at last meeting a most interesting paper on "The Construction of the Glasgow City and District Railway," which time had not allowed to be read, but it had since been printed and circulated among the members in the Transactions. They would be very glad to hear any remarks which any one desired to make upon the paper.

Mr C. P. HOGG remarked that he considered the paper one of permanent value in the Transactions, and that it was a careful record of a difficult work carried to successful completion. The diagrams of the various operations of the driving of the tunnel and the covered ways at several stages of the work conveyed to the mind the nature of these operations better than merely a description could have done. The system of constructing the covered way was absolutely novel, and it would add very much to the value of the paper if Mr Simpson would give them an approximate idea as to how much the covered way in Kent Road cost. A covered way usually cost between £60 and £70 per lineal yard, but it was obvious that the Kent Road covered way must have cost a great deal more, as it must have been a most difficult work. One point of great interest to engineers had been clearly brought out by by Mr Simpson—that in working in sand and mud if the water only were withdrawn there need be no fears entertained for the subsidence of the surrounding buildings. Rock or hard material at or near formation level was favourable for the system of construction adopted by Mr Simpson; but it seemed to have been equally successful in that portion referred to in Fig. 22, where there were 18 feet of mud below the rail level. He thought that referred to a place in West Regent Street. He would like to ask Mr Simpson whether the mud was soft or whether it was harder at that point than usual? He would not have been astonished to find that the old course of the St. Enoch Burn had drawn away the water and made the mud easier to deal with. He observed that in dealing with the covered way across George Street the mud was described as soft, and necessitated the use of brick cylinders, which he thought was a capital plan. Nearly sixteen years ago, when engaged in the construction of the Harbour branch of the City Union Railway, in passing under the Paisley Joint Line at Pollokshields Station, they encountered a bed of mud, and they found it absolutely impossible to get in the walls in the ordinary way. The late Mr Milroy suggested that they should use brick cylinders for the walls, which they did. The cylinders were 14 or 15 feet in depth, sunk about four feet below formation level, and answered the purpose admirably. The system was described by Mr Milroy in one of his papers contributed to the Institution of Civil Engineers, which appeared in their Transactions about the year 1873. He noticed in the paper—another point which he would like to bring out with regard to the construction of the covered way—that in the sinking of the brick cylinders it was considered necessary to get them weighted. In the construction of the Harbour branch under the Joint Line they fell upon the plan of utilising the weight of the passing trains for sinking the cylinders, and what was considered a difficulty turned out to be the easiest part of the construction. He noticed in the description of the tunnelling that Mr Simpson gave two instances—one where the work was carried out in two successive stages, and the rate of progress was 15 yards per month, while in the other case given the progress was only 11 yards per month. If he (Mr Hogg) was right in his supposition, these operations were carried out by different contractors, and as the difference was so great, he would like to know whether the rate of progress differed on account of the methods, or whether it was caused by the difference of the materials excavated? In regard to the cost of the line per lineal yard, or per mile, he would like to know if Mr Simpson could give them the cost of the West Regent Street tunnel. The summary of cost, given at the conclusion of the paper, showed that the City Underground portion cost £334,000 per mile, which was, on the whole, not an excessive cost. Of course, that included the stations, and as there had been a good deal of money spent at the Queen Street Station, could Mr Simpson take out the cost of the stations and give them the approximate cost of the line per mile? He congratulated Mr Simpson on putting such a valuable record of underground railway work on the Transactions of the Institution.

Mr R. DUNDAS said there was one or two points he would like to draw attention to. A principal one was with regard to the covered way illustrated in Fig. 6 (see Plate VII.). He noticed from the illustration that when the piles were got down to the hard rock, they had no hold except on the rock. There would be some cross shoring required when the sand was excavated to the very bottom. He also observed that there was a small shoulder on Figs. 6, 8, and 10, left at the foot of the pile. He supposed that was sand not taken out. The suggestion in the paper, he considered, was a very valuable one, and more especially where the sand was saturated with water, namely, that where water was carefully drained off as pure water, the sand did not shrink.

Mr ALEXANDER SIMPSON said, that if there was any value in this paper it consisted in that part which described the construction of the line in Kent Road. The difficulty experienced was in getting the tunnel made in running sand. They at first tried, in the usual way, to put down a trench from the surface, and to strut it according to the ordinary practice. But they soon found—as described in the paper—that at Dumbarton Road they were in the fair way to bring in the whole street; and so they had to give that system up. Then they hit on the mode that was eventually carried out. In dealing with the mud the great point to be aimed at—and here the difficulty lay—was to make certain never to bring away the water in a dirty condition; for whenever that was the case, there was danger of a subsidence. In order to secure that this should be done thoroughly, the gullet in the interior of the tunnel was excavated slowly—perhaps only three feet at a time—giving time for the water to be drained away as they went along. There was always 8 feet distance between the sheet and the main piles, which allowed the water to go slowly away. It was also a most important matter to be attended to, never to go down so deep as to allow the water to boil up. They found that if the sand was allowed to take a slope of one in five, the water never boiled up through the sand, that is, the head was taken off the water. This gullet was deepened slowly, so as to allow the water to drain off gradually; for if the sand got away there would have been a subsidence, and therefore the sand was thrown back, so as to leave a body of sand always outside of the sheet piling to allow the water to drain through. By this means they were enabled to do the work without any subsidence in the street whatever. He was satisfied that in cases where materials such as those at Kent Road had to be dealt with, and which had formed insuperable difficulties, that if the water had been taken away pure, the work would have been carried out quite successfully. Of course it might be said that the rock had been favourable to them. It happened to come just about formation level, but he did not think it would have caused any difficulty though the rock had been deeper. The only difference in their procedure would have been to have driven the piles further down, as had been done at West Nile Street, where they were driven four or five feet under the formation level to keep the material outside from coming in.

Mr R. SIMPSON, in reply, said as regarded the details of cost requested by Mr Hogg he felt hardly at liberty to give them, as the firm of engineers who carried out the work were desirous that this question should not be gone into further than it had already been in the paper. In reply to Mr Dundas, the cross shoring was required at the points indicated, and that the shoulder of sand referred to was left to save the brickwork. With reference to Mr Hogg's remarks as to the three places where the concrete arch was employed, he (Mr Hogg) was quite right in his surmises. The sand was much sharper in Kent Road than it was in West Nile Street. The stuff at West Nile Street was more mud, and retained the water, and at George Street there was more mud, which would not part with the water, so that the men had to stand on boards in laying the cylinders, which were put down with great facility. As regarded the two systems of carrying out the work in boulder clay, he remarked that in Mr Young's contract there was left a portion in the centre that did not count for the time occupied. The two portions were not done at the same time. In Mr Brand's contract all the material was excavated at once, which took more time. That centre portion, of Mr Young's contract, shown in Fig. 20, was taken out by waggons afterwards, but it could not be said that that was part of the time required to complete the tunnel. In some places there were shores put across, in other places the piles rested on the rock, and there was sometimes a couple of shores put in in the 18 feet distances. But in some cases the little portion of sand left at the side was quite sufficient. The main reason for leaving the shoulder of sand was in order to save the brickwork.

On the motion of the PRESIDENT, a vote of thanks was awarded Mr Simpson for his paper.

On the Erection of the Superstructure of the Forth Bridge.

By Mr ANDREW S. BIGGART, C.E.

(SEE PLATES X., XI., XII., AND XIII.)

Received and Read 24th January, 1888.

THREE years ago, in a paper dealing with the construction of the steel tubes, I stated that to the end of those tubes as they lay in the yard the skewbacks were being connected.

Since that time the whole of the 12 skewbacks have been placed in position, on their respective piers, and are now riveted up and completed.

THE STEEL PIERS.

These piers form three groups, and the skewbacks in each are so placed, in relation to one another, as to represent a rectangle.

In each of these groups there are four skewbacks. They carry the entire steel superstructure, consisting of the steel pier overhead and the cantilevers on each side of the pier.

The skewbacks in each set are joined to one another by tubes and heavy lattice girders. The tubes run parallel to the centre line of the bridge, the lattice girders at right angles and diagonally to the same centre.

The 12 foot vertical columns (improperly so called) spring from the skewbacks. Each pair of these columns batters towards the centre of the bridge as they rise, being 120 feet apart at their base and 33 feet at the top.

The box girders on the top of each set of the columns form a rectangle, the two sides running with the bridge forming the top tension members, while the other two act as braced struts.

In the sloping plane, in which the vertical columns lie, there are the 8 foot diagonal tubes which run from one side of the skewbacks to the top of the opposite vertical column. In the other, or vertical plane, are placed the windbracing and the supports for carrying the internal viaduct. The viaduct extends, unsupported, from the one vertical plane to the other.

Additional diagonal and longitudinal bracing girders, fixed in a horizontal plane at the crossings of the 8 foot tubes, take up the various stresses at these points. These members may be said to complete a steel pier.

THE CANTILEVERS.

Each of the cantilevers may be said to consist of two braced brackets, securely joined along their lower part by diagonal bracing, and fixed otherwise at various points. Moreover, if the vertical columns be looked on as centres, the brackets may be viewed as having been swung around them. They thus approach each other as they recede from the pier, and batter towards one another as they near the top.

The whole of the members in each bracket lie in the same plane.

The bottom, or compression member, of these brackets is made up of six straight bays, straight in themselves but joined at an angle. As the bays approach the point of the bracket they each lie nearer the horizontal, till in the case of the last bay, which is actually level. In section the first 4 bays are circular in form, in the fifth it gradually changes to the rectangular, and continues thus to the end of the sixth.

The top, or tension member, is straight throughout, and, like the bottom member, is divided into 6 bays. These bays are each rectangular in form their full length.

The bracing in the brackets is of the double triangular type. The struts extend from the back of each bay, in the bottom member, to the front of the corresponding bay in the top member. The ties are the converse of this, and on this account the struts and ties cross each other.

At the point of crossing a tie is fixed, which, extending to the bottom member, diminishes some awkward stresses in these members due to dead weight.

Between the struts box girder bracing is placed. Similar bracing is also fixed between the bottom members. Through these the wind stresses of the cantilevers are transferred to the piers. Thus this bracing, in conjunction with that between the struts, is utilised to transfer the wind stresses of the top member to the pier. As a consequence, there is no wind-bracing between the top members.

The internal viaduct, insignificant in itself as compared with the cantilevers required for the carrying of it and its load, is supported by trestles, or girders, at the centre and ends of all the bays.

After the cantilevers have been built, two gaps of 350 feet each will still remain. These will be closed up by a double parallel girder road. The girders will rest on the ends of the brackets, and lie towards one another with a batter similar to that in the piers.

The skewbacks (Fig. 1, Plate X.) are the most complicated parts of the entire structure, the difficulties at this point arising mostly on account of the various angles at which the different parts lie in relation to one another and to the skewback.

Each skewback may be looked upon as being either the starting point or the termination of five separate tubes and five distinct box girders. All these members are so joined to it as to transfer into or through the various parts of the skewback the stresses of each member. The skewbacks also act as the upper, or sliding bed-plates, on which some of the movements of the piers and cantilevers, due to expansion and contraction, take place. The sliding surface is the lowest course of several layers of steel plates, which form the base of the skewback. On the top of these plates a series of longitudinal girders are riveted, while in section these girders are crossed at short intervals by one central and two smaller side diaphragms. Small stamped diaphragms are also placed between the longitudinal girders, immediately under the main ones. Between the centre and side diaphragms, and beyond the latter, are riveted four longitudinal lines of plates, as also a top plate, all of which merge into the horizontal and cantilever tubes at the opposite ends of the skewback. To the inner lines of the plates the sides of the two small 8 foot tubes are riveted. These also serve as part of the connection to the vertical column. Gusset plates and angles are principally used in making the connections of the girders to the skewbacks.

The construction of those parts of the structure subjected to compression is very different from that in those parts subjected to tension, hence the dissimilarity between the bottom and top members.

The cross section of the larger tubes consists of 10 plates and 10 H beams. These all run longitudinally, and as the plates overlap one another in this direction, they form five outer and five inner courses. Butting each other on end, they are there connected by double covers.

The H beams are placed immediately over the laps of the plates, and are secured by the rivets passing through these longitudinal seams. At intervals of 8 feet, stiffening circular diaphragms are introduced for the purpose of preserving the tube in true form.

In the smaller tubes, or those comprising the diagonal columns and struts of the cantilevers, the form is somewhat different. In them two flat sides are introduced to simplify the connections and crossings. The cross section consists of longitudinal plates and ties, varying in number with the size of the columns.

The diameter of the largest tube adopted is 12 feet, while the thickness of the plates employed is in many cases as much as 1¼ inches.

In the cross section of the top members there are four booms, each consisting of ordinary flange and web plates, and in addition an extra horizontal web, for the purpose of securing the wind bracing. This coupled with the vertical bracing binds the whole into a stiff box form.

The ties in section are similar to the top member, with the exception that there are no horizontal webs. In this case the horizontal wind bracing is secured to the flanges.

Much of the wind bracing between the columns is of the same form as the ties, though in some cases it consists of one angle only at each corner of the box.

The internal viaduct consists of two main girders, with the necessary cross girders, bracing, and roadway. The top booms of the main girders serve as troughs for two of the rails, being reversed and having the open part of the boom looking upwards.

The other rails are laid in troughs resting on the cross girders.

ERECTION OF STEEL PIERS AND CANTILEVERS.

The order in which the first portions of the steel superstructure should be erected was easily determined, but as the work proceeded many slight departures from the original plans were made. Some of these were caused by the exigencies, which arose as the work proceeded, while others were dictated by experience.

As a matter of course, the first part of the work—immediately over the piers—was to place the lower bedplates in position. Following these came the skewbacks, which on being lowered were joined to the horizontal tubes and bracing girders. The latter were resting in position on trestles, having been built while the bedplates and skewbacks were being got ready.

The limit of lift of ordinary cranes when placed near the ground level being about 50 feet, so soon as the skewbacks were ready to receive them, the vertical columns and diagonal tubes were by that means built up to this height.

Recourse was then had to rectangular platforms built around the pier.

The platform, weighing in all about 500 tons, was carried by the four vertical columns, and raised in stages of 16 feet at a time, by means of hydraulic rams placed within them. After each lift the four vertical columns, the four diagonal tubes, and as much of the wind bracing as convenient or necessary were built in position. The work proceeded thus until the full height was reached.

The top of the vertical columns, and the top members running between the columns, were then erected. A start was afterwards made to the erection of the top members, and the first ties of the cantilevers.

While the top members of the pier were being built, the internal viaduct over the pier, and the first section of that in the cantilevers, was raised in small sections into position. At an earlier stage than this, however, indeed, shortly after the pier platform was ready, the bottom members and the first struts of the cantilevers were being built out from the skewbacks. After the bottom members were carried out a distauce of about 150 feet, and secured by temporary ties, platforms were built along their upper surface, and were afterwards used for the erection of the ties at the centre of bay 1, strut 1, and sundry other work.

These platforms were raised until they reached a height a little under the crossing of the first ties and struts.

Meanwhile, the first ties were carried from the top, down to, and across the struts. After they were secured a new base was formed for the carrying of the internal viaducts, the bottom and the top members, and the struts and ties, with the necessary bracing another stage forward. Work is now proceeding in the case of the furthest advanced cantilevers at the most of these points, and will so continue until the bay has been erected.

PLATFORMS AND LIFTING PLANT.

In structures like the Forth Bridge, where work requires to be executed at great heights, various kinds of staging, or false works, become a necessity. The first portions of the bridge were erected by ordinary derrick cranes. As soon, however, as the increasing height necessitated the use of platforms, on these, new cranes were placed, which carried the piers to their full height.

The platforms employed are of different kinds, and vary greatly in size. The largest is that presently in use on the top of the Inch Garvie main pier, its dimensions being 350 feet by 56 feet, which gives an area as large as an ordinary railway station. In striking contrast to this is the smallest, that handy little article popularly known as the "Boatswain's Chair." Between these two extremes the number and variety are almost innumerable.

The platform with which the main piers were built, surrounded in each case the entire pier. Those for the Fife and Queensferry sides of the river were similar in form and size, while that on Inch Garvie is larger, and has extra bearing and lifting columns placed in its centre.

The Fife and Queensferry platforms (Figs. 7, 8, 9, 10, Plates XI. and XII.) consisted of two semi-independent platforms, running parallel with the bridge, each surrounding the two vertical columns and the two 9 foot tubes on their respective sides.

Each platform consisted of two parallel lattice girders (placed 18 feet 6 inches apart) with their necessary bracing, and were covered with planking, well holes being left to allow the columns to pass through.

These half platforms rested on sliding blocks, placed on two strong box-shaped main lifting girders, which lay across the bridge, and passed through the vertical columns. On the top of these box girders gangways were laid, which served as bases for much useful work. These main lifting girders were in turn carried by short cross girders (see Fig. 11, Plate XII.) within the vertical columns, pins passing through the girders and the permanent longitudinal H beams of the columns, to take up the weight. Similar cross girders were in like manner secured underneath these, and carried the hydraulic rams used in lifting the platform.

The plant used in connection with these platforms was of a very varied description, and comprised such things as hoists for raising the material, cranes for building the columns, rivet heating furnaces, the large machines for riveting the vertical columns, and numerous other articles. So soon as a length of 16 feet had been added to the top of the columns above the platform, and one riveted underneath, the whole platform was raised another 16 feet. This was effected by means of the hydraulic rams already referred to. On water being admitted to the rams, the weight of the main lifting girder was taken off the top cross girder, which allowed the pins to be withdrawn. This done, the main lifting girder and the cross girders were then raised 12 inches, and the pins re-inserted. One end of the platform now rested 1 foot higher than before. The action of the rams was reversed, and the lower cross girders were then raised the same height as the upper. The other end of the platform was similarly raised, and this, alternately, action was so continued till the full 16 feet lift was accomplished. During the operation of lifting, the two semi-platforms were moved towards each other to prevent them fouling the battering columns as they rose.

To turn now to the cantilevers. Before the pier reached its full height the bottom members of the cantilevers were commenced. As in previous instances, the first lengths were built by ordinary steam cranes. Their usefulness, however, soon came to an end, and other means had to be adopted to carry out the work.

A cage (see Fig. 12, Plate XII.) carried by the tube was secured round each of the members. It projected beyond the outermost point of the tube, and served as a platform whereon the men worked. A hydraulic crane was employed to build the material in position. It travelled along the whole length of the top of the cage, and had other hydraulic gear to enable the crane to be turned completely round, in addition to raising and lowering the load. The cage is rectangular in elevation, plan, and section. It consists of duplicate sections in 8-feet lengths, all of which are interchangeable. The parts are braced independently, and when joined to one another give to the whole cage rigidity and strength, both vertically and horizontally. The cage is held in position by struts and ties, which extend from its corners to rings encircling the tube. As the work advances the sections are transferred as required from the back to the front of the cage.

The hydraulic crane (see Fig. 12, Plate XII.) used is of a peculiar design. It consists of two side travelling carriages, connected together by cross girders, on the latter of which is secured the race and other connections necessary for the carrying of the jib and working of the crane. The bodily movements of the crane along the top of the cage is controlled by a ram on each of the side carriages, the points of reaction being a couple of fixtures on the cage. The slewing and lifting rams are fixed to the jib. Round a drum secured to a fixed centre-post, ropes are led, and over a pulley on the slewing rams, for the purpose of giving the jib this motion. The raising of the load is effected by a single ram lying along the top of the jib. To the plunger of the ram a single pulley is attached, and round it and the pulley on the jib point a rope is made to pass. This arrangement enables the load to be lifted a distance equal to twice the stroke of the ram. The crane is worked by one man.

All the rams are formed of wrought iron tubing. Castings are screwed to the ends of the tubes for the fixtures and stuffing boxes. Steel wire ropes, in all cases, are employed to lift the load and slew the crane.

The material for the bottom member is either run along a tramway (Fig. 9, Plate XI.) fixed to that member, or raised, as the case may be, from the ground, or the water, to position.

For the building of the first section of the cantilevers platforms (Fig. 9 and 13, Plates XI. and XIII.) similar, though smaller, to those used in the case of the piers were employed. They were built immediately over the bottom members, raised to a level position, and then lifted in stages till they reached a height about 200 feet above high water.

The raising was effected by means of hydraulic rams placed at each end of the platform. Those at the pier end were fixed to a projecting girder, secured to the vertical columns. Ties, or hangers, extended down to the platforms from these rams.

Provision was made for the removal of the ties as the platforms were raised. The outer ends of the platforms were raised by rams, within the ties, which extended from the crossing of tie 1 and strut 1 to the bottom members in the middle of the bay. To the main lifting girders, extending across the bridge and carrying the platforms, these rams were fixed. Underneath the rams, and also on the opposite side of the ties, cross girders were secured by steel pins.

The raising of these platforms, as well as the work done by them, was in principle the same as that already described in the case of the piers, and on that account it is unnecessary to go further into details.

In the erection of the top members and the upper parts of the cantilevers (Figs. 14 and 15, Plates XII. and XIII.) generally plant of peculiar capabilities has been adopted. It rests on the upper surface of the top members, and consists of a sliding framework of steel, from which a large platform, providing footing for the men at work, is suspended. This platform also furnishes protection to the men at work underneath. On the top of this framework there are two cranes, one of which is wrought by steam and the other by hydraulic power. The former projects over the framework, towards the point of the cantilever, while the latter points in an opposite direction.

The principal part of the work is done by the steam crane, as it is employed to build the webs of the top members ahead of itself, and also the upper half of the ties and struts. The hydraulic crane, on the other hand, is employed in placing in position the flanges of the top member, and afterwards in the riveting of the same.

The steel framework is composed of two main girders, lying across the two top members, and several connecting cross girders. It is level on the top, and varies in depth and shape, to have a direct bearing on the respective sliding blocks fixed to the members. This is necessary owing to the inclination of the top of the cantilevers.

The steam crane is placed immediately over the top of the main girders. It has a jib 35 feet long, capable of being slewed 115 degrees on each side of the centre line of the bridge. The load can be run along the jib at will. These motions, as well as the lifting of the load, are performed by a steam winch. Gearing is employed for the slewing motion, and the load is lifted and traversed by steel wire ropes. At the present time much of the material handled by this crane is lifted through a distance of 200 feet.

The hydraulic crane rests on a platform projecting from the main framing. It is very similar to those which were described in the paper I read three years ago, already referred to. The principal difference consists in its being supported by back stays, as in an ordinary derrick.

The platform is 76 feet long and 45 feet wide, and is hung to the framework by braced angles. Its length is such that it well-nigh extends as far as the points of the steam and hydraulic cranes, and in width is a little greater than the top members. It is made up of four longitudinal girders, which run the whole length, covered with timber, a hole in the front end being left for the material to pass through.

When a length has been finished in front of the crane, the whole arrangement is slid forward to a position suitable for proceeding with the next length. This building in stages will continue until the end of the cantilevers is reached. The steam crane just referred to also places in position part of the material of the first ties and struts. Small stages are employed to provide a footing for the men at work on these members. That for tie 1 (Fig. 13, Plate XIII.) is a simple timber scaffold, hung by wire ropes from a beam lying across the upper booms of the tie. As the tie is gradually built downwards the scaffold is lowered by tackle. The stage for strut 1 is a steel cage surrounding the tube, having two timber platforms, which are placed at different heights. It is secured to the tube by brackets, fixed at intervals, and is lifted by the steam crane on the top members in convenient stages. This cage is required only for the top half of strut 1, as the lower part has been already built from the platforms used in the erection of the first section of bay 1. Besides the special lifting plant, a large amount of useful work has been all along done by what may be termed ordinary plant, such as common derrick cranes, winches, and block and tackle.

It may be interesting here to mention that while at first chains, or Manilla ropes, alone were employed for the block and tackle, they are now only found where light lifts are required.

Flexible steel wire ropes have been substituted with the best results. Accidents, which were occurring during the period when chains and Manilla ropes were employed, have now happily entirely disappeared. The introduction of the wire ropes necessitated new blocks, provided with pulleys suitable for the new style of tackle. The work done by these ropes has been so satisfactory that they are employed on many of the ordinary derrick cranes, and are there gradually, but surely, gaining in favour.

During the erection, a large number of temporary ties and struts were employed for the purpose of keeping some of the members in position while unconnected, or carrying more temporary material than they would have been otherwise able to bear.

In the piers, both the vertical columns and diagonal tubes had, at several points, to be kept apart by struts (see Fig. 9, Plate XI.), while the diagonal tubes had also to be tied to each other, in elevation, before they reached the top. The bottom members are now kept up by temporary ties (see Fig. 9, Plate XI.). These extend to the vertical columns, and have their stresses taken up by a horizontal tie, running between their two points of fixture. In these diagonal ties, the stress produced, for each bottom member, is about 500 tons.

Wire ropes are freely used for carrying up such work, as in the case of the internal viaduct, while being built by overhang.

Although large platforms have been so much adopted in the past, they have lately given place to others, which are smaller and handier.

The reasons for employing these large platforms to build the piers, were principally a regard to the safety and convenience of the men at work. These enabled them to handle a large quantity of material, not only with speed, but attended by little danger to themselves. The platforms also form a base on which to build the top members, the importance of which can best be appreciated, when I state that, on the Inch Garvie pier, the material of the top member and junctions represents a weight of about 1500 tons.

Large platforms are not now of the same value in the carrying out of the work, because cranes are already placed on the top of the bridge, which, without difficulty, can place material in position at a point 300 feet under themselves.

With this introduction of light scaffolding, only a few temporary ties are required to carry the permanent members. Even such a consideration as this is, in the matter of the first cost alone, of great importance, apart altogether from the acceleration in the erection of the bridge.

RIVETING PLANT.

The hydraulic plant provided for closing by this means, as many as possible of the 8,000,000 rivets in the bridge is, like the work to be done, of a most varied description. It may be divided into the following three types:—

1st,—The ordinary Arrol patent grab machine.

2nd,—Direct acting riveters, using pressures up to three tons per square inch.

3rd,—Special girder machines, for such work as the tubes and large flat surfaces.

The first type mentioned does not call for special comment, as these machines have already been fully described in a paper I read before this Institution, on the "Great Caissons of the Forth Bridge," besides they are well known to the engineers of this city.

The second type, or the direct acting riveters (see Fig. 1, Plate X.), using such high pressures are, however, I believe, novel. The reason for their employment arose out of the peculiar requirements of the work. The riveter consists of a steel cylinder about 7 inches long, provided with a solid piston having a cup leather at the back end. Two cylinders are used together, one acting as the holder-on, while the other is employed to close the rivets. Into each cylinder a pipe is screwed which provides for the ingress and egress of the water, and at this point also, the exhaust is regulated. The high pressure water is controlled by a valve, on the pressure pipe, at a point further back, and from where a convenient connection can be led to both cylinders.

These riveters were originally designed and employed for riveting up the longitudinal girders and diaphragms in the skewbacks. Some of the spaces in whith they had to work were only 2 feet 6 inches long, by 15 inches high, by 15 broad, and access to this small space was still further reduced at the top by a 4 inch angle all round.

The method of application was to place one of two riveters on each side of the work. To each of these the water was led by a copper pipe from the regulating valve. It may be well to mention here that in the pipe leading to the closing riveter, a spring check valve was introduced for the purpose of keeping back the water from the closing riveter, until the holding-on riveter had pushed the rivet home.

When inserting a hot rivet, the holding-on riveter was moved out of position. After being replaced the water was turned on, when the riveter immediately pushed the rivet home, and held it firmly there. The other now came into play and formed the rivet head.

A point requiring careful attention was the timber backing on which the riveters had to take up their thrust. This was equally essential for both the speed and the quality of the work.

Within the skewbacks, and in spaces such as those referred to, it was no uncommon thing for a squad to close one hundred rivets per day, shifting during that time from cell to cell, as they moved along all the copper pipes and connections.

Although designed primarily for the riveting of the skewbacks, the application of these riveters has not been confined solely to them, but they have been usefully employed on other parts of the structure. Thus the heaviest rivets in the top connections of the vertical columns were almost wholly closed by them. In this case, one of these riveters was used within the junction, while without an ordinary ram of about equal power was secured to a slide on a box girder. This girder, moreover, could be moved along the face of other two girders, thus giving the ram complete command of a large surface. The working pressure in this ram was 1000 lbs. per square inch, and in the small cylinder 3 tons per square inch. With this combined machine, 150 rivets, from 8 to 9 inches long, could be closed per day.

Before leaving the subject of high pressure riveters it may be interesting to consider for a little the means adopted for raising the pressure of the water to almost 7000 lbs. per square inch.

The most efficient means to gain this end is a pressure multiplier. This machine (Fig. 2, Plate X.) was constructed almost wholly out of ordinary plant, at the time not in use. The principle was to employ a large ram, with a small pressure, to raise an increased pressure by an attached small ram, this increase being proportional to the difference of the areas. This was effected by securing an 11 inch ram to the one end of a frame, while at the other end of the same frame was a 4¼ inch cylinder. On the first ram a cylinder was placed, and attached to it was a small ram, which acted as a plunger to the small cylinder.

Water at a pressure of 1000 lbs. per square inch was led into the cylinder on the large ram, and as this power was transmitted to the small ram it gave a correspondingly greater pressure on the small cylinder.

The multiplier being self-acting, you will observe we have here simply a hydraulic pump.

As the large cylinder moved backward and forward it reversed a small hydraulic slide valve which served to actuate the larger valve that regulated the water entering or leaving the low pressure ram.

Besides this special form of multiplier there are also some of portable dimensions, They are the same in principle as the large ones, but instead of being automatic in their action they are wrought by hand valves.

It is interesting to note that there is comparative immunity from leaks in the pipes and connections though they are subjected to such high pressures. This is easily demonstrated by watching the movement of the 4¼ inch ram when none of the riveters are at work. In one instance the movement of the ram is scarcely perceptible, although there are scores of joints at which leaks might take place.

The high pressure water pipes are made of wrought iron, and have flanges of the same material screwed and riveted on to their ends. They have a projection and recess. Into the latter a washer is inserted, of the material experience has shown to be best suited for such a purpose, and which, by the way, confirms the remark of the ancient as well as the modern cobblers, that there is "nothing like leather."

The third type of riveting machines employed (Fig. 3, Plate X.) is of an entirely new pattern. Here also two rams are used. If required for such work as riveting the circular tubes, then one of the rams is on a longitudinal girder outside of the tubes, while the other is on a girder inside. These rams are on slides, and are capable of being raised or lowered by a small hydraulic jack at will. On the outside girder the slide is compound, to facilitate the adjustment of the die; but on the inside girder it is not so, as other means serve the same end.

The outer longitudinal girder is, by slides at the top and bottom, secured to ring girders encircling the tube, and is traversed round the former by hydraulic jacks. Within the tube, and opposite these ring girders, are two diaphragms carried on brackets fixed to the longitudinal H beams of the tube. Each diaphragm has a centre socket or step within which the points of the inside longitudinal girder are free to revolve.

By gearing commanded from the platform on which the men are at work this revolving motion is imparted to the girder, and through it to the ram.

Working platforms are secured to both the outside and inside rams, and are raised or lowered along with them. The inside ram, being in most cases far removed from the rivet head, a unique die requires to be used, and its construction becomes even still more special, as in the greater number of cases an angle crosses between the ram and the rivet head. The difficulty caused by the angle is overcome by having a gap in the die opposite the obstruction.

The machines when used for riveting the columns of the main pier were hung to the platform and raised along with it. On the main pier 600 to 800 well closed rivets represented an ordinary day's work with such a machine as we have just described.

The machines used for the diagonal tubes were the same in principle as the above. The outside girders and inside diaphragms were however, different. These had a double D form, being thus similar to the tube. This was to permit of their traversing the longitudinal girders at a distance parallel from the tube, and with the rams always pointing in the right direction. In the case of the outer girder this was effected in a manner similar to that adopted in the large machines, while the inner girder followed a raçe on the diaphragm.

These various movements were obtained by the free use of small hydraulic rams.

The machines were raised and lowered by tackle secured to the tubes, and were quite independent of the movements of the platform.

The work accomplished by this machine was much less than by that last mentioned, as 300 rivets represented a good day's work.

For the riveting of large surfaces of flat plates, such as the bed plates (see Fig. 4, Plate X.) under the main pier, the principle adopted was the same as that for the large tubes—viz., two longitudinal girders, one on each side of the work, both provided with a ram for closing the rivets. The girders were secured at the ends by the plates. These also served as part of the carriage on which the machine was moved along as the work advanced.

Before leaving the riveting plant, it may be well to describe here

THE OIL HEATED RIVET FURNACES.

As time rolls on, and the employment of oil furnaces becomes more general, it will no doubt be interesting to have in the records of our Institution a history of the introduction and development of this form of heating as applied to rivet furnaces (see Fig. 5, Plate X.).

At the Forth Bridge the necessity for some improved mode of heating rivets was early observed by Mr Arrol, and as little or nothing had been done in the matter, he determined that we should, by practical tests, find for ourselves what results could be obtained by the use of oil.

The aim kept mainly in view was to limit as much as possible the size and weight of the furnaces, and otherwise arrange their parts, so that the new furnaces would be more convenient than the coal heated furnaces then in use, particularly on the lifting platforms of the bridge.

About the beginning of 1886 the first experiment was made, and that with ordinary coal heated furnaces. These, we might add, were rectangular in form, and had a fire at one end of the hearth, over which the gases passed before escaping through the funnel. At one end of these furnaces a hole was cut, slightly above the level of the fire, and into this hole the jet of an ordinary Lucigen lamp was inserted. The pipe of the Lucigen had been previously bent until the part entering the furnace lay in a horizontal position. A trial gave results eminently satisfactory, and confirmed the opinion that such a furnace would prove most successful.

The oil used was the ordinary blast furnace creosote, and to keep the oil spray burning, a coal fire was kept lit.

A special furnace was afterward designed, and made in March, 1886, having a series of three heating hearths, and a small fireplace underneath for the purpose of lighting the oil spray should it be extinguished.

This form of furnace proved a great step in advance, and is not yet antiquated, as several are still at work, but without the fire underneath, as experience has proved it to be quite unnecessary.

The next step was to build a furnace with only two hearths, and an application of the regenerative principle. Regeneration is effected by causing the air required for combustion, over and above that entering with the oil, to pass through a chamber immediately above the heated brickwork.

In this case the furnace was longer than the three hearth one just referred to, but had no fire provided. This form proved but the precursor to the single hearth furnace having a regenerator flue and a rounded end for a combustion chamber. Continued use proves this form of furnace to be the best.

The improvement in the furnace soon made it apparent that the oil disintegrator was also capable of a great change for the better. An improved form was accordingly designed, the principal features of which are that the air is made to pass through a centre brass spindle, with the oil as a consequence outside of it. The oil and air are led to the furnaces by means of rubber pipes. The spindle adjusts the quantity of oil, and a cock on the spindle the amount of air entering the furnace.

The disintegrator is composed of an outer barrel with a gland at one end, through which the air spindle is made to pass. At the other end a cap, with a small hole in its centre, is screwed on. The end of the air spindle is close to the cap, and the hole in the spindle is opposite that in the cap. At this point the oil is disintegrated by the air. By moving the spindle nearer to, or further from, the nozzle or cap, the quantity of oil entering the furnace can be regulated at will.

If a little dirt should at any time stop the flow of the oil, all that is necessary is to partly unscrew the spindle, and the obstruction is carried away by the oil. The disintegrator is fixed to the furnace.

As in the Lucigen, so in the improved burners, the full pressure of the air (15 to 20 lbs. per square inch) is exerted on the oil. Separate oil tanks, for the sake of convenience, are used for each furnace, and they may be placed at any distance from it.

No fixed rule can be laid down as to the most suitable size of furnace. Our experience shows that the best results for economy and efficiency are obtained from one of medium size. Varying circumstances, however, may determine a preference for exceptional sizes; thus, it is found to be best to make very small furnaces for use on the lifting platforms, and the more so inside the tubes.

When building the main piers, not the least troublesome form of labour, represented by Vulcan's stirring young sons, was reduced 50 per cent. by the placing of these small furnaces inside the vertical columns. These displaced a large number of hand fires. The expense was lessened, the trouble was reduced, and a larger number of better heated rivets were available for the increasing numbers at that time being closed by the machines. It has not been under exceptional circumstances alone that these furnaces have proved useful.

On land they have even been more serviceable. In one case there is at present a single furnace doing the work of three coal heated furnaces, and this at an expense, in oil, only equal to the outlay entailed with one of the coal type. In this furnace the number of rivets heated in a single day varies from 3000 to 4000. The oil required to heat this number is about 3 gallons per hour. In other cases, where there is only one riveting machine to each furnace, the quantity of oil used per hour is a little over 2 gallons, the number of rivets ranging from 600 to 1500.

At the Forth Bridge, coal furnaces for heating rivets have long ago become a thing of the past, and this new application of oil for heating rivets led to the introduction of this form of heating in the smithy. Here the results obtained in the heating of angle and other bars have been very satisfactory.

At first one of the rivet heating furnaces was used, with some slight alterations. It, however, soon gave place to one of a new design, double the length of the rivet furnace, fitted with a disintegrator at each end, and having its funnel in the centre. The doors and other parts were also altered to suit the new conditions.

The work got from this furnace is more than double that from an ordinary smith's fire, and is of a superior quality, and done at less cost for fuel. Whether the man who wrote the word "Rocket" in bold letters on the first furnace after it had been removed from the smithy, and was replaced by one of a newer pattern, is a prophet or only a wag, of this we are certain, that while coal will still hold its own for most purposes, there is a great future for the natural and artificial oils of the world in the direction I have just been indicating.

In conclusion, I desire to say I feel, somewhat, how far short, I have come, of giving you a complete record of the work of erection thus far accomplished. My excuse, however, is that to have done this thoroughly, would have taken up more of your time than is desirable in connection with one paper. I need hardly remind this meeting that Sir John Fowler and Mr Baker are the engineers of the undertaking, and that Mr William Arrol is the responsible contractor for the carrying out of the scheme.

In the discussion on this paper, on 21st February, 1888,

Mr **Thomas Kennedy** asked if it were not possible to apply oil furnaces on a larger scale than had been done at the works on the Forth Bridge? His firm had lately built a brassfoundry, and had introduced into it the Wilson producer, but they had not the means of regenerating the gas, and of course the result was very poor. Consequently they had tried the use of oil under the Lucigen plan, but it was not very successful. They had tried to melt brass with a No. 16 pot. They did not blow on to the cold pot, but formed a brick line round it, and blew the oil and air round this, bringing it into contact with the crucible afterwards, so that some measure of regeneration took place, but the result of their experiments was not very satisfactory. The oil cost 1½d per gallon. They had 30 lbs. of metal in the crucible, and on the average of two tests they had used 2¾ gallons; which made the cost of fuel 1s 1d per cwt., which scarcely got the heat up to what was necessary. Now, they were using splint coal at 9s and char at 12s per ton, and that made the cost of melting gun-metal and brass 8d per cwt. on the average of three months. This included the re-melting of gates, which, in their case, he took to mean a fifth of the whole. It appeared to him there was no question if they could use oil satisfactorily it would be a great convenience, as they could shut it off whenever they were done with the work; and he had no doubt that as it suited well for small things, such as rivet furnaces, it might be made applicable to larger purposes, say the melting of large masses of metal.

Mr **Biggart** said at the Forth Bridge Works they had done more with oil than heat rivets. He had mentioned in his paper that they also heated bars by its use, although he believed he had not given many results thereof. With the ordinary smith's fires, he found that in the heating of bars it was only possible to do 50 bars, or 100 ends, per day; but in the new oil furnace they heated from 100 to 120 bars daily, or over 200 ends in an ordinary working day. They paid at present 1d per gallon for the oil, and did more than double the work obtained with the ordinary smith's furnace, at 50 per cent. less for fuel for a given quantity of work than could be done in the ordinary smith's fires. The oil furnace easily gave all the heat required, it was cleaner, and more handy, so that all round by its use there was a saving both as to speed and economy. He had no doubt but that heating by oil might be extended to a great degree. They were contemplating making some further experiments on the subject of the use of oil furnaces at the Forth Bridge, but he could say nothing more definite in the meantime.

On the motion of the PRESIDENT, a vote of thanks was then passed to Mr Biggart for his valuable paper.

Mr LIDDELL exhibited and explained a model of Mr Chambers' new form of Unsinkable Semi-Collapsible Life Boat. He stated that Mr Chambers claimed for his boat advantages in stowage, in easy launching, and in buoyancy. It was divided into forty water-tight compartments, which were really two longitudinal bulkheads giving strength to the structure, and divided into twenty water-tight compartments on each side of the boat; it was most difficult to capsize, even by the combined efforts of forty men, as shown by experiments by Board of Trade officers; and that even if such an accident did occur it would form the best life raft that had yet been produced, all the forty men being able to sit on its bottom.

On the motion of the PRESIDENT, Mr Liddell was accorded a vote of thanks for bringing this invention before the members.

On the Stability of Yachts.

By Mr W. D. Archer.

(SEE PLATES XIV., XV., AND XVI.)

Received and Read 21st February, 1888.

The question of the stability of ships is one that has received perhaps more attention than any other problem of naval architecture during the last few years, and the stability of yachts has been by no means neglected. The matter has, however, been treated to a great extent from the point of view of range of stability, or safety against capsizing, and it may therefore be of interest to consider the question of initial stability, or the sail carrying power at moderate angles of heel.

Until a very recent date, yacht designers have been hampered by a measurement rule which made the nominal tonnage of a yacht depend solely on the length and breadth: being thus to a great extent restricted in the employment of *breadth* to afford stability, and driven to the alternative of great draft and a heavy lead keel, there has not been much inducement to examine the comparative values of the two different means of affording stability.

Within the last two years, however, the Yacht Racing Association has adopted, after much deliberation, the following measurement rule—

$$\text{Tonnage} = \frac{L \times A}{6000},$$

where L is the length on load water line, and A is the sail area calculated from certain definite measurements of the spars. It may also be mentioned that the rule of the New York Yacht Club, under which the recent international matches have been sailed, is as follows—

$$\text{Length for rating} = \frac{2\,L + \sqrt{\bar{A}}}{3}.$$

Under either of these rules a designer is perfectly unfettered as to the means he shall employ to provide sufficient stability to carry a given sail area; and it becomes a most important point to determine the form and size of midship section which shall do this, and at the same time offer the least possible resistance to the motion of the yacht under average conditions of weather. When, however, we consider how impossible it is to take account of all the different features of the case, depending as they do on varying conditions of wind and sea, it will be seen that it is hopeless to attempt any definite solution of the problem by mere abstract reasoning unaided by the results of practical experience; it may, however, be none the less useful to consider the main elements of the case, so that we may be enabled to analyse and if possible interpret the results of actual yacht racing.

PRINCIPLES OF STABILITY.

Before going any further, it may be convenient to recal briefly the general principles of the stability of ships, which will be found fully explained in a paper "On the Stability of Ships at Launching," read before this Institution by Mr J. H. Biles in 1883. The forces acting upon a ship when floating at rest in still water may be divided into two sets: the first is equivalent to a single force, W (Fig. 1, Plate XIV.), equal to the weight of the ship, and acting vertically downwards through the centre of gravity, G; the second set consists of the pressure of the water upon the ship's bottom and sides, and is equivalent to a single force, W, also equal to the weight of the ship, acting vertically upwards through the centre of buoyancy, B, which is the centre of gravity of the cavity occupied by the immersed part of the ship. When the ship is upright these two forces act in the same vertical line, and being equal impart no motion to the ship. When, however, the ship is heeled over by a horizontal force, the point, B, moves outward, as shown by B_1 on the diagram, and the two forces form a couple which tend to restore the ship to the upright position. The magnitude of this couple is represented by the product of the weight and the perpendicular distance, GZ, between the lines of action of the two forces, or by W × GZ. On reference to Fig. 1, Plate XIV., it will be seen that the vertical through B_1 cuts the centre line of the section at the point, K, and that the righting lever, GZ, is equal to GK × sin a, where a is the angle of heel. When the angle of heel is very small, the two lines intersect at a certain definite point, M, which is called the metacentre; for small angles, therefore, the moment of stability is given by W × GM × sin a, and even up to 10 or 15 degrees the moment is given with sufficient accuracy by this expression, which is seen to depend for a given angle solely on the weight of the vessel and the heights of the centre of gravity and the metacentre. The height of the centre of gravity depends of course solely on the vertical distribution of the weights in the ship; the height of the metacentre, on the other hand, is quite independent of the weight, and depends entirely on the form of the immersed part of the hull, any increase in the breadth having a very great effect in raising the metacentre. This is well illustrated by Figs. 2 and 3, Plate XIV., which show the positions of G and M, which have been estimated for two yachts of the extreme English and American types, designated A and B respectively. The effect of the height of G upon the range of stability is also shown by the curves of stability for the same yachts on Plate XIV.

STABILITY CURVES.

These curves represent in the usual way the variation of the righting lever, GZ, with the angle of heel.

The curve marked A is for an iron or steel yacht having the same midship section, and approximately the same vertical distribution of weights, as the "Galatea." It is given, however, not as the curve of any yacht actually afloat, but as indicating the sort of curve that can be obtained in this type of vessel when every care is taken to keep the centre of gravity as low as possible.

The curves marked B are for a yacht of the extreme skimming dish type as far as form is concerned. The curve B_1 has been calculated on the assumption that the yacht is built of iron or steel, and that the lead ballast is stowed as low as possible. The weight of sails and spars is taken in this case to be the same as for the yacht A, so that the curves B_1 and A may be taken as affording a comparison of the stability of the two different forms ballasted and rigged in the same way. The curve B_2 has been drawn to show the stability of the same yacht with the weight of spars and sails increased about 50 per cent, to correspond to the greater sail carrying power of the broad and shallow type, the ballast has also been raised one foot, so that the curve B_2 may be taken to represent the stability of the type B, without any extraordinary precautions to secure a low centre of gravity.

The curve B_3 represents the stability of the type B rigged as in B_2, but with the whole of the ballast raised to the same height as the centre of gravity of the hull, and probably more nearly represents the actual stability of many American centreboard yachts than either B_1 or B_2.

The curve which is obtained by using the formula $GZ = W.GM. \sin a$ is shown in each case by a dotted line, and the angle at which the edge of the deck is immersed is marked on the diagrams. It will be noticed that up to this angle the actual curve very nearly coincides with the dotted curve, and that in the case of the yacht A the coincidence is exact.

MEASURE OF SAIL-CARRYING POWER.

In preparing this paper some difficulty was found in deciding upon what should be taken as the most fair measure of the stability of a yacht for the purpose of racing. It was first assumed that the product of displacement and metacentric height would be a sufficiently true indication of the stability, but in considering different types of yachts, with widely different proportions of beam to depth, it is evident that the actual working angle of heel is so different in yachts of extreme types as to introduce a considerable error. It has therefore been assumed that the extreme angle at which a yacht is sailed in racing is that at which the deck edge becomes immersed, and that the mean angle at which she is sailed, taking light winds with strong, is one half of the above angle, so that the sail-carrying power for racing purposes is given by

$$W \times GM \times \sin \frac{a}{2},$$

where a is the angle at which the deck edge becomes immersed.

RESISTANCE.

To return to the special subject of this paper. If we suppose a designer to be engaged upon a yacht of given tonnage by the above Y.R.A. rule, and to have fixed upon the length and sail area which he considers most suitable, and the product of which determines the tonnage, his next step will be to determine what amount of stability should be provided to carry the sail, and also what form and area of midship section will provide the requisite stability and at the same time offer the least possible resistance to the motion of the ship at the average speed of sailing. Before proceeding to determine the stability which is afforded by various forms of section it will be necessary to consider what elements in a yacht of given length chiefly affect the resistance.

The resistance of a ship according to recent investigations on the subject is due to two distinct causes—first, the frictional resistance of the skin of the vessel; secondly, the wave-making resistance caused by the disturbance of the surface of the water. The accepted formula for frictional resistance is as follows :—

$$R = c \times S \times V^m,$$

where S = the area of the immersed surface of the ship;

V = speed;

c is a co-efficient depending on the roughness of the surface, and also on the length of the ship;

m is an index which varies somewhat with the roughness of the surface, but is approximately equal to 2.

According to this formula, for the purposes of this paper, the frictional resistance may be taken to depend solely on the area of the immersed surface, since the length and the nature of the surface are constant. The wave-making resistance is by no means so easily determined, but it is reasonable to suppose that it is affected by the form of the ship in the vicinity of the water-line to a greater extent than by those parts at a considerable depth below the surface, and there is no doubt that an increase of breadth beyond a certain point usually produces an increase in resistance, unless this change is accompanied by others tending to reduce the resistance.

It is important to notice that any change in the weight or displacement of a ship does not directly and of itself affect the resistance of the ship, but only indirectly, according to the laws of resistance noted above.

STABILITY DIAGRAM.

In order to determine the effect on stability of different forms of midship section, the four yachts C, D, E, and F (of which the leading dimensions are given in the Table, Plate XVI.) were taken as a basis for calculation. Each of these yachts has an immersed area of midship section of 115 square feet; the length of each yacht was taken as 85 feet, and the displacement as 160 tons. The ratio of beam to draft amidships in the four cases is ·25, ·5, ·75, and 1·0 respectively. The height of G and M was calculated for each of these yachts upon certain assumptions to be afterwards specified, and the weight of hull, ballast, and spars is given in the Table for each case. The value of the metacentric height, or GM, could be then deduced, by a simple geometrical rule, for midship sections of any size but of similar form to one of these four, and is assumed to be independent of the length of ship. The results of these calculations can be completely represented only by a surface, as there are three variables involved, viz.:—The immersed area of section, the proportion of draft to beam, and the initial stability; but they are more conveniently shown by the series of curves marked righting moment (Plate XVI.).

Along the line of abscissæ is set off a scale of ratios of draft to beam, and each curve represents, for a certain definite immersed area of section, the variation of the product

$$W \times GM \times \sin\frac{a}{2},$$

where a is the angle at which the deck edge becomes immersed.

The effect of a variation of the length of ship is nearly to increase the displacement W, and is allowed for by employing a vertical scale which varies inversely as the length, as shown on the diagram. The curves marked "immersed girth" represent, each for a definite area of section, the variation of the girth with the ratio of draft to beam; and the absolute values of the beam and draft are also shown on the diagram. The object of this diagram is to represent, in a graphical form, the immersed area, and the ratio of beam to draft, of the endless varieties of midship section which are capable of affording a given sail-carrying power, subject to the assumptions before mentioned; and also to represent the immersed surface and the absolute beam and draft involved in the selection of any one section, so that some estimate may be made of the comparative resistance of the various forms. Before proceeding to examine these curves more fully it may be well to specify the assumptions on which they are based.

ASSUMPTIONS.

1. *In estimating the height of the metacentre* for the various types it was assumed that ordinates at corresponding points of the length, and of the draft, bear a constant ratio to the extreme breadth. On this assumption the height of the centre of buoyancy bears a constant ratio to the draft, and the value of BM is a function of $\frac{(\text{breadth})^3}{\text{immersed area of midship section}}$: by these formulæ the height of the metacentre for the different types was determined.

2. *The height of freeboard* has been assumed to be the same with a given immersed area of midship section, whatever the beam and draft may be. It has been taken as 3½ feet for

an immersed area of 115 square feet, and it has been assumed to vary as the square root of the immersed area.

3. In calculating the height of the centre of gravity for yachts of a given length but different form of midship section, it has been assumed that the weight of hull varies as the girth of the midship section, and the height of the centre of gravity of the hull has been taken at a constant proportion of the depth. The weight and centre of gravity of the spars and sails have been determined so that the moment of the weight of the spars and sails about the L.W.L. is proportional to the sail-carrying power estimated as described above by

$$W.GM. \sin \frac{a}{2}.$$

The remainder of the displacement has been utilised as ballast placed as low down as possible, the yachts being supposed of steel or iron in each case.

4. In passing from a yacht of given immersed area of midship section to one of a different area, but exactly similar in under-water form, and of same length, the height of centre of gravity has been assumed to vary as the dimension, or as the square root of the area, which, if the weight of sails and spars be taken to vary as the (sail area)$^{\frac{3}{2}}$ involves the assumption that the area of sail varies as the immersed area of midship section to the power $\frac{3}{5}$.

5. A variation in the length only has been assumed not to affect the height of the centre of gravity, which involves the assumption that the sail area varies as (length)$^{\frac{4}{5}}$ when the midship section is of constant size and form.

Of these assumptions the two last appear to be open to objection, and it has been found that in passing from the exemplar yachts, which formed the basis of the calculations, down to yachts of 3-tonner size, the weight devoted to the sails and spars is considerably greater than accords with the usual practice. But within the limits of size treated of in this paper the error involved owing to the assumption 4 cannot be of importance; and since the comparison is between yachts of the same length, the last assumption does not affect the matter as between ship and ship.

In order to give a definite illustration of the application of the curves (Plate XVI.), I have supposed that a yacht is to be designed having a length on L.W.L. of 85 feet, and a given sail area say of 8000 square feet; that the designer requires to carry this sail a stability represented by a righting moment of 130 foot tons at an inclination of $\frac{a}{2}$ (where a is the angle of immersion of deck edge). It will then be his object to determine, if possible, what form and size of midship section will provide this sail-carrying power, combined in the highest degree with the other qualities which go to make success in yacht racing, and the chief of which is a minimum of resistance. The straight line MM is drawn across the diagram at a distance from the base line which represents 130 foot tons to scale. This line intersects the righting moment curves for 120, 110, and 100 square feet at the points A, B, and C respectively, and on drawing vertical lines through these points to meet the corresponding curves of immersed girth at G_1, G_2, and G_3 a curve GG can be drawn through these points, which represents the variation in the immersed girth for a given moment of stability of 130 foot tons. In the same way curves BB and DD can be drawn representing the variation of beam and draft respectively always for a given righting moment or sail-carrying power, but for varying values of the ratio of $\frac{\text{draft}}{\text{beam}}$. A curve of displacement is also shown on the diagram. It is interesting to notice that the curve of girths GG falls steadily as the ratio of draft to beam is decreased until the ratio ·3 is reached, when it takes a decided turn upwards again; while the curve BB rises uniformly, but takes a sharp turn upwards at about the same point.

To show the effect of the curves in another way, the dimensions have been lifted off the curves, at the ordinates giving a ratio of draft to beam of ·25, ·5, ·75, and are shown under the headings G, H, and K respectively in the Table on Plate XVI.; while the midship sections for the same three yachts are given on Plate XV., together with a midship section of the "Galatea" and one of the "Volunteer,' which has been copied from a daily paper of last year.

On comparing the breadths and immersed girth of the three yachts G, H, and K, it is found that on passing from K to H the beam is increased 18·2 per cent., while the girth is decreased 7·8 per cent.; while in passing from H to G the beam is increased 22·3 per cent., and the girth is decreased only 5·4 per cent.

In estimating the comparative values of different forms and proportions, even for the sole purpose of match sailing, there are, of course, many points to be considered of which these curves take no account, and before attempting to draw any definite conclusions from them it will be necessary to take these into consideration and if possible make a due allowance for them. An exceedingly important quality which has been left out of account is that of lateral resistance as influencing weatherliness. The deeper types could be sailed without a centreboard, but whatever the merits and faults of this contrivance may be, the shallower types could not possibly be sailed with success without it, and the additional resistance caused by the centreboard would have a material effect in neutralising the apparent advantage of the shallower types in their smaller immersed surface for a given sail-carrying power. The effect of this has been indicated approximately in the case of the curve of girths for 130 square feet by the dotted line on the diagram.

On the other hand, it must not be forgotten that in calculating the righting moment curves, shown on the diagram, the yachts have been assumed to be not at the same angle of heel, but, as already explained, at half the angle at which the deck edge is immersed, and this angle varies from 13½ degrees for the extreme deep type to 7 degrees for the extreme shallow type. There can be no doubt that a considerable decrease in lateral resistance would take place in the case of the deep types when heeled to 13 degrees as compared with 7 degrees.

With regard to the relative importance of frictional and wave-making resistance, it is of great importance to form some idea of the average speed at which yachts of a given length sail through the water. At very low speeds the resistance is almost entirely frictional, and varies approximately as the square of the speed; but as the speed is increased beyond a certain point the wave-making resistance becomes the greater element of the total resistance, and increases in the ratio of the fourth or even fifth power of the speed. The value of the speed at which this sudden increase in the wave-making occurs may be taken for vessels of similar type to vary as the square root of the length, and without pretending to any exact information on the subject, the speed in knots will be roughly from $\frac{8}{10}$ to $\frac{9}{10}$ the square root of the length in feet. Applying this rule to a yacht 85 feet in length we get for the speed beyond which this rapid increase in the wave-making takes place from 7¼ to 8¼ knots. Quoting from a writer in *Engineering*, the mean speed of the three yachts "Thistle," "Irex," and "Genesta" in a number of matches during May and June last year, on such various courses as the Thames, the Channel, and the Clyde, is found to be 6·79 knots; while the highest mean speed for any one race is given for the "Thistle" as 10·6 knots. This speed has apparently been estimated on the basis of the length of the course, without making any allowance for the greater distance covered in beating to windward, so that the actual speed through the water would be somewhat greater than given above. Although the data given above are far from sufficient to determine the actual mean speed, they indicate that the average speed of large sailing yachts is somewhat less than might be supposed, and is probably within the critical point which has been mentioned above. With regard to the smaller classes the information which has been collected by the same writer, and which extends over the entire season of 1887, shows that their speed is relatively greater, the means for several boats about 25 feet long being nearly equal to the square root of the length.

With regard to the limitation of speed due to wave-making, I have the advantage of a communication from Mr R. E. Froude, to the effect that the results of model experiments upon the comparative resistance of the deep and shallow type, with equal length and skin area, show that the sudden turn up of the resistance curve due to transverse wave-making is much more marked in the deep than the shallow type. Mr Froude also states that some experiments made on the resistance of models of these two types at very low speeds show that the ratio of resistance to skin area very considerably decreases with increase in the ratio of draft to beam, which indicates that the frictional resistance per square foot of immersed surface is less in the deep than the shallow type. This is a refinement on the formula for the frictional resistance given above, and is probably not generally known. I am indebted to Mr Froude for the curves on Plate XV., which indicate roughly the comparative resistance of two yachts of the deep and shallow types of equal length and immersed surface, and I have his permission to quote the following explanation of them:—"Owing to the circumstance that all the features in the resistance curve due to transverse wave-making, of which the 'turn up' which puts the final stopper on the speed off the wind is the chief, are greatly accentuated by depth of body, it arises that the curves of resistance of a deep and narrow compared with a broad and shallow boat of equal length and skin area will be something of this kind (see Plate XV.). Hence, for example, if we suppose the effective forward propulsive force in a decent breeze to range between A and B, according to the point of sailing, the speed of the shallow boat will range from A to B and that of the deep one only from A_2 to B_2."

Another point of great importance which has not been taken into account is the immense advantage of weight or displacement, at any rate in the smaller classes, to a yacht when racing in rough water as providing sufficient momentum to carry her way. The yacht K, as shown in the Table, has a displacement of 181 tons, while B has only 126½, although the two yachts have equal sail-carrying power. In such large vessels the value of the extra displacement may not be great, but supposing each yacht to be only one-tenth the displacement given above, or 18 tons against 12½, the increased weight of the deep type yacht would no doubt be an immense gain under the conditions of sea mentioned above. This would seem to be borne out by the relatively much greater racing success of the deep cutter type as against the shallow American type when embodied in yachts of the dimensions of "Maggie," "Madge," or "Clara," than in such large yachts as "Genesta" and "Galatea."

In proceeding to draw any definite conclusions, therefore, from the series of curves shown on Plate XVI., it is important to bear in mind—

1st. That a correction must be made for centreboard resistance in the shallower types.

2nd. The fact that the frictional resistance is less per square foot of surface in the deep types.

3rd. That the excessive wave-making resistance begins at a higher speed and is less pronounced in the shallow types.

Of the two latter points, moreover, the first appears to have the greater practical effect on account of the mean speed of sailing falling below the above-mentioned critical speed.

The information which has been brought forward on these points, however, is rather qualitative than quantitative, and in the absence of more exact information I feel it would be rash to point to any one ratio of draft to breadth as absolutely the best for average conditions of racing even for any one size of yacht.

One broad deduction which occurs at once in looking at the curves is that the extremely deep type—say with a ratio of $\frac{\text{draft}}{\text{beam}}$ above ·75—which has come into vogue of late years in this country is not likely to meet with success at any rate in the larger classes.

And the form of the curves at the other end of the diagram gives no reason to fear that an extreme skimming dish type will be successful, except under special conditions, such as running and reaching in strong winds.

Any considerable departure in the direction of a decrease of draft is at present precluded by the fact that the Y.R.A. absolutely prohibits moveable centreboards; but if this artificial restriction is removed it will probably be found that success will not be confined, as in the past, to one particular and extreme type of yachts, but will be more widely distributed according to varying conditions of wind and weather, the deeper type being more successful in light winds, and even in strong winds when beating to windward, while the shallower types may be expected to show exceptional speed when running free in strong breezes, under which circumstances the highest speeds are attained.

In conclusion, I have ventured to bring this paper before the Institution, not with the idea of having found a solution of the intricate problem which has been touched upon, but rather as suggesting a method of looking at the subject, in the hope that when examined and corrected in the light of a wider experience of actual facts it may be of some practical use in yacht designing.

After the reading of the paper, in answer to the call of the President,

Mr Biles begged to thank Mr Archer for the clear way in which he had brought the subject before them; but would like to reserve anything he might have to say till next meeting.

The discussion of the paper was then deferred till next meeting.

In the discussion on this paper on 20th March, 1888,

Mr Biles, on being called upon by the Chairman, said he had had the opportunity of seeing the paper in its earlier stages, and having conferred occasionally with Mr Archer in its preparation, he was to some small extent an ally of Mr Archer in the matter. Therefore, it was almost impossible for him to say anything then, because Mr Archer had so completely covered all that could be said from the point of view that he had taken up. He thought it was the first attempt that had been made in a systematic way to attack the problem with regard to yachts in the same way that the problem with respect to steamships had been attacked; of course, yacht sailing in many respects was a much larger and more difficult question than steamship propulsion, it introduced so many more elements of variations. There was not the uniformity in the propulsive effort in a yacht that there was in a steamship, and the motion was not merely direct, but it was oblique in a more or less expressed manner, according to the direction of the wind; and therefore more difficult to deal with. Further, a question that Mr Archer had not to any extent touched upon, was the question of the method of propulsion. He thought the question of propelling a yacht was very much more difficult to deal with than was the question of the propulsive effort due to a screw propeller. But while he thought the subject more difficult, he was of opinion that they should not be deterred from attacking such a problem. In doing this and calculating the effect of a given effort, they must take all the factors into account, among which one was the best form for a yacht, and included in that was the best proportions and dimensions. It had often occurred to him that sailing yacht designers might get some ideas to help them from studying the propulsive effect of a steamship, or rather by studying why a steamship was so easily propelled, and it had struck him that if the excess of displacement in a steamship form were absorbed very largely in the form of ballast, it would be possible to produce a yacht which would prove very successful. If yacht builders would consider the displacement available for ballast in a steamship form, he thought they would see that there was an amount of propulsive power in the ballast, which had not been so fully used as it might be. He thought that was borne out by the investigations recorded in Mr Archer's paper, for he showed that the flat bottom type of yacht was likely to have the greater speed. He thought the members should note particularly the last sentence in Mr Archer's paper:—"I have ventured to bring this paper before the Institution, not with the idea of having found a solution of the intricate problem which has been touched upon, but rather as suggesting a method of looking at the subject, in the hope that when examined and corrected in the light of a wider experience of actual facts, it may be of some practical use in yacht designing." Now, he thought that it was very desirable that those members of the Institution who had opportunities—both from their knowledge of sailing yachts, and also from designing them—to follow up this line of investigation, putting into the curves, not assumed factors, but actual results, which Mr Archer had a difficulty in obtaining from want of full observation. Many of the members, he had no doubt, could analyse these curves, and find out whether there was much value in them, judged by actual results. He thought that if some of the members would do this, and come forward and give them all the benefit of their experience, either in the form of criticism or additions to the paper, then the Institution would have done some good to yacht circles in bringing this matter into a more systematic or definite shape; for he thought that at the present time it was in a very empirical form. He trusted the discussion would be continued till another meeting.

The CHAIRMAN quite agreed with the suggestion of Mr Biles, and thought that those interested in this subject should be invited to favour the Institution with their views, either by sending a note or by attending at next meeting. He proposed that the discussion be adjourned until next meeting, which was unanimously agreed to.

The discussion of this paper was resumed on the 24th April, 1888, when

Mr ARCHER thanked the members for the patient hearing they had given him when the paper was read. He was sorry that those gentlemen who were engaged in the every-day work of yacht-designing and building had not come forward to make some remarks on the paper, because what little usefulness there was in the paper would only come out when such gentlemen brought to bear on it their practical experience of the subject. He thought the new rule in yacht-sailing which had been passed and introduced during last year had opened up a very much larger field in yacht-designing than that which previously existed, and which made the tonnage of the yacht depend upon its length and breadth, and therefore restricted the model of the yachts. Possibly the time had now come when scientific methods would be more widely applied to yachts than hitherto. There was one point he would notice, in the hope that some one interested might take it up. He thought it would be very useful if the Institution were supplied with some actual curves, such as those Mr R. E. Froude had sent to him when he was preparing his paper. It would be very easy to get such curves by towing yachts. If a dynamometer were fixed upon the towing rope, and the yacht towed past the measured mile, they would obtain resistance curves the same as curves of indicated horse-power in steam vessels. He thought it was most important to know this exactly, as in conjunction with the data which they could get from actual sailing bearing on the speed of yachts in racing, it would enable them to determine what part of the resistance was due to the frictional resistance, and what to resistance from wave-making. He thought that information might have a practical effect on the designing of yachts. Such experiments had been carried out by the late Mr Froude in the case of H.M.S. "Greyhound."

The Chairman (Mr D. J. Dunlop) said he was sure they would award a very hearty vote of thanks to Mr Archer for the able paper he had brought before the Institution, and for the trouble he had taken in putting the matter in such a form before the members. With regard to the few remarks which had been made on the paper, the science of yacht-building has varied much, and he thought it would be difficult to say with certainty how to build a yacht, if one considered the changes during the last 25 years. The shallow yacht of 25 years ago had given place to a different form with lower ballasting; and now that had disappeared, and the yacht that had got the ballast outside of the hull, or on the bottom, had taken her place. In every class of yachts the best of them had done good service, and one could name boats built 25 years ago whose speed had scarcely been surpassed, so that it would be difficult to say how science was to be directed in the building of yachts. In last year's race the American yacht beat the Scotch-built one; and no wonder, for she had the advantage of the centre-board, and the further advantage of sailing more on the surface of the water. He would like to ask Mr Archer how it was possible for any resistance curves derived from the towing of yachts could be of any use in determining the speed that would be obtained in actual racing service; for it must be remembered that yachts while being towed were in an upright position and not subject to wind, whereas in racing they were heeled to various angles according to the strength of the wind, which was quite a different condition of things from the former. It had also to be noted that many yachts sailed faster on the one tack than on the other. It was difficult to explain this, as it could be depended upon that both sides were of the same form. As an example of this fact, the famous yacht "Jullanar" sailed considerably faster on the one tack than on the other. She was the best yacht of her day, and her record had not been beaten much yet.

Mr ARCHER said that he thought the Chairman had misunderstood him to say that those speed trials would give the actual resistance of the yacht while being towed at the same speed as with her own canvas. He did not intend to convey that meaning, for the yacht when sailing had many points of difference—such as leeway—which could not be taken account of in towing; but he wanted to point out that these speed trials would afford an accurate basis of comparison of different forms of yachts.

A vote of thanks was then awarded to Mr Archer for his paper.

On Liquid Fuel.

By Mr James M. Storrar.

(SEE PLATE XVII.)

Received and Read 21st February, 1888.

I do not suppose that any one present considers that the subject before us is invested with special importance by reason of any prospect of a more or less early exhaustion of our coal supply. But although, fortunately, that contingency is so remote that it sounds no present call to search for a coal substitute, nevertheless the discovery or adaptation of another substance equally or more suitable as a fuel, would be a distinct gain to the world.

The question of the utilisation of liquid hydro-carbons as fuel is of no recent origin, having been the subject of inquiry and invention for the last half-century; but the recent discovery of new petroleum fields in all parts of the world, together with the increase of residual oils produced from oil refineries, gasworks, and smelting furnaces, is now obtaining for it increased consideration. That hydro-carbon oil can be used as a fuel, and, under certain circumstances, advantageously, is not alone a matter of opinion, but also of history. For a dozen years or so the Russian Admiralty have employed it on ten or twelve steamers and gunboats belonging to their Caspian fleet, and recently have taken steps to apply it to several on their Black Sea station; and, including those belonging to Nobel's Company, over a hundred steamers plying on the Caspian and Volga use it, as do also many of the Russian railways. It is not, however, in use to any great extent either in our own country or in America.

Meantime, let us examine the mode of application and combustion. Several inventors have attempted to burn liquid fuel without the aid of steam or compressed air; but now, all who have studied the subject, agree in recognising the necessity for one or other of those being employed. All, however, are not at one as to the construction of the furnace. In the case of residual oils more than that of any other kind of fuel, it is necessary, in order to obtain the best results, that the gaseous products should be kept from contact with the boiler-plates until combustion is complete; and, to secure this end, various kinds of furnaces have been successively devised. The generality of these take the form of a modified muffle of fire-brick, into which the oil, with sufficient air for combustion, is injected, and from which the gases are not allowed to escape until they are more or less completely consumed. Whilst the main object—complete combustion—is undoubtedly attained by such furnaces, it is said that they are not, however, free from objections—amongst others, this very serious one, that the heat generated within the confined space of the muffle is so intense that no bricks can long withstand it. Mr Tarbutt's furnace, which is constructed on a different principle, is free from that objection; although, from the recorded results which have come under my notice, its evaporative powers do not seem to be so great. Nevertheless, it appears to me that it suggests the direction in which we ought to move, and I propose to describe it in detail. I use the inventor's own phraseology, and have placed on the wall an enlarged copy of the diagram which accompanies this description—"I have," he says, "adopted the principle of heating by radiation only, which Sir William Siemens found so efficient in gas furnaces. By this means any reasonable quantity of oil may be consumed in furnaces of the ordinary size without the production of any smoke, the steaming capacity of the boiler is considerably increased, and the bricks are not subjected to a destructive temperature. In applying my system to a Cornish or Lancashire boiler, the fire-bars are removed, and the bottom of the flue is lined with thin bricks. Pigeon-hole walls, A (see Plate XVII.), are built from the door along the flue to a distance dependent on the size of the boiler. At the end of the walls is a check-plate, B, and at various intervals are brick rings, C, which are in contact with the plates of the flue. On the bottom of the furnace is placed a coil of pipe, D, which is covered with thin brick slabs when the furnace is in full work, to protect it from too great heat. One end of this coil is connected to steam or air supply, and also to the starting apparatus about to be described, and the other end to the outer tube of the burner, the inner tube of which is connected with the oil tank. In order to escape from the dilemma of not being able to start the fire until steam has been raised, and of not having steam until the fire has been started, a starting apparatus is employed. It consists of a force-pump, E, and pressure-tank, F, the latter being connected, through a regulating cock to the coil in the bottom of the furnace already described. To start the fire, the coil is uncovered, and a few handfuls of wood soaked in oil are lighted upon it, and water is forced into the pressure-tank by the pump. As soon as the coil is sufficiently heated, the regulating cock, G, is slightly opened, and water is allowed to trickle into it, where it is at once converted into steam. As this cannot escape back into the tank, it rushes through the burner, H. The oil regulator, J, is then opened, and the oil is carried into the furnace by the steam, where it is at once ignited by the fire on the coil. The oil-flame now continues to keep the coil hot, and, by occasionally forcing more water into the tank, in order to maintain the pressure, the fire is kept going until steam is raised in the boiler. This occupies from three-quarters of an hour to an hour and a-half, according to the size of the boiler. The starting gear is then shut off, and, by means of the cock, K, steam is admitted from the boiler to the coil, where it is thoroughly superheated before escaping through the burner. The coil can now be covered with the thin brick slabs, and the fire is thenceforth self-feeding so long as the tank is kept supplied with oil. By varying the thickness of the brick slabs covering the superheater, according to the construction of the furnace and the intensity of the heat evolved, the steam may be safely raised to a very high temperature. The advantage of this is that the oil is thoroughly heated in passing through the burner without condensing the steam, and the latter is so greatly expanded that a much less quantity is required for injecting and diffusing the oil. From its position on the floor of the furnace, the superheater absorbs heat that would otherwise be practically lost, and hence the expansion of the steam and the heating of the oil is obtained at a minimum cost."

Mr Tarbutt's plan of obtaining steam when it cannot be had from the boiler is, I think, open to several serious objections; but it is not an essential part of the furnace, and the preliminary steam could be obtained easier and safer by the use of a small auxiliary boiler. I am also inclined to think that, to obtain perfect combustion, oil furnaces should be constructed with a gas-generating chamber from which the gases pass into the combustion chamber, such as, or similar to, the Archer furnace.

I have already said that opinion is divided as to the respective merits of steam and compressed air for injecting and pulverizing the oil; but, as our time is limited, we cannot enter into the discussion of this question, nor, under the circumstances, is it necessary. I would, however, venture to make this remark, that, on ocean-going steamers, one conspicuous advantage which compressed air has over steam is that, unlike the latter, the former does not materially increase the consumption of water, and thereby accelerate the salting-up of the boilers.

I have deemed it necessary to describe, however imperfectly, the mode of application and combustion of liquid fuel, and although perfection has by no means been reached in this department, nevertheless sufficient progress has been made to demonstrate that the non-adoption of oil as a fuel cannot justly be attributed to impracticability of application.

The real practical question now is—Is it, or is there a reasonable prospect that it can be made commercially available? And this again involves the question of supply, of which we shall speak later on.

In comparing the relative theoretical values of hydro-carbon oil and coal, it is found that the heat-producing constituents of the different oils vary almost as much as do those of the different kinds of coal; but the following, according to Mr Tarbutt, is the approximate average of the two fuels, viz.:—Coal, about 80 per cent. carbon, 5 per cent. hydrogen, 8 per cent. oxygen, the remaining 7 per cent. being nitrogen, sulphur, and ash; liquid hydro-carbons available as fuel, about 87 per cent. carbon, 12 per cent. hydrogen, and 1 per cent. oxygen. But whereas in coal a considerable part of the hydrogen is neutralised by the oxygen, being in fact present in the form of water, in oil the whole of the hydrogen is uncombined with oxygen, and, therefore, available for combustion; consequently the theoretical evaporative value of the latter is largely increased, and the comparison in lbs. of water evaporated per lb. of fuel, at and from 212° Fahr., is as follows, viz.:—Average coal, 14·48 lbs.; average oil, 20·7 lbs. In actual, practical use, however, the theoretical difference is materially increased. The hydro-carbons in coal, being in a solid state, absorb a considerable amount of heat in volatilizing; and, in the ordinary method of hand-stoking, a large excess of air is periodically admitted into the furnace, which has the effect of cooling it down, and that at the very moment when heat is most necessary. I shall not, however, enlarge upon the respective theoretical values of the two fuels, but proceed at once to place before you the records of several more or less practical trials by way of arriving at the actual working values. Admiral Selwyn (than whom there is no higher authority on liquid fuel) informs me that, in many instances, his experiments have given an evaporation of 46 lbs. of water per lb. of fuel, in the shape of oil; and adds that, under more scientific treatment, even higher results would be obtained. I do not know the circumstances under which these particular results were obtained, but, in other experiments of Admiral Selwyn's, made with a common 40 H.P. boiler, an average evaporation of 5040 lbs. of water per 230 lbs. of oil was obtained, which gives 22 lbs. of water evaporated per lb. of oil, and a consumption of ·55 lbs. of oil per indicated H.P. per hour.

The following are the results obtained under a series of experiments, conducted on two small steamships, by another expert, Mr

Henwood:—The first of these experiments was on a vessel of about 120 B.O.M. and 100 feet long. The engines were a pair of inverted, direct-acting, 12⅜-inch diameter and 16-inch stroke, working a propeller 5 feet diameter and 8 feet pitch. The boiler was an ordinary return-tubular, 8½ feet diameter and 7½ feet long, with two furnaces, and having 24 square feet of grate and 480 square feet of tube surface. The results showed a rate of evaporation of 30 lbs. of water per lb. of oil, and a consumption of 55 lbs. of oil per hour when the engines were indicating 78 H.P., and hence a proportion of ·7 lbs. of oil per indicated H.P. per hour. The second experiment was conducted on a steam launch, 38 feet long over all, by 7 feet beam and 3 feet draught of water. The engine had a single cylinder, 7 inches diameter by 8 inches stroke; the boiler was of the marine return-tubular type, 6 feet long and 4½ feet diameter, with 200 square feet of heating surface and 7½ square feet of grate surface, designed to supply steam at 100 lbs. pressure, and built according to Lloyd's requirements. The launch was first run with coal, and then with oil fuel, and the respective results were as follows:—

	With Coal.	With Oil.
Mean speed with and against tide, -	7·2 knots	8·1 knots.
Mean revolution per minute, - -	246	288
Mean working pressure, - - -	100 lbs.	102 lbs.
Mean indicated H.P., - - -	20	23
Consumption of fuel per hour, - -	140 lbs.	55 lbs.
Price per ton, - - - - - -	20s	—
Quantity of coal carried (say 9 hours' supply), -		12 cwt.
„ oil „ („ 24 „), -		12 cwt.

The recorded results (so far as I have been able to obtain them) with Mr Tarbutt's furnace—that which I have described—are not numerous, and are not altogether so favourable to oil fuel as those which I have already given, or as others which follow. A series of trials made on a small steamship at Newcastle gave an evaporation of 15½ lbs. of water per 1 lb. of oil, as compared with 7½ lbs. of water per 1 lb. of coal. The steamship "Himalaya," which was fitted up by Mr Tarbutt to burn oil, and which ran on oil fuel from London to Grangemouth and back, gave such unfavourable results that they were not published. Several land boilers have also been fitted up by Mr Tarbutt to burn oil fuel, the majority of which are still working, and I am able to give the result over a fortnight's run of one of these—a Robey boiler—which was, that one ton of oil was found to perform the work of 2·6 tons of coal. In another case, the user himself informed me that, from several months' experience, he found that one ton of oil was equal to three tons of coal at 6s 6d per ton.

To turn to Russia and railway locomotives. Mr Urquhart, in reporting upon the use of oil on certain Russian railways, states that the combustion is smokelessly perfect, and that a practical evaporation of 12 to 13½ lbs. of water per lb. of oil was attainable, and gives the following comparative record of coal and oil consumption, being the average result of twelve months' experience, viz.:—

		Fuel per mile.
On 8-wheeled locomotive, with coal,	-	81·43 lbs.
„ 8 „ „ „ oil,	-	45·83 „
„ 6 „ „ „ coal,	-	57·25 „
„ 6 „ „ „ oil,	-	32·23 „

or 44 per cent. less oil than coal in both classes of locomotives.

I desire to put before you one more record of results from practical working—those obtained on three large freight and passenger ferry-steamers, belonging to the Central Pacific Railroad Coy., and plying on San Francisco Bay. In the case of the "Thoroughfare," the comparison is made as between the experience of twelve months and 22,662 miles run with coal and twenty months and 40,800 miles run with oil, and the result was that 4½ cwt. of oil did the work of 20 cwt. of coal; or, to state it in another way, the weight of oil fuel required was only 21½ per cent. that of coal. In the case of the "Piedmont," a much larger steamer, the trial was over nine months and 43,525 miles run with coal and eleven months and 44,307 miles run with oil, and the result was 10 cwt. of oil against 20 cwt. of coal, or 50 per cent. And, in the case of the "Solano," the largest steamer of the three, the record was taken over fourteen months and 7504 miles run with coal and seventeen months and 7308 miles run with oil, and the result was 7 cwt. of oil to 20 cwt. of coal, or 35 per cent. Overhead on the three vessels 7 cwt. of oil did the work of 20 cwt. of coal, thereby effecting an average saving in money of 22 per cent.—17½ per cent. in the cost of fuel, and 4½ in stoking. Owing to coal being cheaper and oil dearer in this country than in America, the same experience here would not, however, have the same happy financial result. As regards the rate of speed overhead, it was practically the same with the two fuels: with oil it was slightly under in the case of the first two steamers, and slightly over in the case of the last. The general master mechanic accounts for the results from oil, in the case of the "Piedmont," being so much poorer than those of the other two vessels, by the fact that the boiler of the former was of a different and unsuitable design. Doubtless the combustion of the oil must have been less perfect in the case of the "Piedmont"—probably, to a great extent, arising from the construction of the boiler. The master mechanic states further that, "during the time the different boats were burning oil, we were not called upon to make repairs on the boilers; while, when burning coal, there is not a week when more or less repairs are not necessary." I may add, however, that, notwithstanding these very favourable results, the Central Pacific Railroad Company have discontinued the use of oil, and reverted to coal. The only reason which I have seen assigned for this apparently foolish step is, that the Company, being owners of an extensive coal mine, coal steamers, &c., wish to support their own industries.

I do not claim that the practical trials, of which I have now submitted the results, authoritatively determine the relative steam-raising powers of hydro-carbon oil and coal, but they give a more or less valuable indication. Some authorities claim that oil does the work of three times its weight in coal; but, whether or not that be an over-estimate, I think that it cannot well be disputed that it is at least equal to 2½ its weight in coal. Further, it does not follow that oil must be had at a price less than 2½ times that of coal to be of any advantage. There is to be remembered the great saving in stoking, and, in the case of steam-ships, the further very important gain in cargo space, and that not alone because of the less quantity of fuel required, but also because oil can be stowed where coal cannot. By way of example, let us see what the "Etruria" would show under oil compared with coal. When her engines are working at their maximum (14,500 indicated H.P.), she uses from 300 to 310 tons of coal per 24 hours; and, assuming that she carries seven days' fuel on both her outward and homeward trips, with coal she would require to carry 2100 tons, and with oil only 840 tons; thus setting free for cargo an area sufficient to accommodate 1260 tons (I leave out of account any possible additional gain of cargo space, by reason of the oil being capable of being stowed where neither coal nor cargo can). I do not know the average rate of freight presently obtained either for the outward or homeward voyage, but I do not think that I am over-estimating when I take the former at 15s and the latter at 30s, together 45s per ton, which, on 1260 tons (the space reclaimed for cargo), amounts to £2835. To this falls to be added the saving on stoking charges. With coal, the "Etruria" requires 72 firemen and 36 trimmers; whereas with oil no trimmers would be required, and 18 firemen would be sufficient; the resultant saving in wages and rations being somewhere about £500 on the round trip, which, added to the gain in cargo space already stated, makes a total of £3335; and, taking twelve double journeys per annum, the yearly saving in these two directions would be £40,000—an imposing sum. Assuming this comparison to be accurate, and to be a fair average measure of what might proportionally be realised in steam-ships generally, it follows that if hydro-carbon oils could be obtained at, or less than, 2½ times the price of coal, their use would be a great and manifest pecuniary advantage. And this leads to the question—Can oil be obtained at the price just indicated, and that in sufficient quantity? Here we touch the vital point of the Liquid Fuel question—the Supply. The present output in Great Britain of hydro-carbon oils of all descriptions and from all sources—gasworks, shale-oil works, and blast furnaces—is utterly inadequate. Were every pound produced to be devoted to use as fuel, by steam-ships, there would scarcely be enough to supply the requirements of 25 steamers similar to the "Etruria;" and, so long as that is the condition of the supply, it is unnecessary to discuss the question of cost. It may be said—"What of the immense yields from the oil-wells of Russia and America?" I answer that, large as they are, they are nothing compared to the requirements of steam-ships, if oil is to take the place of coal entirely. Besides, I consider that it would be unwise for us to allow either our war or merchant ships to be dependent upon foreign countries for their fuel supply. Nor would we need to do so did we adequately develop our own resources. According to Admiral Selwyn, there exists in this country more oil-producing shale than all the coal which has yet been found. There are beds of shale stretching right across England, varying in thickness from 650 to 1100 feet, and lying close to the surface. Different samples of this shale have been analysed at various times by eminent chemists, and the yield of oil has varied from 50 to 120 gallons per ton, which, even at the lower figure, would give a practically unexhaustible supply.

Assuming these statements regarding the supply of shale to be correct, at what price could the crude oil be obtained? It would require to be, and certainly could be, produced at less cost than is the crude oil from our present Scotch shale. Lying near the surface, and in seams of immense thickness, it could be worked open-cast instead of by mines, and the cost of winning thereby very greatly reduced; and, containing 50 gallons of oil instead of 26 to 28 (the average yield from Scotch shale), a proportionably less quantity of shale would require to be handled to obtain one ton of oil, and consequently the cost of retorting would be little more than half. I estimate that a ton of oil from such shales would cost somewhere about 25s, varying with the rate of lordship and other conditions. This, of course, is the cost naked at the producing work, and to that figure would require to be added the cost of transit to the ship's side, or other destination—where practicable pipe-lines would require to be laid down to the principal ports and centres of consumption, and tank-waggons employed where pipes are not available. With either of these modes of transit the cost of delivery would not be great, even were the distance considerable. Indeed, I think it would be safe to estimate the cost, at the principal ports of the United Kingdom, at from 30s to 35s per ton. At this figure, against coals at their present prices, the use of oil on steam-ships would be a considerable economy, when the saving in stoking charges and stowage-room is taken into account. But it may be said that, when oil comes into competition with coal to any appreciable extent, the price of the latter will fall. That is impossible, unless in a very limited degree; because miners' wages, and other mining expenses, as well as the coalmasters' profit, are presently at, or very near, the lowest possible point.

But, assuming that an adequate supply of hydro-carbon oils were obtainable, and at a sufficiently low cost, one drawback to its use for steam-ships would still remain, viz., the element of danger. Let the main bulk of the oil be stowed where it may, the reservoir, from which the supply runs to the burner, must be situated above the level of the furnace; and, in the event of the reservoir being ruptured by collision, or otherwise, it would empty itself, in all probability, into the stoke-hole, and the result, I need not say, would be disastrous in the extreme. That this is merely a constructive difficulty, which might readily be overcome, is a point on which I, of course, can have no opinion.

One very important advantage which liquid fuel has over coal, upon which I have not dwelt, but which cannot well be overestimated, is its smokelessness. In this connection I will venture to make only one remark by way of suggestion. The authorities ought to make the use of oil-fuel compulsory on all river steamers, and thus remove from our beautiful river the mantle of smoke in which it is so frequently enveloped. If the authorities do not presently possess that power, they ought to lose no time in acquiring and exercising it.

I have not said anything regarding the use of liquid fuel for land boilers, because, owing to the saving in stowage space being non-existent with them, it is questionable whether any pecuniary advantage would result. It goes without saying, however, that its use in that department would be an unqualified blessing to the inhabitants of manufacturing districts, although, possibly, the cause of diminished trade to soap manufacturers.

To sum up—

While I do not say that the apparatus for the consumption of liquid fuel is perfect, nevertheless (although I do not profess to be competent to judge) I think that sufficient progress in that direction has been attained to justify the belief that, if liquid fuel does not ultimately come into more or less general use, it will not be because of any inefficiency in the apparatus.

In the case of land boilers, I fear that, unless in exceptional circumstances, such as proximity to oil supply, or remoteness from coal supply, it is not likely to become pecuniarily advantageous.

In the case of marine boilers it may, or ought to be, cheaper than coal, when the saving in stowage space and stoking is taken into account; but, on the other hand, the element of danger may not be easily removed.

But there is little use discussing its advantages so long as the article is practically unobtainable. For the present, therefore, it is not so much a question for the engineer, the shipbuilder, or the shipowner, as for the oil manufacturer. Need we doubt, however, that in the future, as in the past, our native energy, enterprise, and skill will, in due time, surmount all difficulties, and make available for the use of man the wealth of power in the form of oil, now lying dormant in nature's great storehouse.

The discussion was adjourned till next meeting.

In the discussion of this paper on the 20th March, 1888,

Mr F. J. **Rowan** said he had of late paid some attention to the subject of the paper. Formerly the custom was to estimate the value of liquid and all other fuels from their ultimate chemical composition, but since he learned the results obtained by Admiral Selwyn in his experiments with liquid fuel he had come to be of opinion that that mode of estimating the value of fuel was at least questionable. In consequence of that he had devoted some little time to the study of the subject. He observed that Mr Storrar, when comparing the theoretical calorific value of hydro-carbon oils with that of coal, adopted the usually accepted proportion of 2 to 1; but he (Mr Rowan) thought it could be shown that the value of oil for fuel was about four times the value of that of coal, providing the oil were properly used. He thought that they would admit that if that could be substantiated it would place the value of oil for fuel in a totally different position from that which it had until now occupied. Mr Storrar had remarked that opinion was divided as to the respective merits of steam and compressed air for injecting or pulverising the oil, but that was a question which would be determined by the chemical composition of the oil and the method in which its full value for heating was to be obtained. He was of opinion that the correct way of estimating the value of oil as fuel was to take its value for gas production. In making oil gas, especially where steam was used, gas of a high calorific value was formed. The results of trials of different oils for gas-making had been published in 1886, and more recently, and they showed that gas of up to 70 candle-power could be produced from intermediate oils; and where steam was used the deposition of solid carbon in the retorts was prevented by mutual decomposition of the heavier hydro-carbons and the steam, carbonic oxide and hydrogen or lighter hydro-carbons being formed. Taking an average specimen of oil gas produced in apparatus using steam, which had a light-giving value of 56 candles, he found that its thermic value was equal to the evaporation of between 40 and 43 lbs. of water per lb. of oil used. Now that, they would observe, was more than four times the ordinary value of coal. Admiral Selwyn's experiments had given an evaporation of 46 lbs. of water per lb. of oil. He had seen Admiral Selwyn's boiler at work, and watched its operation, and although it had been frequently urged against such results that they must be due to priming, no evidence of priming could be discovered. However, it ought to be observed that the Admiral did not get such high results continuously, but he (Mr Rowan) believed that was due to imperfections in the apparatus. The fact that he occasionally got such results showed that in these special cases the condition of his furnace must have been such as to ensure the entire decomposition of the oil into gas, none of the oil being burned except in the shape of gas. He believed that that was the secret of the whole subject, and that the apparatus that would give the full evaporative value of oil had yet to be devised. If they could get from 40 to 50 lbs. of water evaporated per lb. of oil it would put oil as a fuel on a totally different and very much higher basis than it had ever held. He had recently given a paper on this subject before the Society of Chemical Industry, in which he had gone pretty fully into the matter, but he had now merely given an outline of the way in which he viewed the question. The calorific values of coal and liquid fuel had hitherto been ascribed practically to the carbon which they contained, and had been calculated on the assumption of its being burned as solid carbon of the value of wood charcoal burning to carbonic acid; but that was erroneous in the case of coal, and very much more so as regarded liquid fuel. What was required was a method of estimation founded upon the thermic value of the gas produced by the action of heat on coal, or on liquid fuel combined with steam, and this, he submitted, would give theoretical results much nearer the actual value of the oil or coal for fuel than those obtained by the rules in ordinary use.

Mr Storrar begged to thank Mr Rowan for the very clear and very serviceable remarks he had made on the subject of the paper. As regarded the apparatus for properly using liquid fuel so as to get the most power out of it, not being an engineer, he felt that he had no opinion, and did not pretend to have any opinion, beyond this, that, as he had remarked in his paper, from whatever source the fuel was obtained, the right method was to form it first into gas before burning it, and to have the gas-generating apparatus outwith the consuming furnace. That was the best way to get the greatest amount of heating power out of oil. He could not add anything further that would justify him taking up the time of the meeting, but he was prepared to go into explanatory details of all the statements he had made in the paper, and maintain the accuracy of the figures therein given.

The CHAIRMAN (Mr Dyer, vice-president) said that Mr Storrar had explained that, not being an engineer, he had not entered into the details of the mechanical arrangements connected with the subject of the paper; but now that the attention of the Institution had been directed to the subject of liquid fuel, he trusted that some more perfect apparatus would be devised for using that fuel. He would like to draw the attention of the members to the fact that a very extensive series of papers on this subject had appeared in the Transactions of the German Society of Engineers, from the pen of Prof. Busley, and that a condensed account of these papers was now appearing in the columns of the *Engineer*. Gentlemen interested in this matter would find something worthy of notice in these articles, because they were very thorough, and seemed to give good grounds for the use of such fuel, although he must say that he thought they were somewhat deficient in the theoretical side of the subject. He hoped that some of the members would contribute papers on this subject during next session.

A vote of thanks was then passed to Mr Storrar for his paper.

On the Application of Electricity to Portable Engineering Tools.

By Mr Fredk. J. Rowan, C. E.

(SEE PLATES XVIII. AND XIX.)

Received and Read 20th March, 1888.

During the period which has been dealt with in the recent interesting address of the President of the Institution, the development of engineering science has resulted in the introduction of engines, machinery, and structures in general of greatly increased power and size. This necessarily exerts a powerful influence on the methods of carrying out constructive works; in particular making it desirable to minimise the amount of moving or carrying the materials or portions of machinery in process of construction.

Competition, too, which has flourished greatly — perhaps too greatly—during the last half century, necessitates the employment of the cheapest methods of doing work, while it is at the same time imperative that precision should in no way be diminished with the cost, but rather the reverse.

Hand labour, as being in general more costly, has been superseded where possible by machine work; and as the necessity for improved quality of work has been concurrent with that of increased cheapness, and we may say, also, that of increased speed of production, a state of matters has come about which involves the sinking of large amounts of capital in machinery and tools, as well as in the workshops which these require.

A familiar example of this development is found in the construction of modern steam boilers. Improved materials have been introduced, and, generally, machines and methods of turning out work have been rendered more accurate and rapid. Punching has been almost entirely abolished, and costly drilling and riveting machines are employed, which as a rule necessitate the use of heavy cranes and more expensive buildings; so that the amount of capital required to equip a modern boiler shop is by no means a trifle. In certain kinds of constructive work, such as shipbuilding, it has not hitherto been practicable to substitute drilling for punching, except at a greatly increased cost and diminished rate of work, in spite of the acknowledged great superiority of drilled over punched work. And even in fully equipped modern workshops, it is frequently necessary to carry out operations such as drilling, tapping, and the like, under circumstances which render the application of power, under any of the older methods, extremely difficult; and in such cases hand labour is resorted to.

The introduction of electricity into engineering and shipbuilding operations is full of promise, supplying as it does a means of transmitting and applying power which is at once flexible, compact, and economical.

We may have to wait some time for the period when instead of having the present systems of shafting, pulleys, and belts, or steam pipes, or hydraulic pipes, as power distributors, we shall have, throughout workshops and yards, electrical cables connecting the various stationary and portable machines, or their motors, with the source of power, the same main cables serving also for the distribution of light and heat, but the writer looks forward to nothing less than this.

At present, however, he has the honour of bringing before you what may be considered merely as a modest beginning of that new order of things, and has to be content with showing the accomplished application of electrical force to portable machine tools and other appliances of various kinds.

The wonderful magnetic properties of the electric current are those which are called into requisition in these machines, in which they produce a variety of effects—magnetism operating both in preventing motion and in producing motion in the same machine.

In practical work these machines have shown themselves to be serviceable tools which enable labour to be diminished by substituting for the handling of heavy masses of work the more cheap and expeditious method of handling comparatively light tools.

The amount of capital required to equip, say a boiler shop, on this system is very small in comparison with the requirements of the ordinary colossal machine tools; and the usual heavy travelling cranes, sheer-legs, or other lifting appliances which are wanted where whole boilers are lifted on and off machines, are rendered unnecessary.

Drilling and tapping in shipbuilding, boiler-making or bridge-building work, and riveting, or other work at present done by hand, can be carried out economically by these machines, as they know little, if anything, of difficulties in the position in which the work must be done, and require no elaborate fixing to their work or work to them. Moreover, the power required by them can be conveyed, through the air or through tortuous passages, to a considerable distance by means of light and flexible "leads," with the minimum of loss in transmission, while the control of this power is perfect.

In shipbuilding, punching may be dismissed in favour of the more accurate and less barbarous method of drilling the plates in position, as in boiler making; and this, with its attendant results of stronger and more durable structures, is surely of as great importance to ships as it has been to boilers.

In a paper presented to the Institution of Mechanical Engineers, and read at their meeting in Edinburgh in August last, the author referred to this point, and appealed to the evidence of their own Research Committee on Riveted Joints for proof of the statement that "in plates of ½ inch and upwards in thickness, the loss in tenacity due to punching ranges from 10 to 23 per cent. of the original strength in iron plates, and from 11 to 33 per cent. in the case of mild steel."

The accompanying table of results of experiments on the tenacity of punched iron and steel plates, carried out by several independent investigators outside of the Research Committee of the Institution of Mechanical Engineers, establishes the same point and proves incontestably that punching is doomed to give way before practicable methods of drilling in all departments of work.

Table No. I.—Experiments on the Tenacity of Punched Iron Plates.

Authority.	Thickness of plate. Inches.	Width of plate. Inches	No. of holes.	Diameter of holes. Inches.	Tenacity.	Loss of tenacity in per cent. of original strength.
Barnaby	0·625	2¼	-	0·875	16·4	
	0·375	2	-	0·75	17·45	
	0·375	2	-	0·75	16·66	
Stoney	0·375	3	1	0·75	15·4	15·6
	0·375	4	2	0·875	19·24	10·2 mean
	0·375	8	5	0·875	22·22	7·4 11·45
	0·375	8	5	0·875	21·97	12·6
Fletcher	-	-	-	-	20·15	5
Kirk	1·15	-	1	1·18	15·27*	18
	1·16	-	1	1·18	15·95*	
	1·17	-	1	1·22	16·81†	8
	1·16	-	1	1·22	17·02†	
Martell	0·8	-	-		-	20 to 23
Barba	-	1·24	1	0·66	16·81	5
	-	1·95	1	0·66	16·69	5½
	-	2·62	1	0·66	15·10	14
	-	3·35	1	0·66	14·72	17
	-	4·05	1	0·66	14·79	16
Maynard	-	-	-	-	-	19‡
Barnaby	0·54 to 0·75	2·8 to 3·3	2	1·00	19·00	11§
,,	-	-	-	-	17·7	17‖
Parker	0·74	4·0	1	1·1&1·17	18·19	18·8
	0·74	4·0	1	1·1&1·32	18·93	

* Hole in die block ⅛ larger in diameter than punch.
† ,, ,, ¼ ,, ,, ,,
‡ This is loss of punched *as compared with drilled plates.*
§ Punched before shaping.
‖ ,, after ,,

Table No. II.—Experiments on the Tenacity of Punched Steel Plates.

Authority.	Thickness of plate. Inches.	Width of plate. Inches.	No. of holes.	Diameter of holes. Inches.	Tenacity.	Loss of tenacity in per cent. of original strength.
Barnaby	0·625	2¼	1	0·875	14·5	
	0·375	2	1	0·75	18·54	
Wilson	0·375	2	1	0·75	22·08	23
Kirk	0·75	-	1	1·02	17·96*	33
	0·75	-	1	1·02	11·18*	
	0·75	-	1	1·05	23·21†	19
	0·75	-	1	1·05	20·40†	
	0·25	-	1	0·75	29·10	2
Boyd	-	-	-	-	-	51
	-	-	-	-	-	35
	-	-	-	-	21·15	31
Martell	0 8	-	-	-	-	22 to 33
Barba	0·27	1·24	1	0·66	26·98	Cylindrical punching. Hole in die 0·76 in. dia.
	0·27	1·95	1	0·66	26·11	
	0·27	2·65	1	0·66	24·39	
	0·27	3·35	1	0·66	23·09	
	0·27	4·05	1	0·66	23·88	
	0·27	4·75	1	0·66	23·31	
	0·27	1·24	1	0·66	31·95	Conical punching. Hole in die 0·82 in. dia.
	0·27	1·95	1	0·66	27·85	
	0·27	2·65	1	0·66	25·25	
	0·27	3·35	1	0·66	23·27	
	0·27	4·05	1	0·66	23·57	
	0·27	4·75	1	0·66	23·98	
Barnaby (open hearth)	0·6 to 0·7	2·9 to 3·3	2	0·875 to 1	23·7	13‡
	,,	,,	2	,,	24·5	11§
,, (converter)	0·54 to 0·72	,,	2	,,	21·7	21‡
	,,	,,	2	,,	24·8	9§
Parker‖	0·687	4·0	semi-hole at each edge	$1\frac{1}{8}$ & $1\frac{3}{16}$	22·92	17·8
	0·7	4·26	1	1·1 & 1·35	24·46	12·3
	0·7	4·26	1	1·0 - 1·35	21·04	24·5
	0·75	-	2	1·09- 1·11	20·00	24·2
	0·75	-	2	1·08- 1·24	18·69	28·7
	0·75	8¼	2	1·09- 1·19	20·50	30·0
	0·75	8¼	2	1·09- 1·22	19·08	
	0·25	-	2	0·69- 0·74	29·48	8·1
	0·375	-	2	0·84- 0·94	24·06	18·7
	0·468	-	2	0·97- 1·11	21·38	26·2
	0·593	-	2	0·96 1·11	19·57	33·8
	0·75	-	?	$1\frac{1}{8}$	19·80	33·0

* Hole in die block $\frac{1}{16}$ larger than punch. ‡ Punched after shaping.

† ,, ,, $\frac{1}{8}$,, ,, § ,, before ,,

‖ The two dimensions in fifth column for these experiments are diameters of punch and hole in die block.

It is not too much to expect that, among the safeguards which are from time to time introduced for the protection of the lives continually subjected to the risks of navigation, we shall soon find a higher class given to vessels which are built with the utmost regard to accuracy of work, and by methods which conserve as much as possible the original strength of the materials of which the structure is composed. The machines here described are offered as means of attaining these ends.

The general features of the machines will be readily understood from the illustrations. Several forms and arrangements have been used, but in the main electro-magnets are employed for fixing or holding the machines or tools to their work, while the necessary motion of the tools is usually derived from electro-motors. This gives the most compact arrangement, and requires no attachment to the machine other than the one pair of electrical leads or wires which conveys the power from a dynamo or battery.

Figs. 1, 2, 3, 4, and 5, Plate XVIII., show different arrangements for drilling on this system. Fig. 1 shows a driller composed of a powerful electro-magnet AA, the yoke of which carries the framing B, the drill spindle D, with its feed gear F, and the bevel gearing reducing the speed of the motor M, which is also carried by the magnet and yoke. Fig. 2 shows a similar self-contained machine arranged for spur gearing, and having the drill spindle outside the magnet poles instead of between them, as in Fig. 1.

Fig. 3 shows a driller having a motor which may be worked by hydraulic power, steam, gas, or compressed air, and in which speed-reducing gear is not required.

Fig. 4 illustrates a machine recently constructed with worm gearing—the framing above the magnet yoke consisting of a barrel or cylinder, within which the drill spindle, the feed screw, and the worm gearing work in oil, and on the outside of which the motor is fixed.

Fig. 5 shows a driller combined with a traversing frame, which may be fastened in position by electro-magnets or by bolting. If the latter, it has been found advisable to have holding-on magnets on the drilling machine in order to take the thrust of the drill feed from the frame, which may thus be comparatively light.

Figs. 6, 7, and 8, Plate XVIII., illustrate the general form of riveter which has been made, AA being the holding-on magnets and M the motor which, by means of the gearing G and cam C, lifts the hammer H against the spiral spring S. The amount of compression given to the spring, and thus the force of the blow given by its expansion, is capable of easy adjustment by means of the disc D, which is moved by the screwed columns R and spur gearing W. The rivets are held up by another electro-magnet, Figs. 7 and 8, carrying a bolster or dolly B, which has a spring S for compensating the slight flattening of the rivet head during the riveting. The curved arm E, shown on the holder-up (Fig. 8), is intended for insertion under reverse bars of ships or into confined spaces.

Fig. 9 shows the riveter and holder-up in position when working, as reproduced from a photograph of one of the machines.

The riveter and holder-up illustrate most clearly the convenience and advantage of having a considerable holding or gripping power quickly applied and within small compass such as electro-magnets afford. In fact, in no other way is it practicable to apply machine riveting to ship-plating. Moreover, the effects of magnetic induction combine to assist in the process, for the magnets on opposite sides of the plating act by powerful attraction on each other, when their poles are properly arranged, and thus hold the work together. It would, of course, be possible to make magnets in this position act directly to close rivets by pressure, as in hydraulic machines, but it is probable that any advantage possessed by this method of riveting would be more than counterbalanced by the weight and size of the magnets necessary rendering it difficult to carry it out. The *method* of riveting is, however, not the most important point. In the paper already referred to the writer has given reasons for concluding that, "provided the plates or other materials are held together with sufficient power during riveting and during the cooling of the rivets, and provided also there is brought to bear on the rivets (either by pressure or by percussion) sufficient force to ensure their being expanded so as to fill the rivet holes completely, then the best results in ultimate strength and tightness of the joints will be realised, and no increase in either of these directions is to be expected from merely exceeding the necessary force;" and, also, that there is nothing inherent in the *mode* of riveting which interferes with the strength of the work, so that, if made satisfactory as regards tightness, riveting done by means of hammer blows is as good as that produced by continuous pressure.

For these reasons he does not think that any valid objection can be urged against riveting by means of the machines illustrated.

The magnetising and demagnetising actions, upon which the attaching and detaching of the machines depend, are practically instantaneous. The *amount* of gripping force possessed by any machine is a simple question of the size of magnets and of current, provided the mass to which the magnet is attached is of sufficient size to conduct the magnetism. In riveting work the magnets of the riveter and holder-up mutually strengthen each other, but in the case of attaching a driller to very light or thin work, such as the framing of composite or other ships, or thin tanks, or bridge work, it is advisable to make use of a second magnet and imitate the conditions of the riveting arrangement. The amount of cutting or of striking power, in the same way depends on the size and power of the motor employed.

Fig. 10, Plate XIX., illustrates a machine designed for tapping work. It is of the same general design as one of the drillers but has gear for a much greater reduction of speed of tool from that of motor, whilst it has also a reversing arrangement for withdrawing the tapping bar.

Figs. 11, 12, and 13, Plate XIX., show different forms of a tool for chipping and caulking; and Fig. 14, illustrates the method of working one or more of those upon a guide attached to the work by magnets or bolts, so as to embrace a considerable length of seam.

A general idea of the manner of applying the machines in shipbuilding is given by Figs. 15 and 16, Plate XIX. In working, however, on the side of a ship, or at bridge or boiler work, where the machines are not on a flat, horizontal surface, they are always attached to a light sling, or lifting appliance, such as differential pulley blocks, or the chain and screw used at shearing and punching machines. Under the bilges supporting guide bars are provided, such as are shown at J, J, Fig. 15. By these, or by similar arrangements of a simple kind, provision is made for changing the position of the machines when the holding magnets are demagnetised, and these slings or frames also prevent the machines falling should the electric current be cut off from them by any accident. This is very unlikely to happen in regular work, but is mentioned to dispose of any question which may arise as to the support of the machines when their magnets are switched out of circuit.

In the after discusssion,

Mr LAURENCE HILL asked if magnetism caused by the use of the magnets on the hull of a vessel had any sensible effect on the correctness of the compasses?

Mr ROWAN said that the objection indicated by Mr Hill had been raised more than once. Fully stated, it was to the effect that the plating of ships would, if operated upon by these machines, have permanent magnetism produced in them, which would in effect make the hull a large magnet to the damage of the compasses. There were two or three answers to that objection, all of which showed that such an effect was impossible. First, it was very difficult to magnetise even steel permanently, and practically impossible thus to magnetise iron. But some might reply that vessels were now built of steel. That he would answer by saying that while the material of which ships were now usually built was called steel, it was only "mild steel," which was in reality merely a very pure quality of iron, and that it would be almost impossible to magnetise permanently steel of that quality. A piece of tool steel might be magnetised, but even this would be a matter of much difficulty, and there was a very wide variation between tool steel and the material of which ships and boilers were constructed. Then the area embraced by one application of any of these machines was very small in comparison to that of even one plate, and although while one magnet was holding on magnetism would be induced in that part of the plate embraced by the holding-on magnet, as soon as the machine was moved to the next position the direction of the magnetic circuit would be reversed (by the southward pole of the magnet occupying the position previously occupied by the northward one, or *vice versa*), and the magnetism induced in the plate would thus be destroyed. Moreover, even if in one or more plates or parts of the plates of a ship permanent magnetism were induced, it would be perfectly impossible to make the hull into a huge magnet which would interfere with the action of the compasses. The objection had also been raised that the magnets would act by increasing the corrosive forces at work in a boiler; but, unfortunately for the objectors, in this objection they confounded magnetism and galvanic action. They were thinking of the electric current which is capable of producing chemical effects, but they spoke of magnetism. Now, magnetism produced no chemical effect either as to preventing or increasing corrosion, which was essentially chemical action.

Mr W. J. MILLAR (the secretary) said he had observed in testing mild steel that the pieces after being broken were found to be highly magnetised where the change of form due to extension had taken place. This magnetic property seemed to some extent to be permanent, as he had some pieces which still retained it, although fully a year since broken, and that led him to expect that wherever there had been any deformation in the material there would be a certain magnetic character established, but for how long this would be retained he could not say.

Mr COTTAM, on the invitation of the Chairman (Mr Dyer, vice-president), said he was much obliged to Mr Rowan for bringing this interesting subject before them, but thought he might have said more about the holding-on feature of the machines. He had been under the impression that very mild steel did not retain its magnetism. Of course, it was well known that very hard steel did hold magnetism. All steel and iron could be temporarily magnetised, but the softer kinds were less likely to hold it than the hard; but the rivets being put in hot would destroy the magnetism to a great extent.

Mr ROWAN hoped no one imagined that the holding magnets of these machines were permanent magnets, because in that event if the machines were once put on he did not know how they could be removed. Electro-magnets composed of soft iron could be magnetised and demagnetised almost instantaneously, and this gave the power of rapid attachment and removal of the machines. In his previous remarks he had only dealt with the supposed effect of the magnetism on the plates to which these machines were attached. Mr Millar had introduced another element by showing that magnetism endured for a time if produced by rapid and violent deformation or alteration of section, but this effect could not be present in the cases where these machines were being used.

The discussion of this paper was then adjourned till next meeting.

In the resumed discussion on this paper, on the 24th April, 1888,

Mr W. CARLILE WALLACE said that he regretted he had not been able to be present when Mr Rowan read his paper, as it was on a subject in which he was very much interested. The firm with which he was connected were at present making some trials with Mr Rowan's tools in boiler-making work. It appeared to him that since drilling was a necessity in all first-class work, and especially in steel boilers, there were many places in which Mr Rowan's drillers would be of great advantage—for example, where the furnace mouth came out into the front plate of the boiler, then to get really a satisfactory job it was necessary to drill the holes in the front plates after the furnace was in place. They had been applying Mr Rowan's driller to this work, but in the machine he first sent there was some discrepancy between the current supplied by the dynamos and that required by the motor of the machine, which did not do such satisfactory work as it otherwise would have done. There was no doubt that in work where it was impossible to do without drilling, it was often very much easier to take a machine to a boiler (especially if the boiler was 60 tons weight), than the boiler to the machine. There was a point on which Mr Rowan could throw some light—namely, the fixing of the machine on open work, such as the drilling of the side of a ship. It appeared to the speaker that there was likely to be some difficulty in placing the drill on the centre mark: it might be a little off when the magnets took hold, and, so far as he knew, there was no means for setting the drill with accuracy, so that the only thing that could be done was to release the magnets and make a fresh trial. Another thing connected with the driller was its weight. It appeared to him they should be made lighter, if possible. The machines weighed about 2 cwts. at present, so that there was some trouble in moving them about, the magnets taking up a considerable part of this weight. He thought that in some cases it would be possible to support the drill and the motor without holding-on magnets. It would be interesting to know also if it would be possible to have the motor apart from the drill and holding-on magnets, the motor being fixed in the neighbourhood of the work, and the power conveyed to the drill by a flexible shaft. If so, they might by that means be able to move the light drill about without moving the motor at all. Mr Rowan might give them some information upon that point. He thought that electricity, as a means of distributing power, was a matter to which engineers should now give a good deal of consideration, for it was rapidly coming to be a thing of everyday use, and that in a very satisfactory and economical way.

Mr ROWAN said he had no other remarks to offer except to reply to Mr Wallace. He was obliged to him for speaking so favourably of the machines, because, as he had said, the experience of his firm had so far been rather against them, but as that had been occasioned merely by a slight want of power in the motor, it was not a very serious matter. But, on the other hand, when Mr Wallace, in spite of the demand for power, wanted to have lighter machines, that put him in a position of considerable difficulty, because those machines were required to exert a really considerable amount of power. He did not know yet how power was to be obtained without weight in engineering work. When machines were wanted to drill holes, or to close rivets in iron or steel, he was afraid it was hopeless to think of getting a sufficient amount of power for such work with a machine that could be handled with one hand. As all such machines must be supported by independent slings to provide for moving them when the magnets were not in action, a half-hundredweight more or less in their weight was no great matter. Of course if the machines had to be lifted about by hand it would be a different matter, but if engineering works were to be carried on on the same scale, and with the same speed as at present, machines must have the necessary power and bulk. The mere matter of holding-on by electro-magnets, for instance, was well-known to be a question mainly of the mass of the magnets, and of the current circulating in the coils surrounding the cores. They could not have this holding power without a certain amount of weight. It was possible to separate the holding-on part from the motor, and in a former paper on this subject he had dealt with this plan. On the other hand, however, if the plan were adopted of having a separate motor and flexible shafting carrying the power to the tool, they were liable to considerable loss of power from that kind of transmission. As to the question of setting the drills to the mark of a centre-punch, it was a very simple matter, and he had found no difficulty in getting ordinary labourers to fix them accurately. In shipbuilding it was not at present necessary to be quite so accurate as in boiler-making in the position of the rivet holes, but even in that work, with centre-punch marks, he had found no difficulty in entering the point of the drill into the centre-punch, the machine being raised or lowered by pulley blocks until the point of the drill entered, and then the putting on of the holding magnet did not alter the position at all. He had designed machines with traversing drills, but this involved still heavier machines and possibly not more useful, as with the lighter machines in use he had found no difficulty in getting the driller to hit the position accurately enough in any work that had yet been done. He was under an obligation to the Institution for permitting him as a stranger to bring the subject of this paper before them, and he begged to thank them for the kind reception they had accorded him.

A vote of thanks was then passed to Mr Rowan for his paper.

On Collisions at Sea:
How to Avoid and How to Minimise their Disastrous Results.

By Mr LAURENCE HILL.

(SEE PLATE XXI.)

Received and Read 20th March, 1888.

"Then rose from sea to sky the wild farewell,
  Then shrieked the timid, and stood still the brave,
Then some leaped overboard with dreadful yell,
  As eager to anticipate their grave.
* * * * * *
                                    and all was hushed,
Save a distant shriek, the last despairing cry
Of some strong swimmer in his agony."

—*Byron.*

IT does not require a vivid imagination to picture such a scene, on hearing that another ship has suddenly gone to the bottom with scores—it may be hundreds—of valuable lives, *by a collision;* and the horror is much enhanced by the thought that the accident was brought about by wicked neglect of well-known rules, and completed by the refusal to adopt equally well-known means of security against immediate foundering.

Such being the case, it is little wonder that from time to time, for a quarter of a century, many right thinking persons have called attention, both by newspapers and pamphlet, to the system that prevails, and is sanctioned by the Government—viz., that of sending off crowds of passengers in vessels which, in the event of a bad collision, must inevitably and almost immediately sink with those on board.

When I began shipbuilding, many years ago, it was my endeavour to have sea-going vessels made secure against *preventible* accidents, At that time, ship owners and builders were assisted in these good endeavours by those in authority; for, though occasionally annoyed by the requirement of what we thought to be frivolous details, the Board of Trade and Lloyds' then kept *essentials* prominently in view.

When iron ships came into use, it was imperative to divide the holds by water-tight bulkheads, and the Board of Trade would not grant certificates to sea-going vessels unless they were so divided. Though safety by these arrangements was not fully provided for, yet they nevertheless were the means of saving not only many lives, but also ships and cargoes. Abundant testimony can be had in support of this statement.

But, about a quarter of a century ago, the then Board of Trade rescinded these most proper provisions, and ever since the Board, if other minor requirements were fulfilled, has not refused a certificate, even though no bulkheads are provided; and consequently (with some honourable exceptions) they are not supplied for sailing ships. In the case of many steamers, two small bulkheads, one in each peak, and the bulkheads before and abaft the engine space only, are supplied, these being required by Lloyds' rules. But, so far as the Board of Trade is concerned, the hold of sailing ships may be one *single vast water space;* and the certificate is given all the same.

I never heard any reasons assigned for this change in the requirements for safety that were of the least weight. In fact, none can be maintained; while there are many reasons why they should be again enforced, and *more stringently.* The relaxation of these requirements was carried without any public expression of opinion being asked; and, as it did not prevent good men from providing *their* ships with bulkheads, the public generally took little interest in the matter.

The objection urged against bulkheads was, that they interfered with the stowage, and that this and their cost were a tax on the shipowner. Now, with the exception of timber ships and colliers, they need not interfere with stowage or discharge. The cost is little, and even if ships had a greater number of bulkheads than usual, the additional cost would be many times recouped by saving in insurance and other economies.

The reasons for subdividing are:—

1. Bulkheads, judiciously placed, greatly diminish the risk of a ship's foundering, should her side or bottom be stove in.
2. In passenger ships, bulkheads can be so provided as to ensure the ship against foundering *immediately after* a collision, and they greatly enhance her safety if run ashore.
3. In the case of vessels having to be abandoned, they give the crews time to prepare for this last resource.
4. Bulkheads and double bottoms strengthen a vessel.
5. Instead of interfering with stowage, they would (except as aforesaid) cheapen the loading and discharging, and would tend to prevent injury to the goods by improper stowage. The chief expense for stevedore's wages consists, not in the raising and lowering of the cargoes, but in the great labour and difficulty in moving heavy and bulky articles to their positions along a confined and imperfectly-lighted space. With more bulkheads and more hatches the expense of stowage and risk of injury to goods would be greatly lessened.
6. There would be a reduction in insurance, not only against the effects of collision, but also against damage from fire and *ordinary* leakage, for in the event of a leak or a fire, the injury is confined to the one compartment, and the goods in others escape.
7. Part cargoes of tea or such like are not liable to be injured by contact with other cargoes giving forth offensive odours.

I could produce many satisfactory instances of the value of properly-placed bulkheads in saving life and property, and a much greater number of deplorable losses of life and property, caused by their absence, or insufficient number, or by imperfect workmanship; and also of some fairly well subdivided vessels which have been sunk by the water-tight doors being left open, or the tunnel floors not being water-tight. For example, there is the loss of the "Oregon" from this cause; fortunately, owing to most opportune coincidences, no lives were lost; but had the collision occurred at *night*, and beyond the reach of succour, the results would have been fearful. Not so long before this, there was the loss of H.M.S. "Vanguard" from same cause; fortunately, many ships and boats were near to rescue the crew. A large French steamer, well subdivided, was lost with many lives from this same cause; and more could be mentioned.

Many vessels have been saved after the bows were stove in, by having the collision bulkhead placed where it should be, viz., abaft the bows, and not merely stepped on the forefoot. Many have been saved after a collision which caused the filling of one compartment; others have kept afloat and been saved from total loss after an accident to stern tubes by their bulkheads and tunnels being tight.

One large passenger steamer, though the after hold filled and she settled down till the main deck aft was under sea-level, was able to steam for hundreds of miles to shore, the inside of tunnel and all forward being perfectly dry.

On the other hand, another Atlantic steamer, suffering from similar disaster, was lost with many lives, when near home, *because the tunnel and its flooring plates* were not tight.

Many instances could be given of smaller vessels steaming safely home with water above deck forwards, all saved by the proper placing and proper workmanship of bulkheads.

A common reply of foremen to an inspector when objecting to insufficient workmanship in the bulkheads was:—"Oh, it doesn't matter, no one expects them to be tight; they are only put in just to fulfil the law!"

The owner of a steamer I built wrote me that he was under the impression that bulkheads could not be relied on, but that had those in this steamer not been tight, the vessel and passengers would have been lost, and as the insurance had expired just before the accident and had not been renewed, the value of the vessel would have been lost to him; but the steamer was repaired for a trifling expense, she steamed into Kingstown with water up to within two inches of the top of the fore combings.

A notable instance of the use of bulkheads is that of the S.S. "Sarah Sands." Fire broke out in the after hold, but the after bulkhead confined it there though the contents of that hold and decks above it were burned clean away, and at the finish a magazine exploded and blew out the port quarter, and yet the ship steamed for some days and got safely with her passengers into the Mauritius. There are satisfactory instances of vessels which though ashore and pierced in one compartment have been saved, with their crews and most of their cargo; and there is a case of a steamer, broken in two halves by stress of weather, the after part floating ashore, with all who were on it when she broke up.

Much more might be said in favour of subdivision, but let that suffice. As to the reverse side of the picture. I could detain you for hours with particulars of vessels and lives lost through the want of proper bulkheads, but it is too well-known, as shown in the Abstract of Returns to the Board of Trade on Shipping Casualties. The *total* losses from collisions, and consequently preventible loss of life is very great, and collisions though not total losses are enormous. The list, big as it is, does not contain the full number of vessels which, in all probability, were lost by collision or fire, as in the year 1885 51 ships were reported as missing. Any shipbuilder who knows what a good ship should be, will agree with me, that a well-built and properly loaded ship ought to withstand any storm. Had these missing ships got ashore, their fate would have been ascertained.

These disasters are brought about mainly—

1. By insufficient or total neglect of look-out.
2. By wilful defiance of well-known rules in regard to lighting.
3. By the sinful cupidity which risks the lives of innocent persons in order to save a few gallons of oil.

4. They are frequently caused by even careful navigators being in doubt as to which side the meeting ship was steering.
5. By neglect or ignorance of well-known means for securing ships against immediately foundering so soon as a big hole is knocked into her side.
6. And in emigrant ships the calamity is fearfully increased in consequence of these not being sub-divided.

In order to minimise these deplorable disasters, chiefly occasioned by carelessness, strenuous endeavours ought to be made to get an international law for the vigilant observance of uniform rules as to lighting and look-out, the neglect of which should be severely punished.

Means ought to be used whereby meeting ships instantly apprise each other how they are about to steer, by automatically signalling to which side their rudders are put over. If this were done, there could be no doubt as to which side each vessel was then steering. In the *Nautical Magazine* of last year there is an ingenious mode of doing this by placing the lights in triangular form, the mast-head light being the apex; but this has the objection of requiring time, as ships, especially large ones, require time before they veer sufficiently to alter the appearance of their side lights. A better plan would be the use of similarly coloured lamps placed some feet above those prescribed by law. These additional lights to be always screened when the rudder is "steadied," but the first turn of the wheel to port or starboard exposes them, and they continue exposed till the helm is again *righted.* The double lights instantaneously telegraph to the approaching vessel to which side the rudder is put, and how the vessel is about to head. This may be done in various ways at little expense; and if electrical lighting be used, the cost will be still less, and the working expense *nil.*

Besides other life-saving apparatus, one or more big "rolling pads" should be carried, ready to let down over any opening so soon as clear of the offending vessel.

The "collision pad" exhibited here last year by Mr Richardson goes far in the right direction.

Ships' captains should exercise their crews at launching boats, putting out pads, &c.

Render any inrush impossible of water into the engine room, in consequence of the water-tight doors not being shut. It is not possible to get hard-worked stokers or trimmers to keep them shut by even the most stringent regulations. But this is easily accomplished by building a water-tight compartment (sufficient to hold one or more small trucks of coal), opposite the present bulkhead door, and fitting a second door in this compartment opposite the other one. A bar is fitted so as to reach from over the top of door No. 1, which is shut to the back of door No. 2, which is open. The trimmer having brought his coal into the compartment, cannot open door No. 1 until No. 2 is shut, because he cannot pull the bar from off the top of No. 1 until *No. 2 is quite shut*, and so permits the bar to be pulled over it, and so relieve No. 2. Had the "Oregon" and "Devastation" been so provided neither ship would have sunk.

The Inman Company, in their new steamers, are adopting the good old plan of having *no doors*. This is what used to be 30 years ago; but few companies can afford the expense incurred for coal trimming without doors.

Mr Thomas Gray said truly in his admirable lecture last year that "counter's" owners played with were "men's lives," and this should not be permitted. I sincerely trust that Mr Gray will have the courage of his convictions.

It is certain that the loss of life would be greatly lessened if shipping companies carrying emigrants did not look on collisions as a remote contingency, and did not trust to Providence *until* they had first done all in their power to guard against the results of what—instead of being only possible—has really now become the chief danger of the seas.

No passengers should be carried except in subdivided ships, and I am sure the owners of otherwise well-appointed vessels would greatly promote their business if they could advertise that their ships were subdivided, and that therefore the safety of their passengers in case of a collision was as far as possible insured.

I have always been of Mr Chamberlain's opinion that sea insurance should be so regulated that it would be impossible for either owner or shipper to make money by the loss of a ship.

I suggest that efforts be made:—

1.—To obtain an International law; regulate and enforce uniform regulations for lighting, and look out on *all* nations.
2.—The adoption of automatic signalling, to meeting ships of how each is steering.
3.—To prohibit passengers ships sailing from British ports unless they are sufficiently subdivided.
4.—Reformation of sea insurance, so as to render it impossible that either owner or shipper can make money by the loss of a ship.

In the after discussion on this paper, on the call of the Chairman,

Mr LEONARD GOW said he quite agreed with the object of Mr Hill's paper. He believed, however, that notwithstanding the number of collisions that took place at sea, and the loss of life therewith connected from causes preventible and not preventible, the number of fatalities was steadily decreasing. In looking over statistics which had been pretty frequently brought before the public during the last few years, on account of the measure brought forward by Mr Chamberlain, these statistics had been laid before the public very amply, and they had been analysed very carefully, and exact comparisons made with the losses of lives in previous years. During the last fifteen years the shipping trade had greatly increased, and the number of sailors, engineers, firemen, and passengers was therefore greatly in excess of what it was previously, and yet it was well known that not only was the ratio of fatalities decreasing year by year, but the actual number of lives lost annually was decreasing, and that notwithstanding the immensely increased number of people afloat. Another proof that the safety of life at sea was enhanced was, that the rates of insurance were now about one-third of what they were fifteen or twenty years ago. If the ratio of losses had gone on the same during all these years, it is quite clear that underwriters could not have carried on their business. No doubt they grumble, and say they cannot now show a profit; but even at a rate of insurance of 6s 8d, as compared with 25s or 30s, they seem to live, and that must arise from the immense decrease that has taken place in collisions and loss of ships at sea. At the same time he agreed with Mr Hill that these collisions were still too frequent, caused largely by so many steamers flying about our coasts. He was of opinion that the ratio of decrease might be improved, and the method of lights shown by Mr Hill might very beneficially be introduced. It would cost very little, oil being very cheap at present, and in vessels where the electric light was used it would cost almost nothing. The arrangement of the doors from bunkers to the stokehold would also be an improvement. He thought the water-tight compartments of vessels could be improved upon, and large ships, especially those carrying passengers should be compelled to be built so that they would not sink, although water got into two of their compartments. He did not think that that would cause much increased expense in building, and it would certainly reduce the charges for insurance.

Mr **Laurence Hill** said he was glad to hear that Mr Gow agreed generally with his paper. He would insist that the Government should require vessels to be so built that they might still float after a collision. Although the rate of insurance was less than it used to be, still the underwriters had recently been complaining, particularly of their losses from collisions. His censures applied not to the good ships of the passenger lines, but to sailing ships where there was no interference on the part of the Board of Trade, and where there were no proper bulkheads.

Mr **James Syme** asked if he understood Mr Hill to say, that a sailing vessel without a single bulkhead might be sent to sea by permission of the Board of Trade? He did not believe this to be the case.

Mr HILL replied that that was so. The Board of Trade could not refuse its certificate to a sailing ship on any such ground. They might stand at the stern-post and view the whole hold as one vast space, and that ship might be sent off with 500 or 600 lives on board, and yet the Board of Trade would not refuse to let her go. If she wanted a few gallons of lime juice they would perhaps stop her.

The discussion was then adjourned.

In the discussion on this paper, on 24th April, 1888,

Mr MOLLISON said that the drawing exhibited (see Plate XXI.) had been in his office for years, and he had given it Mr Hill to lay before the members as illustrative of the subject of his paper. The collision with the "Thistle" occurred a number of years ago and in that case, as her engine-room bulkheads were all right, although the fore and aft compartments were full of water, they were able to bring the vessel safely into port, showing the value of bulkheads in saving life and property.

Mr LAURENCE HILL said he was much gratified by the remarks of Mr Gow. His remarks, however, about the decrease of fatalities at sea were rather misleading. All that Mr Gow said was true, for there were fewer lives and ships lost during late years than previously, but this was accounted for from the fact that ships were now larger and better built and better navigated than formerly; and also when shipwrecks occurred their crews were often saved by the efficient services of tug and life-boats that now surrounded our shores. Still there were a great number of collisions, and a great number of losses at sea due to collisions, which he maintained might be prevented. An underwriter had told him that he had omitted to mention a very important item from his causes of collisions—viz., the bad practice of meeting vessels not giving one another a wide enough berth. That gentleman also told him that he was going to the Mediterranean on one occasion, and with him as fellow passengers were two shipmasters, who ridiculed the conduct of the captain in charge of the vessel for his cautious navigation—one of them in particular for the captain's extreme caution in avoiding or keeping clear of dangerous headlands, and the other laughed at him for giving so much sea-room to a coming vessel. His friend had made a note of these two masters' names, in order to trace their future career, and it was remarkable that the one lost his ship on the very rocks which he had laughed at the captain for giving a wide berth to, and the other's vessel was lost by collision near the same place. Mr Hill further said that the decrease in losses at sea, mentioned by Mr Gow, showed that the losses still occurring were greatly due to collisions, as underwriters said that these occurred at the rate of two a-day.

A vote of thanks was then awarded Mr Hill for his paper.

Mr David Kirkaldy, who made the original drawings lithographed in this plate, states that the "Thistle" was launched in 1848, and was of the following dimensions:—

Length, 198·4 feet; Breadth, 26·3 feet; Depth, 16 feet.

Tonnage of Hull and Poop, - -	$653\frac{15}{100}$
„ of Engine Space, - -	$276\frac{43}{100}$
„ Register, - - - -	$376\frac{72}{100}$

The "Thistle" appears to have met with the accident described about the year 1860.

On the Construction and Laying of Two Lines of Submarine Pipes, Sixteen Inches diameter, across the Bay of San Francisco, California.

By Mr Robert S. Moore,
Superintendent of the Risdon Iron Works, San Francisco.
Communicated by Mr Ralph Moore, C.E.

(SEE PLATE XX.)

Received 13th March, 1888.

In July, 1887, the Spring Valley Water Works Company, of San Francisco, through their engineer, Mr H. Schussler, submitted plans and specifications for an iron pipe line to convey water from Calavaras Creek, Alameda County, to San Francisco, by way of San Mateo, and in the same year they entered into a contract with the Risdon Iron Company, of the same place, for its construction.

The total length of the conduit is 146,000 feet, and consists of 139,400 feet of 36-inch wrought-iron riveted pipe for the land, and about 13,200 feet of submarine ball joint pipe for the bay crossing

The conduit is distributed as follows.

Beginning at a stone aqueduct on Alameda Creek, it passes along the public road through the towns of Centerville and Newark, and thence it is carried over a salt marsh on a trestle, to a point on San Francisco Bay called Dumbarton Point (crossing a navigable slough 360 feet wide with a double line of submarine pipe on the way); thence across the Bay of San Francisco with a double line of submarine pipe to the westerly shore of the bay, thence in a 36-inch pipe to the main at San Mateo.

At the present writing, the entire submarine pipe has been laid, and about 60,000 feet of the 36-inch pipe on either side of the bay. In a former paper read before this Institution,* the writer has described the construction and laying of large-sized wrought-iron riveted pipes. The present paper will only deal with the construction and laying of the submarine portion of the work. The small portion across the slough was laid in a similar manner to that in the bay, and it is therefore unnecessary to describe it separately.

The mode of constructing the pipes was as follows:—

Sixteen-inch lap-welded tubing, in twenty-two feet lengths, five-sixteenth inch thick, was selected as the most suitable pipe to be used. The lengths, after being fitted with ball and socket ends were to be joined, with hot lead, to each other on a large floating barge, and then lowered slowly into the bay, forming its own bed on the mud or sand bottom as it happened to be. To prevent deterioration, the pipes were zinc galvanised inside and out, then dipped twice in a hot bath of asphaltum and coal tar, and, just previous to being lowered into the bay, were again painted with a heavy coat of paraffin paint.

Eighteen feet was found to be the average length of the pipes received, and nineteen feet the maximum length the mills could deliver.

Ball and socket joint castings (see Figs. 1, 2, and 3, Plate XX.) were made and riveted on to the tubes, after which each length was tested by hydraulic pressure to 125 lbs. per square inch. (Testing machine shown by Fig. 5.)

At first, the castings were heated by wood fires and shrunk on, after which the pipes were put into a lathe and expanded into the castings by a tool specially prepared.

But it was found that the tube not being exactly round, was too heavy to be expanded in this manner, and the better plan was adopted of putting the castings on by an hydraulic press, and then

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* See Trans. Inst. E. and S., Vol. XXX.

peening the tubes on the inside with hand hammers until the castings were tight. A few holes were then drilled through both casting and tube, and a few hot rivets driven as an additional precaution to prevent the castings from becoming loose. Each pipe was tested in an hydraulic testing machine (see Fig. 5, Plate XX.) and had very seldom to be recaulked, and then only to take up some trifling leak next the castings.

After being satisfactorily tested, the pipes were transported on a lighter thirty miles up the bay to the point where they were to be laid.

Owing to the strong trade winds that prevail on the bay during the summer months, it was decided that the submarine pipes should be laid in October and November, two months usually the calmest of the year.

The distance between the two shores was about 6500 feet, and rarely could a clear view be had of more than one-fourth of this distance. To overcome this difficulty, and for the purpose of keeping the barge in as straight a line as possible, a row of guide-piles was driven parallel to and 50 feet north of the proposed line, and about 500 feet apart.

The depth of the water varied from 0 to 60 feet; it was greatest in the middle, where for a distance of 2000 feet it varied from 50 to 60 feet. (See Fig. 4, Plate XX.) The current at times was not less than six miles per hour.

No accurate diagram of the bottom of the bay had been prepared, although numerous and accurate soundings were made by the Company's engineers, and by the Government officials, some years ago. The bottom consisted of hard sand; and the sides, for a distance of several hundred feet, of soft mud.

The arrangements for laying were as follows:—

The two lines of pipe were to be laid side by side; and to save time and expense, the author decided to lay both at the same time. With this object in view, a working barge, 40 × 100 feet, was fitted up specially for the work. Two heavy inclined shutes or aprons, fourteen feet from centre to centre, were built on the stern end, so swung on an axle and boxes as to admit of the angle being quickly changed to suit the varying depth of water.

Trails, extending some ten feet under water, were fastened to the shutes for the pipes to slide down on.

In order to be able to perfectly control and move the barge against strong tides and winds, a 5-inch steel cable was stretched across the bay, and both ends hauled taut with heavy winches and made fast. The cable was taken aboard the barge, passing over the bow and stern through two suitable guide pulleys. A double tackle was attached to the cable some 200 feet from the bow of the barge, and led to the gypsy of a powerful steam winch.

By this means we were enabled to move the barge ahead at will but the next difficulty was to keep it from swinging while moving ahead or while the joints were being poured. This was accomplished by a system of ropes, anchors, and windlasses. Four 5-inch manilla ropes, each 600 feet long, were attached to as many anchors on either side of the barge. Each rope was led to a capstan, and when the barge had been moved ahead sufficiently the lines to the bow anchors were shifted (the anchors remaining stationary) so as to become the stern lines, and the stern anchors were raised and fleeted to become the bow anchors, and so on, only two anchors being raised at a time and passed from stern to bow.

Erected on the barge, and straddling both shutes, was a large pair of shear legs 100 feet high, so arranged that, with steam power, the pipes could be taken from lighters alongside and dropped into either shute. Into these shutes the pipes were placed ready for joining.

A steel wire cable, attached by a chain sling to the end pipes, and through heavy snatch blocks at the upper end of the shutes, was used for lowering the pipes into the bay.

The socket end of the last pipe (being upward) was fastened to the apron by strong chains and clamps, and by an extra safety chain with plenty of slack. The pipe about to be joined was hoisted up to the rails, with the socket end up, and the lowering cable and safety chain attached to it.

Before entering the pipes both castings were thoroughly cleaned, dried, and heated by a jet of direct steam through a 2-inch rubber hose. The steam not only cleaned the joints but warmed them, and prevented the hot lead from chilling when the joint was poured. A braid of hemp packing was wound into a groove in the spigot end (see Fig. 3, Plate XX.), after which the pipe was carefully entered into the socket of the pipe below.

A clay sausage was placed tightly around the entered pipe and against the face of the socket, leaving an opening on top for receiving the hot lead and allowing the air to escape.

The lead (heated to a straw colour) was now poured in until the joint was filled. After the lead had cooled the clay was removed and the lead caulked home (see Fig. 1, Plate XX.). The joint being finished and ready to be lowered into the bay, the chains and clamps were removed from the now second pipe from the end, and at the command "lower away," the steam winch hauled on the steel cable, the barge began to forge slowly ahead, and the pipes in the shutes were allowed to slide down until their upper ends were in proper position for the next joints to be poured. In this position the pipes were again fastened by clamps and chains, and another pipe was hoisted into each shute. The ball and socket ends were steamed, the pipes placed together for joining, the joints poured, and the pipes lowered away as before. A sufficient strain had to be kept on the lowering cables so that none of the joints in the suspended portion of the pipes deflected more than 10 degress.

In the manner above described the entire submarine pipe was laid without an accident of any kind. As many as fifteen pipes in each shute were laid per day of ten hours. But, owing to the delay in receiving the pipes, and the approaching stormy season, the work of laying was carried on at night by aid of electric lights, with which the barge was equipped. Often, during the progress of the work, the bay became so rough that the men could not pour the lead into the joints, and at such times the pipes were made secure until the weather moderated. During such weather the barge heaved considerably, but the suspended pipes raised and lowered with it, and the side or twisting motion was transmitted to the first joints below the barge, the pipes in the shutes never being allowed to move except in the roughest weather. The displacement of the pipes made them lighter than the water, and to keep them from floating, they were filled with sea water by a pump on the barge. After the entire line had been laid, fresh water was run through them, showing them to be absolutely tight. At low water, several hundred feet of pipes were exposed, and notwithstanding the fact that in laying them the joints had been subjected to irregular deflection, close examination failed to discover any leak.

For the purpose of knowing how much deflection the joints would stand without leaking, some interesting experiments were made at the works.

Two 16-inch pipes were connected by the ball and socket joint described in Plate XX., and placed under a crane capable of deflecting the pipes in any and all directions. The ends were stopped up with blank flanges, and a hydraulic pressure of 200 lbs. applied. Under this pressure, it was found difficult to change the position of the pipes (the joint was not designed to be deflected under pressure); but it was perfectly tight. Several times the angle of deflection was changed (the pressure first having been removed), and no matter at what angle the pipes stood, the joints still remained tight.

Towards the last of these experiments, and after the lead had become slightly compressed under the heavy pressure, the joint allowed the water to escape, but only for a moment. The hemp packing in the groove was carried into the joint, which at once became absolutely tight.

The pressure was finally raised to 500 lbs., but with no bad effect on the joint.

It may be stated that the ball joints are bored out in a lathe by special tools to a perfect circle.

The author considers the hemp packing indispensable to water-tight joints of the above class; when the joint is being made, it also prevents the lead from escaping beyond the space intended for it. Although the pipe ends are intended to be in contact iron to iron, it is next to impossible to keep them so, the slightest movement of the barge being enough to change their position. All this, however, was obviated by the use of the hemp.

The work of laying the 36-inch pipe is now progressing rapidly, and in five months' time the entire line will be connected and in operation. The pressure on the submarine pipes will be 70 feet, but this may be considerably increased at a future time when it is the intention to lay two more submarine pipes similar to those just laid.

After laying, the socket castings on the pipes at once became firmly imbedded in the sand or mud, and, acting as anchors, prevented the slightest movement of the pipes on the bottom.

Not a diver was required during the entire work, the degree of deflection of the joints of the suspended pipes (the pipes hanging between the barge and the bottom) being readily determined by the first joint above the surface of the water. This joint showed whether or not the angle of the first pipe below the barge was the same as that of the inclined shute on which the joints were made.

In order to prevent the joints of the suspended pipes from becoming cramped or broken, the angle of the pipe entering the water was kept less than the angle of the shute. (This angle could be varied by lowering away the pipe faster or slower than the speed of the barge when being moved ahead.)

The proper position for the suspended pipes could only be maintained by regulating the angle at which the pipe left the shute to enter the water; in other words, the pipe being lowered had to *rise* from the T rails as it entered the water. If it had hugged them, the position of the suspended pipes would have been lost to those on the barge, and the joints exposed to the great danger of becoming cramped. Not a single pipe was lowered without the greatest attention being paid to the relative angles of the shute and that of the pipe leaving it. Sometimes, on resuming work in the morning (owing to the rise or fall of the tide), this relative position had become changed, but it was invariably rectified before laying any pipes, by changing the position of the barge either ahead or backward.

In answer to the Chairman (Mr D. J. Dunlop, Vice-President),

Mr Ralph Moore said he might give the history of the paper. His nephew, the author, had told him that he was laying a line of 18-inch water-pipes across the Bay of San Francisco, which is two miles wide and from one to sixty feet deep. The mode adopted for joining the pipes was by ball and socket joints, so that the pipes were like links of a chain, and accommodated themselves to the bed of the bay. After they were laid down they were tested with a high head of water, and were found to be quite tight. He took the opportunity of asking for an account of the work, which in due time he received, and the papers having been accepted had now appeared in the Transactions. The method adopted of pipe-laying seemed to be very satisfactory. Of course, it was not new, as many of the members would remember in the old waterworks of Glasgow the pipes laid by James Watt to convey the water from the filters across the bed of the Clyde were somewhat on the same plan.

Mr D. C. Glen asked if any one present had seen the pipe that James Watt had laid, referred to by Mr Moore? The story was, that being out at supper James Watt was asked how he would make the water pipes for crossing the bed of the Clyde. He took up a lobster, and, pointing to its tail, he said he would joint it like that. A similar description of a 12-inch pipe, but of cast-iron, made by Messrs M'Farlane, Strang, & Co., Lochburn Iron Works, for South America, could be seen at the back of the Exhibition building, close to the Kelvin. It was jointed with lead, but no rope yarn was used. A mile and a half of this piping had been made by Messrs M'Farlane, Strang, & Co. for crossing a river, which, he understood, was very deep. He would like to know if any of the James Watt joints had been preserved?

Mr Moore said he had seen James Watt's joint at the water works, only it was double and made in halves. He did not think the jointing of the pipes described was put forth as anything new, but what struck him on reading the paper and examining the photographs was the complete nature of the arrangements, and the thorough manner in which they were carried out. The double line of 16-inch pipes were laid across the bay in rough water, with an excessive tide current, at the rate of 500 feet per day, without any mishap, and without lifting a single length of pipe after it had been laid.

Mr GLEN said he had been informed that the river at Winnipeg had been so crossed between two and three years ago. The pipes were laid on the ice, the river being nearly frozen to the bottom at the time, and the sockets having been made in halves and jointed, when thaw came they were lowered by derricks, but before they were lowered three feet the water was running over them. They were sunk in the bottom of the river, in a groove cut where the pipe was to lie.

On the motion of the CHAIRMAN, a vote of thanks was awarded Mr Moore for his paper.

Photographs of the work and specimens of the coating of the pipes and the pitch used were exhibited.

Institution of Engineers and Shipbuilders
IN SCOTLAND
(INCORPORATED).

THIRTY-FIRST SESSION, 1887-88.

MINUTES OF PROCEEDINGS.

The First General Meeting of the **Thirty-First Session** of the Institution was held in the Hall of the Institution, 207 Bath Street on Tuesday, the 25th October, 1887, at 8 P.M.

Mr **Alexander C. Kirk**, President, in the Chair.

The Minute of Special General Meeting of 10th May, 1887, was read and approved, and signed by the President.

The **President** delivered his Inaugural Address. On the motion of Professor **James Thomson**, LL.D., a vote of thanks was awarded the President for his Address.

Mr **W. Carlile Wallace** read a paper on "The Indicator in its Application to Modern Steam Machinery," the discussion of which was deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr **James Denny**, Mechan'l Engineer and Shipbuilder, Dumbarton.
Mr **Lewis P. Garrett**, Mechan'l Engineer, 19 Renfield St., Glasgow.
Mr **Charles G. Hepburn**, Engineer, 130 Elizabeth Street, Sydney.
Mr **Robert Band Pope**, Mechanical Engineer, Messrs Denny & Co., Dumbarton.
Mr **John Weir Smith**, Mechanical Engineer, Pernambuco.
Mr **David Wilson**, Engineer, Arecibo, Porto Rico.

AS GRADUATES :—

Mr ROBERT LAWRIE, Engineering Student, 12 Scotia St., Glasgow.

Mr JOHN MACDONALD, Apprentice Engineer, Brisbane, Queensland.

Mr DAVID H. REID, Apprentice Mechanical Engineer, 144 Renfrew Street, Glasgow.

Mr JAMES BROWN WYLLIE, Assistant Civil Engineer, 23 Miller Street, Glasgow.

THE SECOND GENERAL MEETING of the THIRTY-FIRST SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd November, 1887, at 8 P.M.

Mr ALEXANDER C. KIRK, President, in the Chair.

The Minute of General Meeting of 25th October, 1887, was read and approved, and signed by the President.

The discussion of Mr W. CARLILE WALLACE'S paper on "The Indicator in its Application to Modern Steam Machinery," was terminated, and a vote of thanks awarded the author.

The following papers were read :—

On "An Improved Riveting Machine," by Mr HUGH SMITH.

On "Copper and Copper Castings," by Mr GEO. C. THOMSON, F.C.S.

Discussions followed, and were carried to next General Meeting.

On "Experiments on Strength of Copper Pipes," by Mr NISBET SINCLAIR. The discussion of this paper was deferred till next General Meeting.

The Chairman announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows :—

AS MEMBERS:—

Mr MICHAEL RATCLIFFE BARNETT, Civil Engineer, Johnstone.
Mr HUGH M'INTYRE, Shipbuilder, 19 Albion Crescent, Partick.
Professor GEORGE PATON, C.E., Royal Agricultural College, Cirencester.
Mr ROBERT L. WEIGHTON, M.A., Mechanical Engineer, Newcastle.

AS A GRADUATE:—

Mr JAMES PEACOCK, Engineering Draughtsman, 75 Wilton Street, Glasgow.

THE THIRD GENERAL MEETING of the THIRTY-FIRST SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 20th December, 1887, at 8 P.M.

Mr ALEXANDER C. KIRK, President, in the Chair.

The Minute of General Meeting of 22nd November, 1887, was read and approved, and signed by the President.

The PRESIDENT announced that the James Watt Anniversary Dinner, which had formerly been held yearly under the auspices of the Association of Foremen Engineers, would in future, by a mutual arrangement, be held under the joint auspices of this Institution, the Philosophical Society, and the Association of Foremen Engineers.

The Discussion of Mr HUGH SMITH'S paper on "Hydraulic Machine Tools" was resumed and terminated, a vote of thanks being awarded Mr Smith.

The discussion of Mr GEO. C. THOMSON'S paper on "Copper and Copper Castings," and of Mr NISBET SINCLAIR'S paper on "Strength of Copper Pipes," took place. Mr SINCLAIR making some further remarks on the Experiments at Lancefield. The further discussion of these papers was continued to next General Meeting.

The paper on "The Construction of the Glasgow City and District Railway," by Mr ROBERT SIMPSON, B.Sc., on account of the lateness of the hour, was held as read, the discussion to take place at next General Meeting.

Members elected at previous General Meeting were presented with Diploma of Membership.

The Chairman announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows :—

AS MEMBERS :—

Mr DAVID ARCHER, Naval Architect, Dalmuir.

Mr NISBET SINCLAIR, Engineer, 33 La Crosse Terrace, Hillhead.

AS GRADUATES :—

Mr CECIL P. HARRINGTON, Apprentice Mechanical Engineer, Broadfield, Port-Glasgow.

Mr DAVID MYLES, Mechanical Draughtsman, Neptune Engine Works, Walker-on-Tyne.

Mr MATTHEW ROBIN, Apprentice Engineer, 69 Paisley Road, W., Glasgow.

THE FOURTH GENERAL MEETING of the THIRTY-FIRST SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 24th January, 1888, at 8 P.M.

Mr ALEXANDER C. KIRK, President, in the Chair.

The Minute of General Meeting of 20th December, 1887, was read and approved, and signed by the President.

The Discussion of Mr GEO. C. THOMSON's paper on "Copper and Copper Castings," and of Mr NISBET SINCLAIR's paper on "Strength of Copper Pipes," was resumed and terminated, votes of thanks being awarded the authors of the papers.

The Discussion of Mr ROBERT SIMPSON's paper on "The Construction of the Glasgow City and District Railway," was proceeded with, and terminated, a vote of thanks being awarded Mr Simpson for his paper.

A paper on "The Erection of the Superstructure of the Forth Bridge," by Mr ANDREW S. BIGGART, C.E., was read. The Discussion being deferred till next General Meeting.

Mr WM. LIDDELL exhibited a "Model of Chambers' Patent Unsinkable Semi-Collapsible Lifeboat," and explained its construction. A vote of thanks was awarded Mr Liddell.

Members elected at previous General Meeting were presented with Diploma of Membership.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows :—

AS MEMBERS :—

Mr F. W. ANDERSON, Mechanical Engineer, 314 Dumbarton Road.
Mr JOHN DARLING, Marine Engineer, 34 Queen's Square, Glasgow.
Mr PHILIP JENKINS, Prof. of Naval Architecture, Glasgow University.

AS ASSOCIATES :—

Mr THOMAS STRUTHERS M'INNES, Manufacturer of Engineering Instruments, 8 Buchanan Street.
Mr SAMUEL SMILLIE, Coppersmith and Brassfounder, 71 Lancefield Street, Glasgow.

AS GRADUATES :—

Mr HUGH WALLACE AITKEN, Student Mechanical Engineer, Netherlea, Pollokshields.
Mr JAMES ALLAN, Apprentice C.E., 108 Raeberry Street, Glasgow.

Mr Angus Campbell, Apprentice Engineer, 31 Elderslie Street.

Mr Mark Brand, B.Sc., C.E., Apprentice Mining Engineer, Faulds Park, Baillieston.

Mr Daniel L. Hutchison, Apprentice Civil Engineer, 8 Great Western Terrace, Kelvinside.

Mr James Venn Paterson, Marine Draughtsman, 187 Bath Street.

Mr John A. Rudd, Marine Engine Draughtsman, 6 Breadalbane Street, Glasgow.

Mr Archibald Stodart, Civil Engineering Draughtsman, Netherton, Newton Mearns.

Mr Andrew Orr Wyper, Apprentice Civil Engineer, 7 Bowmont Gardens, Kelvinside.

Mr J. Denholm Young, Student Engineer, 10 Bonnington Terrace, Edinburgh.

THE FIFTH GENERAL MEETING of the THIRTY-FIRST SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 21st February, 1888, at 8 P.M.

Mr Alexander C. Kirk, President, in the Chair.

The Minute of General Meeting of 24th January, 1888, was read and approved, and signed by the President.

The Discussion of Mr A. S. Biggart's paper on "The Erection of the Superstructure of the Forth Bridge," took place and was terminated, and a vote of thanks awarded Mr Biggart for his paper.

The following papers were read:—

On "The Stability of Yachts," by Mr W. David Archer.

On "Liquid Fuel," by Mr James M. Storrar.

The discussion of these papers was deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS :—

Mr **Archd. Denny**, Shipbuilder, Braehead, Dumbarton.

Mr **Peter Denny**, jr., Marine Engineer and Shipbuilder, Bellfield, Dumbarton.

Mr **George B. Laurence**, Manager, Clutha Iron Works, 1 Belmar Terrace, Pollokshields.

Mr **Hugh D. Lusk**, Engineering Draughtsman, Rosebank, Greenock.

AS A GRADUATE :—

Mr **Leslie S. Robinson**, Assistant Engineer, Engine Works, Dumbarton.

The Sixth General Meeting of the **Thirty-first Session** of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 20th March, 1888, at 8 p.m.

Mr **Henry Dyer**, C.E., M.A., Vice-President, in the Chair.

The Minute of General Meeting of 21st February, 1888, was read and approved, and signed by the Chairman.

The Discussion of Mr **Archer's** paper on "The Stability of Yachts" was proceeded with, and continued to next General Meeting.

The Discussion of Mr **James M. Storrar's** paper on "Liquid Fuel" was proceeded with and terminated, and a vote of thanks awarded Mr Storrar for his paper.

The following papers were read :—

On "The Application of Electricity to Portable Engineering Tools," by Mr F. J. Rowan, C.E.

On "Collisions at Sea," by Mr LAURENCE HILL, C.E.

Discussions followed, and were continued to next General Meeting.

Messrs PETER STEWART and CHARLES C. LINDSAY were appointed Auditors to audit Annual Financial Accounts.

The Chairman announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS :—

Mr ERNEST GEARING, Mechanical Engineer, Southampton.
Mr ROBERT HOUSTON, Mechanical Engineer, Renfrew.
Mr ANDREW LAING, Engineer, 2 Glenavon Terrace, Partick
Mr WILLIAM MORISON, Engineer, 25 St. Vincent Crescent, Glasgow.
Mr GEORGE WHITEHALL, Civil Engineer, Bombay.

AS GRADUATES :—

Mr JAMES BROWN, Assistant Civil Engineer, 12 Dalhousie Street, Glasgow.
Mr B. B. DONALD, Foreman Bridge Builder, 9 Balgray Terrace, Springburn.

THE THIRTY-FIRST ANNUAL GENERAL MEETING of the INSTITUTION was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 24th April, 1888, at 8 P.M.

Mr D. J. DUNLOP, Vice-President, in the Chair.

The Minute of General Meeting of 20th March, 1888, was read and approved and signed by the Chairman.

The Treasurer's Annual Financial Statement was submitted by the Chairman, and adopted, a vote of thanks being awarded the Auditors.

The CHAIRMAN intimated that the Council had agreed that no medals should be given for papers read during Session 1886-87, but that premiums of books might be awarded.

On the motion of Mr W. R. WATSON, seconded by Mr ROBERT DUNDAS, premiums of books were awarded Mr HECTOR MACCOLL for his paper on "The Shafting of Screw Steamers," and to Mr GILBERT M. HUNTER for his paper on "The Ailsa Craig Lighthouse."

The Election of Office-Bearers then took place:—

Mr W. RENNY WATSON, proposed by Mr Robert Dundas, and seconded by Mr Matthew Holmes, was unanimously elected a Vice-President; Mr JAMES MOLLISON, proposed by Mr D. J. Dunlop, and seconded by Mr James Caldwell, was unanimously elected a Vice-President; and, by a majority of votes, the following gentlemen were elected Councillors:—Messrs ROBERT DUNDAS, GEORGE HERRIOT, DUNCAN ROBERTSON, PETER STEWART, C. P. HOGG, and JAMES ANDERSON.

The continued Discussions of the following papers took place and terminated:—

On "The Stability of Yachts," by Mr W. DAVID ARCHER.

On "The Application of Electricity to Portable Engineering Tools," by Mr F. J. ROWAN, C.E.

On "Collisions at Sea," by Mr LAURENCE HILL, C.E.

The paper by Mr R. S. MOORE on Laying Submarine Pipes was held as read, and the Discussion proceeded with and terminated. Votes of thanks were awarded the authors of these papers.

The CHAIRMAN announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS :—

Mr J. F. **ROBINSON**, Mechanical Engineer, Atlas Works, Springburn.

Mr **JAMES M'KECHNIE**, Mechanical Engineer, 8 Glenavon Terrace, Partick.

AS GRADUATES :—

Mr **RICHARD W. ALLAN**, Engineering Student, 1 Maxwell Street, Partick.

Mr **HARRY D. D. BARMAN**, Marine Engine Draughtsman, 100 Elderslie Street.

Mr **JOHN CAMPBELL M'CULLOCH**, Assistant C.E., 3 Germiston St.

Mr **ALEXANDER WOODBURN**, Assistant C.E., 3 Germiston Street.

Mr R. E. **KINGHORN**, Engineering Draughtsman, 12 Bute Gardens, Hillhead.

The **CHAIRMAN** announced that the invitation by the Council of this Institution, and the Directors of the Steam Ship Owners' Association, and the Sailing Ship Owners' Association of Glasgow to the Institute of Naval Architects, to hold their annual summer meetings in Glasgow this year, had been accepted. The meetings would take place in the last week of July. He trusted that the members of this Institution would do their utmost to carry out such a programme as would make the meetings as great a success as they were in 1877.

TREASURER'S STATEMENT—1887-88.

GENERAL FUND.

Dr.

To Balance in Union Bank at close of Session 1886-87,				£177	9	6
Subscriptions received :						
Session 1887-88, . .	£669	0	0			
Arrears of Previous Sessions,	80	10	0			
	£749	10	0			
Deduct Entry Money transferred to Building Fund, . .	10	10	0			
				739	0	0
Sales of Transactions, ...				18	11	3
Bank Interest, ...				1	5	11
				£936	6	8

Cr.

By Amount paid Treasurer of House Committee as Institution's proportion of Expenditure, for Session 1887-88,...				£140	0	0
Taxes, ...				2	18	1
Printing, ...				171	1	6
Lithography, ...				43	2	0
Premiums for Papers, ...				10	3	3
Graduate Section Medal, Session 1886-87, ...				1	7	6
Salary to Secretary, ...				125	0	0
Commission Collection of Arrears of Subscriptions, viz. :—						
For Session 1887-88, ...	£423	0	0			
For Previous Sessions, ...	80	10	0			
	£503	10	0 at 5 %	25	3	6
Postages, ...				53	1	7
Delivery of Annual Volumes, ...				4	6	10
Stationery, &c., ...				14	3	4
New Books for Library, ...				21	1	4
Binding Periodicals in Library, ...				10	2	6
Cash to New Buildings Account to meet Interest on Loan, from Medal Funds, ...				16	0	0
Petty Cash, ...				2	15	11
Balance in Union Bank, ...				295	19	4
				£936	6	8

MARINE ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1886-87, ...	£54 19 10	*By* Mortgage, Glasgow Corporation, ...	£50 0 0
Interest on Capital lent to New Buildings Account, ...	10 0 0	Balance in Union Bank, ...	15 6 6
Bank Interest, ...	0 6 8		
	£65 6 6		£65 6 6

RAILWAY ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1886-87, ...	£36 17 8	*By* Mortgage, Glasgow Corporation,.. ...	£20 0 0
Interest on Capital lent to New Buildings Account, ...	6 0 0	Balance in Union Bank, ...	23 3 3
Bank Interest, ...	0 5 7		
	£43 3 3		£43 3 2

GRADUATE MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1886-87,	£22 9 1	*By* Mortgage, Glasgow Corporation,... ...	£20 0 0
Bank Interest, ...	0 5 1	Balance in Union Bank, ...	2 14 2
	£22 14 2		£22 14 2

BUILDING FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1886-87,	£322 18 0	*By* Mortgage, Glasgow Corporation, ..	£360 0 0
Entry Money, ...	1 10 0	Balance in Union Bank, ...	15 7 11
Two Life Members at £20, ...	40 0 0		
Bank Interest, ...	1 19 11		
	£375 7 11		£375 7 11

NEW BUILDINGS ACCOUNT.

Dr.			Cr.		
To Capital to meet Cost of New Buildings, viz.:—			*By* Paid on New Buildings, ...		...£2,047 8 1
From General Fund, ...	£542 15 7		Interest on Loans, viz.:—		
,, Marine Engineering Medal Fund, ...	351 11 2		To Marine Engineering Medal Fund,	£10 0 0	
,, Railway Engineering Medal Fund, ...	213 13 3		,, Railway Engineering Medal Fund,	6 0 0	
,, Building Fund, ...	939 8 1	£2,047 8 1			16 0 0
Cash received from General Fund to meet Interest on Loans, ...		16 0 0			
		£2,063 8 1			£2,063 8 1

Glasgow, *19th April, 1888.*—We have examined the foregoing Annual Financial Statement of Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Graduate Medal Fund, the Building Fund, and the New Buildings Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

(Signed) PETER STEWART, } Auditors.
A. A. HADDIN, }

SUBSCRIPTION ACCOUNT.

Dr

To Subscriptions due as per Roll :—			
Arrears due at close of last Session, ...		£144 10 0	
Deduct Irrecoverable, ...		51 0 0	
		£93 10 0	
Add received formerly struck off as irrecoverable, ...		12 0 0	
Add elected at Annual General Meeting, April, 1887, ...		2 0 0	
			£107 10 0
Session 1887-88 :—			
378 Members	at £1 10 0 —	£567 0 0	
8 New Members	,, 2 10 0 —	20 0 0	
4 ,,	,, 2 0 0 —	8 0 0	
12 ,,	,, 1 10 0 —	18 0 0	
34 Associates	,, 1 0 0 —	34 0 0	
2 New Associates	,, 1 10 0 —	3 0 0	
192 Graduates	,, 0 10 0 —	96 0 0	
			746 0 0
			£853 10 0

Cr.

By Subscriptions received, as per Cash Book, viz.:—			
Arrears of Sessions previous to Session 1887-88, ...			£80 10 0
Session 1887-88 :—			
347 Members	at £1 10 0 —	£520 10 0	
8 New Members	,, 2 10 0 —	20 0 0	
4 ,,	,, 2 0 0 —	8 0 0	
7 ,,	,, 1 10 0 —	10 10 0	
31 Associates	,, 1 0 0 —	31 0 0	
1 New Associate	,, 1 10 0 —	1 10 0	
155 Graduates	,, 0 10 0 —	77 10 0	
			669 0 0
Arrears due for Session 1887-88, ...		£77 0 0	
Arrears due for previous Sessions,		27 0 0	
			104 0 0
			£853 10 0

BANK ACCOUNT.

Dr.

To Balances at close of Session 1886-87 :—	
General Fund, ...	£177 9 6
Marine Engineering Medal Fund, ...	54 19 10
Railway Engineering Medal Fund, ...	36 17 8
Graduate Medal Fund, ...	22 9 1
Building Fund, ...	322 18 0
Amounts lodged, Session 1887-88, ...	487 7 5
Interest, Session 1887-88, ...	4 3 2
	£1,106 4 8

Cr.

By Amounts Drawn, Session 1887-88, ...	£753 13 6
Balances in Union Bank, ...	352 11 2
	£1,106 4 8

CAPITAL ACCOUNT.

GENERAL FUND.

	£	s.	d.	£	s.	d.
Loan to New Buildings Account, ...	£542	15	7			
Cash in Union Bank, ...	295	19	4			
				£838	14	11

MARINE ENGINEERING MEDAL FUND.

	£	s.	d.	£	s.	d.
Loan to New Buildings Account, ...	£351	11	2			
Mortgage, Glasgow Corporation, ...	50	0	0			
Cash in Union Bank, ...	15	6	6			
				416	17	8

RAILWAY ENGINEERING MEDAL FUND.

	£	s.	d.	£	s.	d.
Loan to New Buildings Account, ...	£213	13	3			
Mortgage, Glasgow Corporation, ...	20	0	0			
Cash in Union Bank, ...	23	3	3			
				256	16	6

GRADUATE MEDAL FUND.

	£	s.	d.	£	s.	d.
Mortgage, Glasgow Corporation, ...	£20	0	0			
Cash in Union Bank, ...	2	14	2			
				22	14	2

BUILDING FUND.

	£	s.	d.	£	s.	d.
Amount to New Buildings Account, ...	£939	8	1			
Mortgage, Glasgow Corporation, ...	360	0	0			
Cash in Union Bank, ...	15	7	11			
				1,314	16	0

ARREARS OF SUBSCRIPTIONS.

	£	s.	d.	£	s.	d.
Arrears due for Session 1887-88, ...	£77	0	0			
Do. previous Sessions, ...	27	0	0			
				104	0	0
				£2,953	19	3

Dr. HOUSE EXPENDITURE ACCOUNT. (ABSTRACT 1887-88.) Cr.

Dr.						
To Balance in Treasurer's hands, ...				£16	3	6
Rents for Letting Rooms, ...				62	1	0
Amounts Received by Treasurer to meet Expenses, viz.:—						
From Institution of Engineers and Shipbuilders, ...	£140	0	0			
From Philosophical Society, ...	159	18	0½			
				299	18	0½
Balance due Treasurer, ...				3	14	6½
				£381	17	1

Cr.			
By Interest on Bond, ...	£130	15	7
Salary to Curator, ...	100	0	0
Salary of Attendant at Library, Cleaning, &c., ...	42	12	4
Taxes, ...	27	5	1
Feu-duty, ...	0	18	1
Gas Rates, ...	15	0	5
Water Rates, ...	5	12	6
Coals, ...	7	15	4
Insurance, ...	7	15	0
Repairs, ...	27	1	7½
Furnishings, ...	17	1	1½
	£381	17	1

The Account of the House Committee is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Philosophical Society.

W. J. MILLAR, *Secretary to House Committee.*

DECEASED MEMBERS.

DURING Session 1887-88 the following gentlemen have been removed by death from the roll of membership of the Institution—viz., Messrs H. W. BALL, JOHN INGLIS, W. J. CLARK, Members; Mr ROBERT HADFIELD, Life Member; and Mr JOHN MACDONALD, Graduate.

Mr H. W. BALL joined the Institution in 1873. He studied engineering with Messrs W. & G. Bertram, Edinburgh, and afterwards joined the firm of Messrs Alex. Chaplin & Co., Engineers, Glasgow. Mr Ball retired from the firm in 1885, and died in June, 1887.

Mr W. J. CLARK joined the Institution in 1875. He was born at Hylton, near Sunderland, in 1847. After studying at the University of Durham, Mr Clark served his apprenticeship with his father, Mr George Clark, at his marine engine works, Sunderland. He then went to St. John's College, Cambridge, taking honours there, and receiving the degree of M.A. Mr Clark afterwards joined the Southwick Marine Engineering Works, belonging to his father, where, in conjunction with his brothers, he assisted in the management. Besides the management of the workshop, Mr Clark found time to devote to mathematical and scientific studies, contributing papers from time to time. Mr Clark died on the 3rd of February, 1887.

Mr ROBERT HADFIELD joined the Institution as a Life Member in 1879. He was born at Sheffield in 1831, where he commenced business as a steel manufacturer in 1865. Afterwards he started the steel casting industry at Attercliffe, which he developed with great energy and skill until his death on 19th March, 1888.

Mr JOHN INGLIS was one of the original Members of the Institution, and was also a Member of the Scottish Shipbuilders' Association, which was incorporated with the Institution in 1865. Mr Inglis was a Member of Council of this Association during Sessions 1862-63 and 1863-64. Mr Inglis was a native of Glasgow, where he was born in 1819. He served his apprenticeship with Messrs Tod & M'Gregor. In 1847 Mr Inglis joined his brother, the late Mr Anthony Inglis, when the well-known firm of A. & J. Inglis was started as engineers at Whitehall Foundry. In 1862 the firm commenced shipbuilding at their Pointhouse Yard, to which was afterwards added a slip dock. The work of this firm is well known, a specialty being the American type of steamers for the China river trade. Mr Inglis died on 9th May, 1888.

Mr JOHN MACDONALD joined the Institution as a Graduate in 1887, and was engaged at Brisbane, Queensland, where he died on 19th February, 1888.

REPORT OF THE LIBRARY COMMITTEE.

DURING the past year 487 volumes have been lent out to 364 readers, and, in addition, a very large number of books have been consulted by the Members in the rooms of the Institution. The Committee would point out, however, that the Reading Room might be taken advantage of to a much greater extent than at present. The Members have access not only to the Periodicals and Transactions supplied to the Institution, but also to those which are obtained by the Philosophical Society, and thus are able to keep themselves acquainted with the advance in the different departments of science in all parts of the world.

During the year 67 volumes, 18 pamphlets, and 26 parts have been added to the Library. Of these 42 volumes were bought, 19 exchanged, and 6 presented. To the donors of the latter the Committee beg, on behalf of the Institution, to tender its best thanks. They think, however, that more of the Members should keep the Library in mind, and present it with books or drawings. The Committee are especially anxious that the Library should contain as complete a record as possible of the engineering of the district, and they hope the Members will help them to accomplish this.

The Institution exchanges Transactions with 41 scientific societies. Fourteen weekly, one fortnightly, eleven monthly, three quarterly periodicals are received regularly in exchange for the Transactions. During the past year 67 volumes have been bound. There are in the Library about 1735 volumes.

The following are the Lists of Donations and Exchanges for the year:—

DONATIONS TO LIBRARY.

Report, British Association, 1886. From the Council of the Association.

Transactions, Canadian Society of Civil Engineers, Vol. I.

Engineering Popularly and Socially Considered, by J. W. C. Haldane, Esq., C.E. and M.E. From the Author.

Proceedings of the Naturalists' Society, Bristol. From the Society.

Annual Catalogue, Massachusetts Institute of Technology, Boston. From the Institute

Proceedings, Bristol Naturalist Society, Bristol. From the Society.

Report on the River Tay, by David Cunningham, Esq., C.E., F.R.S.E. From the Author.

Treatise on Shipbuilding, by Marmaduke Stalkartt. Presented by J. H. Carruthers, Esq.

NEW BOOKS ADDED TO LIBRARY.

Submarine Boats—Havgaard.
Arc and Glow Lamps—Maier.
Magneto and Dynamo Electric Mechanics—Esson.
Electric Transmission of Energy—Kapp.
Hand Book for Steam Users—Bale.
Hydraulic Power and Machinery—Robinson.
Notes on Concrete—Newman.
Steam Boilers—Munro.
Railway Problems—Jeans.
The Steam Engine—Holmes.
Text Book of the Steam Engine—Goodeve.
Electricity in the Service of Man—Urbauitzky.
Conversion of Heat into Work—Anderson.
Cable and Rope Traction—Smith.
The Engineer's Handbook—Hutton.
Mechanics and Machinery—Kennedy.

Drainage of Lands, Towns, &c.—Dempsey.
Bridge Construction—Fidler.
British Mining—Hunt.
Papers and Memoirs of Professor Fleeming Jenkin, second volume.
Six Centuries of Work and Wages—Rogers.
The Ordnance Survey of the United Kingdom—White.
Great Industries of Great Britain, 3 vols.
Elements of Metallurgy—Phillips.
The Design and Construction of Harbours—Stevenson.
Gold, its Occurrences and Extraction—Lock.
Reign of Queen Victoria, 2 vols.
Instructions as to the Survey of the Hull, Equipments and Machinery of Steam Ships.
Mine Surveying—Brough.
Notes of Formula—Laharpe.
Electrical Instrument Making—Battone.
On Electricity—Forbes.
Moteurs à Gaz Tonnant—M. Aime Witz.
Statique Graphique—Hermann.
Marine Steam Engine—Sennet.
Depreciation of Factories—Mathieson.
Testing of Material of Construction—Unwin.

Copies of Library Catalogue, price 1s, may be had at the Library, 207 Bath Street, or from the Secretary.

HENRY DYER, *Convener.*

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &c.:—

Institution of Civil Engineers.
Institution of Civil Engineers of Ireland.
Institution of Mechanical Engineers.
Institution of Naval Architects.

Institute of Mining and Mechanical Engineers.
Iron and Steel Institute.
Liverpool Polytechnic Society.
Liverpool Engineering Society.
Literary and Philosophical Society of Manchester.
Midland Institute of Mining, Civil, and Mechanical Engineers.
Mining Institute of Scotland.
Patent Office, London.
Philosophical Society of Glasgow.
Royal Scottish Society of Arts.
Royal Dublin Society.
South Wales Institute of Engineers.
Society of Engineers.
Society of Arts.
Manchester Association of Engineers.
North-East Coast Institution of Engineers and Shipbuilders.
The Sanitary Institute of Great Britain.
The Hull and District Institution of Engineers and Naval Architects.
Bristol Naturalists' Society, Bristol.
American Society of Civil Engineers.
American Society of Mechanical Engineers.
Geological Survey of Canada.
The Canadian Institute, Toronto.
The Canadian Society of Civil Engineers.
Master Car Builders' Association, U.S.A.
The Technical Society of the Pacific Coast, U.S.A.
Smithsonian Institution, U.S.A.
Bureau of Steam Engineering, Navy Department, U.S.A.
Royal Society of Tasmania.
Royal Society of Victoria.
The Engineering Association of New South Wales.
Royal Academy of Sciences, Lisbon.
Société des Ingénieurs Civils de France.
Société Industrielle de Mulhouse.
Société d'Encouragement pour l'Industrie Nationale.

Société des Anciens Elèves des Ecôles Nationales d'Arts et Métiers.
Société des Sciences Physiques et Naturelles de Bordeaux.
Austrian Engineers' and Architects' Society, Vienna.
Engineers and Architects' Society of Naples.
The Association of Civil Engineers of Belgium.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

Annales Industrielles.
Colliery Guardian.
Engineering.
Indian Engineering.
Industries.
Iron.
Iron and Coal Trades' Review.
Journal de l'Ecole Polytechnic.
Nature.
Revue Industrielle.
The Engineer.
The Indian Engineer.
Indian Engineering.
The Machinery Market.
The Marine Engineer. The American Manufacturer and Iron World.
The Contract Journal. The Mechanical World. Stahl und Eisen.
Revue Maritime et Coloniale, Paris. L'Industria.
The Scientific News.

COPIES OF THE TRANSACTIONS ARE FORWARDED TO THE FOLLOWING COLLEGES, LIBRARIES, &C.:—

Glasgow University.
University College, London.
M'Gill University, Montreal.
Stevens Institute of Technology, U.S.A.
Cornell University, U.S.A.
Mitchell Library, Glasgow.
Stirling's Library, Glasgow.
Dumbarton Free Library.
Lloyds' Office, London.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
Mercantile Marine Service Association, Liverpool.
The Yorkshire College, Leeds.

The Library of the Institution, at the Rooms, 207 Bath Street, is open daily from 9-30 a.m. till 8 p.m.; on Meeting Nights of the

Institution and Philosophical Society, till 10 p.m.; and on Saturdays till 2 p.m. Books will be lent out on presentation of Membership Card to the Sub-Librarian.

Members have also the privilege of consulting the Books in the Library of the Philosophical Society.

The use of Library and Reading Room is open to Members, Associates, and Graduates.

The Library is open during Summer from 9-30 a.m. till 5 p.m., and on Saturdays till 2 p.m.

The Portrait Album lies in the Library for the reception of Members' Portraits.

Members are requested when forwarding Portraits to attach Signature to bottom of Carte.

The LIBRARY COMMITTEE are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to Library.

The Council, being desirous of rendering the Transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such Papers should be sent to the Secretary, so that the dates of reading may be arranged.

Annual Subscriptions are due at the commencement of each Session, viz.:—

MEMBERS, £1 10s; ASSOCIATES, £1; GRADUATES, 10s.

LIFE MEMBERS, £20; LIFE ASSOCIATES, £15.

Membership Application Forms can be had at the Secretary's Office, 261 West George Street, or from the Sub-Librarian at the Rooms, 207 Bath Street.

Copies of the Reprint of Vol. VII., containing Paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary. Price to Members, 7/6.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his Office, 117 George Street, be furnished with Billets for attending the Meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each Month, from November till April, with the exception of the 4th Monday of December.

LIST

OF

HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

OF THE

Institution of Engineers and Shipbuilders in Scotland

(INCORPORATED),

SESSION 1887-88.

HONORARY MEMBERS.

James Prescott Joule, LL.D., F.R.S., 12 Wardle Road, Sale, near Manchester.

Professor **Charles Piazzi Smyth**, F.R.S.E., Astronomer-Royal for Scotland, 15 Royal Terrace, Edinburgh.

Professor Sir **William Thomson**, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow.

Professor R. **Clausius**, the University, Bonn, Prussia.

Professor **John Tyndall**, D.C.L., LL.D., F.R.S., &c., Hindhead House, Haslemere.

His Grace the Duke of Sutherland, Trentham, Stoke-upon-Trent.

Lord **Armstrong**, C.B., LL.D., D.C.L., F.R.S., Newcastle-on-Tyne.

Professor H. **Von Helmholtz**, Berlin.

MEMBERS.

DATE OF ELECTION.			
1883, Mar. 20:	Geo. A.	Agnew,	2 Osborne Terrace, Govan.
1859, Jan. 19:	James	*Aitken, Jun.,	Shipbuilder, Whiteinch, Glasgow.
1860, Dec 26:	William	Aiton,	Sandford Lodge, Peterhead.
188[illegible], Jan. 25:	Prof. Thomas	Alexander,	C.E., Trinity College, Dublin.
Original:	Alexander	Allan,	Glen House, The Valley, Scarborough.
1872, Feb. 27:	A. B.	Allan, C.E.,	Burgh Surveyor, Burgh Chambers, Govan.
1869, Jan. 20:	William	Allan,	Scotia Engine Works, Sunderland.
1864, Dec. 21:	James B.	Alliott,	The Park, Nottingham.
G. 1865, Feb. 15: M. 1877, Dec. 18:	Wm. M.	Alston,	50 Sardinia Terrace, Hillhead, Glasgow.
1886, Dec. 21:	Alexander	†Amos,	Sydney, New South Wales.
1886, Dec. 21:	Alexander	†Amos, Jun.,	247 George Street, Sydney, New South Wales.
G. 1874, Feb. 24: M. 1880, Nov. 23:	James	Anderson,	100 Clyde St., Glasgow.
1888, Jan. 24:	F. W.	Anderson,	314 Dumbarton Road, Glasgow.
1860, Nov. 28:	Robert	Angus,	Lugar Ironworks, Cumnock.
1887, Dec. 20:	W. David	Archer,	Edin Villa, Dalmuir.
1883, Dec. 18:	J. Cameron	Arrol,	18 Blythswood Square, Glasgow.
1875, Dec. 21:	Thomas A.	Arrol,	18 Blythswood Square, Glasgow.
1885, Jan. 27:	William	†Arrol,	10 Oakley Ter., Glasgow.
Original:	David	Auld,	65 Rochester St., Glasgow.
1885, Apr. 28:	John	Auld,	Whitevale Foundry, Glasgow.

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

1881, Oct. 25:	Allan W.	Baird,	Eastwood Villa, St. Andrew's Drive, Pollokshields.
1880, Feb. 24:	William N.	Bain,	Collingwood, Pollokshields, Glasgow.
1887, Nov. 22:	Michael R.	Barnett,	Lilybank House, Johnstone.
1876, Jan. 25:	James	Barr,	Underwood House, Paisley.
1882, Mar. 21:	Prof. Archd.	Barr, B.Sc., C.E.,	The Yorkshire College, Leeds.
1868, Apr. 22:	Edward	Barrow,	136 Rue Mercator, Sud, Antwerp, Belgium.
1881, Mar. 22:	George H.	Baxter,	Ramage & Ferguson, Leith.
G. 1877, Nov. 20: M. 1887, Apr. 6:	J. T.	Baxter,	9 Brighton Ter., Govan.
G. 1871, Feb. 21: M. 1865, Nov. 24:	William S.	Beck,	246 Bath Street, Glasgow.
1875, Jan. 26:	Charles	Bell,	21 Victoria Place, Stirling.
	David	*Bell,	Shipbuilder, Yoker, near Glasgow.
1880, Mar. 23:	Imrie	Bell, C.E.,	36 Kersland Terrace, Hillhead.
G. 1883, Mar. 20: M. 1884, Nov. 25:	Andrew S.	Biggart, C.E.,	Forth Bridge Works, South Queensferry.
1884, Mar. 25:	John Harvard	Biles,	Clydebank Shipyard, near Glasgow.
1866, Dec. 26:	Edward	Blackmore,	Rookwood Road, Stamford Hill, London, N.
1864, Oct. 26:	Thomas	Blackwood,	Shipbuilder, Port-Glasgow.
1869, Feb. 17:	Geo. M'L.	Blair,	127 Trongate, Glasgow.
1867, Mar. 27:	James M.	Blair,	2 Bute Gardens, Hillhead, Glasgow.
1883, Jan. 23:	Chas. C.	Bone, C.E.,	23 Miller Street, Glasgow.
1883, Oct. 23:	William L.	Bone,	Ant and Bee Works, West Gorton, Manchester.
1874, Jan. 27:	Howard	Bowser,	13 Royal Crescent, W., Glasgow.

	1880, Mar. 23:	James	Brand, C.E.,	109 Bath Street, Glasgow.
	1873, Dec. 23: 1884, Jan. 22:	James	Broadfoot,	55 Finnieston St., Glasgow.
	1865, Apr. 26:	Walter	*Brock,	Engine Works, Dumbarton.
	1859, Feb. 16:	Andrew	*Brown,	London Works, Renfrew.
G. M.	1876, Jan. 25: 1885, Nov. 24:	Andrew M'N.	Brown,	Castlehill House, Renfrew.
	1886, Mar. 23:	George	Brown,	Comely Park, Dumbarton.
	1885, Apr. 28:	Walter	Brown,	Castlehill, Renfrew.
	1880, Dec. 21:	William	Brown,	Albion Works, Woodville Street, Govan, Glasgow.
G. M.	1874, Jan. 27: 1884, Jan. 22:	William	Brown,	Houston Terrace, Paisley Road, Renfrew.
	1858, Mar. 17:	James	Brownlee,	23 Burnbank Gardens, Glasgow.
	1877, Oct. 30:	Robert	Bruce,	157 West George Street, Glasgow.
	1860, Dec. 26:	James C.	Bunten,	100 Cheapside St., Glasgow.
	1866, Apr. 26:	Amedee	Buquet, C.E.,	15 Chemiss, St. Martin, Pontoise, S. O. France.
G. M.	1872, Oct. 24: 1885, Nov. 22:	Hartvig	Burmeister,	Burmeister & Wain, Copenhagen, Denmark.
	1880, Dec. 21:	James W.	Burns,	5 Cecil Street, Paisley Rd., W., Glasgow.
	1881, Mar. 22:	Thomas	Burt,	26 Carrington St., Glasgow.

	1878, Oct. 29:	Edward B.	Caird,	20 Lynedoch St., Glasgow.
	1878, Dec. 17:	James (*Member of Council.*)	Caldwell,	130 Elliot Street, Glasgow.
	1885, Mar. 24:	John B.	Cameron,	160 Hope Street, Glasgow.
	1875, Dec. 21:	J. C.	Cameron,	24 Pollok Street, Glasgow.
	1886, Jan. 26:	Andrew	Campbell,	53 Crookston Street, S.S. Glasgow.
	1868, Dec 23:	David	Carmichael,	Ward Foundry, Dundee.
	1859, Nov. 23:	Peter	Carmichael,	Dens Works, Dundee.
	1862, Jan. 8:	John	Carrick,	6 Park Quadrant, Glasgow.

1881, Nov. 22:	John H.	Carruthers,	Craigmore, Queen Mary Avenue, C'shill, Glasgow.
1859, Oct. 26:	Robert	Cassels,	168 St. Vincent Street, Glasgow.
1867, Jan. 30:	Albert	Castel,	3 Lombard Court, London, E.C.
1883, Jan. 23:	John	Clark,	British India Steam Navigation Co., 16 Strand, Calcutta.
1880, Nov. 2:	James	Clarkson,	Maryhill Engine Works, Maryhill, Glasgow.
1860, Apr. 11:	James	Clinkskill,	1 Holland Place, Glasgow.
1884, Feb. 26:	James T.	Cochran,	Duke Street, Birkenhead.
1881, Oct. 25:	George	Cockburn,	Rhodora Villa, St. Andrew's Drive, Pollokshields, Glasgow.
G. 1876, Dec. 19: M. 1884, Mar. 25:	Charles	Connell,	Whiteinch, Glasgow.
G. 1877, Dec. 18: M. 1885, Nov. 24:	James	Conner,	Isle of Wight Railway, Sandown, England.
1864, Feb. 17:	James	Copeland,	16 Pulteney St., Glasgow.
1864, Jan. 20:	William R.	Copland, C.E.,	146 West Regent Street, Glasgow.
1868, Mar. 11:	S. G. G.	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1866, Nov. 28:	M'Taggart	Cowan, C.E.,	109 Bath Street, Glasgow.
1868, Apr. 22:	David	Cowan, C.E.,	Mount Gerald House, Falkirk.
1861, Dec. 11:	William	Cowan,	46 Skene Terrace, Aberdeen.
1883, Dec. 18:	Samuel	Crawford,	Clydebank, near Glasgow.
1881, Mar. 22:	William	Crockatt,	2 Marjory Place, Pollokshields, Glasgow.
1866, Dec. 26:	James L.	Cunliff,	Plewlands House, Merchiston, Edinburgh.

1872, Nov. 26: David Cunningham, C.E., Harbour Chambers, Dundee.

1884, Dec. 23: Peter N. Cunningham, 5 North East Park Street, Glasgow.

1869, Jan. 20: James Currie, 16 Bernard Street, Leith.

1888, Jan. 24: John Darling, 34 Queen Square, Glasgow.

G. 1874, Feb. 24:
M. 1882, Dec. 19: James Davie, 234 Cathcart Road, Crosshill, Glasgow.

1861, Dec. 11: Thomas Davison, 248 Bath Street, Glasgow.

1864, Feb. 17: St. J. V. Day, C.E., 115 St. Vincent Street, Glasgow.

1869, Feb. 17: James Deas, C.E., Engineer, Clyde Trust, 7 Crown Gardens, Glasgow.

1882, Dec. 19: J. H. L. Van Deinse, Heerengracht No. 81, Amsterdam.

1883, Nov. 21: James Denholm, 5 Derby Terrace, Sandyford Street, Glasgow.

1866, Feb. 14: A. C. H. Dekke, Shipbuilder, Bergen, Norway.

Peter *Denny, Helenslee, Dumbarton.

1887, Oct. 25: James Denny, Engine Works, Dumbarton.

1888, Feb. 21: Archibald Denny, Braehead, Dumbarton.

1888, Feb. 21: Peter Denny, jun., Bellfield, Dumbarton.

G. 1873, Dec. 23:
M. 1884, Jan. 22: Peter Dewar, 163 Sandyford St., Glasgow.

1878, Mar. 19: Frank W. Dick, Hallside Steel Works, Newton.

G. 1873, Dec. 24:
M. 1878, Jan. 22: James S. Dixon, 97 Bath Street, Glasgow.

1871, Jan. 17: William Dobson, The Chesters, Jesmond, Newcastle-on-Tyne

1864, Jan. 20: James Donald, Abbey Works, Paisley.

1876, Jan. 25: James Donaldson, Almond Villa, Renfrew.

1863, Nov. 25: Robert Douglas, Dunnikier Foundry, Kirkcaldy.

1886, Nov. 23: Patrick Doyle, C.E., 19 Lall. Bazar, Calcutta.

1884, Dec. 23: John W. W. Drysdale, 5 Whitehill Gardens, G'gow.

1882, Oct. 24: Chas. R. Dubs, Glasgow Locomotive Works, Glasgow.

1886, Nov. 23: John Duncan, Ardenclutha, Port-Glasgow.

1887, Apr. 6: D. J. Russell Duncan, C.E., 2 Victoria Mansions, Westminster, London, S.W.

1864, Oct. 26: Robert *Duncan, (*Past President.*) Shipbuilder, Port-Glasgow.

1881, Jan. 25: Robert Duncan, Whitefield Engine Works, Govan, Glasgow.

1873, Apr. 22: Robert Dundas, C.E., (*Vice President.*) 3 Germiston Street, Glasgow.

1869, Nov. 23: David Jno. Dunlop, (*Vice President.*) Inch Works, Port-Glasgow.

1877, Jan. 23: John G. Dunlop, J. & G. Thomson, Clydebank, Dumbartonshire.

1880, Mar. 23: Hugh S. Dunn, Earlston Villa, Caprington, Kilmarnock.

1886, Oct. 26: Peter Dunn, C.E., 3 Germiston St., Glasgow.

1883, Oct. 23: Henry Dyer, C.E., M.A., (*Vice President.*) 8 Highburgh Terrace, Dowanhill, Glasgow.

1876, Oct. 24: Jn. Marshall Easton, Redholm, Helensburgh.

1885, Feb. 24: Francis Elgar, LL.D., Director, H. M. Dockyard, Admiralty, London, S.W.

1875, Oct. 26: James G. Fairweather, C.E., B.Sc., 21 St. Andrew Square, Edinburgh.

G. 1869, Nov. 23: M. 1878, Mar. 19: John Ferguson, Shipbuilder, Leith.

1874, Feb. 24: Immer Fielden, 2 Thornton villas, Holderness Road, Hull.

1880, Jan. 27: Alexander Findlay, Hamilton Road, Motherwell.

G. 1873, Dec. 23: M. 1884, Nov. 25: E. Walton Findlay, Ardeer, Stevenston.

1884, Dec. 23: Finlay Finlayson, Alexandria Place, Colt Terrace, Coatbridge.

Original: William Forrest, 66 Bath Street, Glasgow.

1872, Nov. 26: Thomas Forrest, M.E., Dumfries Ironworks, Dumfries.

1883, Dec. 18: Lawson Forsyth, 10 Grafton Sq., Glasgow.

1870, Jan. 18: William Foulis, (*Member of Council.*) Engineer, Corporation Gas Works, 42 Virginia St., Glasgow.

1880, Nov. 2: Samson Fox, Leeds Forge, Leeds.

1879, Nov. 25: John Frazer, P. Henderson & Co., 15 St. Vincent Place, Glasgow.

1885, Jan. 27: Peter Fyfe, 1 Montrose St., Glasgow.

1858, Nov. 24: James M. Gale, C.E., (*Past President; Member of Council, and Treasurer.*) Engineer, Corporation Water Works, 23 Miller Street, Glasgow.

1862, Jan. 8: Andrew Galloway, C.E., St. Enoch Station, Glasgow.

1887, Oct. 25: Lewis P. Garrett, 19 Renfield St., Glasgow.

1873, Dec. 23: Bernard Gatow, Veritas Office, 29 Waterloo Street, Glasgow.

1888, Mar. 20: Ernest Gearing, Abbotrule, Woolston, Southampton.

G. 1873, Dec. 23:
M. 1882, Mar. 21: } Andrew Gibb, Rait & Gardiner, Millwall Docks, London.

1886, Nov. 23: Paterson Gifford, 6 Union Street, Glasgow.

1859, Nov. 23: Archibald *Gilchrist, 11 Sandyford Place, Glasgow.

G. 1866, Dec. 26:
M. 1878, Oct. 29: } James Gilchrist, Stobcross Engine Works, Finnieston Quay, Glasgow.

1859, Dec. 21: David C. Glen, 14 Annfield Place, Dennistoun, Glasgow.

1868, Nov. 25: Thomas Goldie, Waverley Mills, Ceres Road, Cape of Good Hope.

1864, Feb. 17: James Goodwin, Ironfounder, Ardrossan.

1866, Mar. 28:	Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.
1868, Mar. 11:	Joseph	Goodfellow,	136 Sackville Place, Stirling Road, Glasgow.
1882, Apr. 25:	H. Garrett	Gourlay,	Dundee Foundry, Dundee.
	Edwin	*Graham,	Osbourne, Graham, & Co., Hylton, Sunderland.
1858, Mar. 12:	George	Graham, C.E.,	Engineer, Caledonian Railway, Glasgow.
1876, Jan. 25:	Thomas M.	Grant,	108 Hill Street, Glasgow.
1862, Jan. 8:	James	Gray,	Pathhead Colliery, Cumnock, Ayrshire
1881, Dec. 20:	L. John	Groves,	Engineer, Crinan Canal, Ardrishaig.
1872, Feb. 27:	A. A.	Haddin, C.E.,	131 West Regent Street, Glasgow.
1881, Jan. 25:	William	Hall, jun.,	Shipbuilder, Aberdeen.
1876, Oct. 24:	David	Halley,	Burmeister & Wain, Copenhagen, Denmark.
G. 1874, Feb. 24: M. 1885, Nov. 24:	Archibald	Hamilton,	New Dock Works, Govan.
G. 1873, Dec. 23: M. 1881, Nov. 22:	David C.	Hamilton,	Clyde Shipping Co., 21 Carlton Place, Glasgow.
G. 1866, Dec. 26: M. 1873, Mar. 18:	James	Hamilton, Jun.,	Ardedynn, Kelvinside, Glasgow.
	John	*Hamilton,	22 Athole Gardens, Gl'gow.
G. 1869, Nov. 23: M. 1875, Feb. 23:	J. B.	Hamond,	28 Upper Park Road, Hampstead, London, N.W.
1876, Feb. 22:	Walter	Hannah,	Barwood, Helensburgh.
G. 1880, Nov. 2: M. 1884, Jan. 22:	Bruce	Harman,	Lancefield House, Lancefield Street, Glasgow.
1878, Mar. 19:	Timothy	Harrington,	61 Gracechurch Street, London, E.C.
1875, Jan. 26:	Peter T.	Harris,	19 West St. (S.S.), Glasgow.

G. 1874, Feb. 24: M. 1880, Nov. 23:	C. R.	Harvey,	166 Renfrew St., Glasgow.
1887, Feb. 22:	John H.	Harvey,	Benclutha, Port-Glasgow.
1864, Nov. 23:	John	Hastie,	Kilblain Engine Works, Greenock.
1871, Jan. 17:	William	Hastie,	Kilblain Engine Works, Greenock.
1879, Nov. 25:	A. P.	†Henderson,	30 Lancefield Quay, Glasgow.
1877, Feb. 20:	David	*Henderson,	Meadowside, Partick, Glasgow.
1873, Jan. 21:	John	†Henderson, Jun.,	Meadowside, Partick, Glasgow.
1879, Nov. 25:	John L.	†Henderson,	Westbank House, Partick, Glasgow.
1878, Dec. 17:	William	Henderson,	Meadowside, Partick, Glasgow.
1870, May 31:	Richard	Henigan, C.E.,	Alma Road, Avenue Place, Southampton.
G. 1881, Oct. 25: M. 1887, Oct. 25:	Charles G.	Hepburn,	130 Elizabeth Street, Sydney.
1877, Feb. 20:	George Laurence	*Hill, C.E.,	2 Alfred Terrace, Hillhead, Glasgow.
1880, Nov. 2:	Charles P.	Hogg, C.E.,	175 Hope Street, Glasgow.
1883, Mar. 20:	John	Hogg,	Victoria Engine Works, Airdrie.
1880, Mar. 23:	F. G.	Holmes, C.E.,	109 Bath Street, Glasgow.
1883, Mar. 20:	Matthew (*Member of Council.*)	Holmes,	Netherby, Lenzie.
1888, Mar. 20:	Robert	Houston,	Clyde View Cottage, Renfrew.
Original:	James	Howden.	8 Scotland Street, Glasgow.
1884, Apr. 22:	John G.	Hudson,	18 Aytoun Road., Pollokshields, Glasgow.
Original:	Edmund	*Hunt,	87 St. Vincent St., Glasgow.

1881, Jan. 25:	James	Hunter,	Aberdeen Iron Works, Aberdeen.
G, 1873, Dec. 23: M. 1885, Nov. 24:	Guybon	Hutson,	Kelvinhaugh Engine Works, Glasgow.
G. 1873, Dec. 23: M. 1877, Feb. 20:	P. S.	Hyslop,	14 Leven Street, Pollokshields.
1861, May 1:	John	Inglis,	Point House Shipyard, Glasgow.
1879, Jan. 21:	Thos. F.	Irwin,	2A Tower Chambers, Old Churchyard, Liverpool.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan, Glasgow.
1888, Jan. 24:	Prof. Philip	Jenkins,	Glasgow University.
1884, Jan. 22:	J. Yate	Johnson, C.E.,	115 St. Vincent Street, Glasgow.
1879, Feb. 25:	David	Johnston,	Eden Villa, Govan, G'gow.
1870, Dec. 20:	David	Jones,	Highland Railway, Inverness.
1883, Jan. 23:	F. C.	Kelson,	Angra Bank, Waterloo Park, Waterloo, Liverpool.
1872, Mar. 26:	Ebenezer	Kemp,	Linthouse Engine Works, Govan, Glasgow.
1875, Nov. 23:	William	Kemp,	Ellen St. Engineering Works, Govan, Glasgow.
1878, Mar. 19:	Hugh	Kennedy,	Redclyffe, Partickhill, Glasgow.
1877, Jan. 23:	John	Kennedy,	R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.
1876, Feb. 22:	Thomas	Kennedy, (*Member of Council.*)	Water Meter Works, Kilmarnock.

1876, Oct. 24:	Andrew	Kerr, C.E.,	Town Surveyor's Office, Warrnambool, Victoria, Australia.
	David	*Kinghorn,	172 Lancefield St., Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	Tower Buildings, Water Street, Liverpool.
1885, Nov. 24:	Frank E.	†Kirby,	Detroit, U.S., America.
1864, Oct. 26:	Alex. C. (*President.*)	Kirk, LL.D.,	19 Athole Gardens, Kelvinside, Glasgow.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, 99 Southwark Street, London, S.E.
1885, Jan. 27:	Charles A.	Knight,	107 Hope Street, Glasgow.
1880, Mar. 23:	Frederick	Krebs,	Copenhagen, Denmark.
1858, Apr. 14:	David	Laidlaw,	Chaseley, Skelmorlie, by Glasgow.
1884, Mar. 25:	John	Laidlaw,	98 Dundas Street, S.S., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 E. Milton St., Glasgow.
1875, Oct. 26:	William	Laing,	17 M'Alpine St., Glasgow.
1880, Mar. 20:	Andrew	Laing,	2 Glenavon Ter., Partick.
1880, Feb. 24:	James	Lang,	c/o George Smith & Sons, City Line, 45 West Nile Street, Glasgow.
1884, Feb. 26:	John	Lang, Jun.,	Church Street, Johnstone.
1888, Feb. 21:	George B.	Laurence,	1 Belmar Terrace, Pollokshields.
Original:	James G. (*Past President.*)	*Lawrie,	2 Westbourne Terrace, Glasgow.
G. 1873, Dec. 23: M. 1876, Oct. 24:	Charles C.	Lindsay, C.E.,	167 St. Vincent St., Glasgow.
1884, Feb. 26:	John	List,	D. Currie & Co., Blackwall, London, E.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.

1865, Dec. 20:	John L.	Lumsden,	19 Old Hall St., Liverpool.
1888, Feb. 21:	Hugh D.	Lusk,	Rosebank, Greenock.
1885, Oct. 27:	John	Lyall,	69 St. Vincent Crescent, Glasgow.
1873, Jan. 21:	James M.	Lyon, M.E.,	Engineer and Contractor, Singapore.
1858, Feb. 17:	David	M'Call, C.E.,	160 Hope Street, Glasgow.
1874, Mar. 24:	Hector	MacColl,	MacIlwaine, Lewis, & Co., Shipbuilders and Engineers, Belfast.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
1883, Oct. 23:	James	M'Creath, C.E.,	208 St. Vincent Street, Glasgow.
1871, Jan. 17:	David	M'Culloch,	Vulcan Works, Kilmarnock.
1884, Feb. 26:	James	M'Ewan,	Cyclops Foundry, 50 Peel Street, London Road, Glasgow.
1880, Nov. 2:	James W.	Macfarlane,	16 Queen's Cres., Cathcart.
1886, Oct. 26:	Walter	Macfarlane,	12 Lynedoch Cres., Glasgow.
G. 1874, Feb. 24: M. 1885, Nov. 24:	George	M'Farlane,	65 Great Clyde Street, Glasgow.
1886, Jan. 26:	Thomas	M'Gregor,	10 Mosesfield Terrace, Springburn.
1887, Nov. 22:	Hugh	M'Intyre,	19 Albion Cres., Partick.
1887, Apr. 6:	Edward	Mackay,	8 George Square, Greenock.
1881, Mar. 22:	William A.	Mackie,	3 Broomhill Terrace, Partick, Glasgow.
1888, Apr. 24:	James	M'Kechnie,	8 Glenavon Ter., Partick.
1873, Jan. 21:	J. B. Affleck	M'Kinnel,	Dumfries Iron Works, Dumfries.
1859, Dec. 21:	Robert	M'Laren,	Eglinton Foundry, 22 Canal Street, S.S., Glasgow.

G. 1880, Nov. 2: M. 1885, Dec. 22:	Robert	M'Laren, Jun.,	Eglinton Foundry, 22 Canal Street, S.S., Glasgow.
	Sir Andrew	*Maclean,	Viewfield House, Partick, Glasgow.
G. 1874, Feb. 24: M. 1885, Nov. 24:	Andrew	M'Lean, Jun.,	Viewfield House, Partick.
1884, Dec. 23:	James	M'Lellan,	———
1858, Nov. 24:	Walter	M'Lellan.	127 Trongate, Glasgow.
1886, Dec. 21:	William T.	†Maclellan,	Clutha Iron Works, Glasgow.
	John	*M'Millan,	Shipbuilder, Dumbarton.
	William	*MacMillan,	19 Elgin Terrace, Partick, Glasgow.
1884, Dec. 23:	John	M'Neil,	Helen St., Govan, Glasgow.
1883, Jan. 23:	James	M'Ritchie, C.E.,	Singapore.
1875, Dec. 21:	George	Mathewson,	Bothwell Works, Dunfermline.
1884, Apr. 22:	Henry A.	Mavor,	140 Douglas St., Glasgow.
1876, Jan. 25:	William W.	May,	11 Grey Road, Walton, Liverpool.
1887, Jan. 25:	Henry	Mechan,	17 Fitzroy Place, Glasgow.
1883, Feb. 20:	James	Meek.	Alfred Holt & Co., L'pool.
G. 1876, Oct. 24: M. 1882, Nov. 28:	James	Meldrum, C.E.,	3 Elmbank Street, Glasgow.
1883, Jan. 23:	William	Melville, C.E.,	Caledonian Ry., Buchanan Street, Glasgow.
1881, Mar. 22:	William	Menzies,	7 Dean Street, Newcastle-on-Tyne.
1861, Dec. 11:	Daniel	Miller, C.E.,	204 St. Vincent St., Glasgow.
G. 1873, Dec. 23: M. 1881, Nov. 22:	John F.	Miller,	Greenoakhill, Broomhouse.
Original:	James B.	Mirrlees,	45 Scotland St., Glasgow.
1886, Jan. 26:	Alexander	Mitchell,	4 Bellevue Terrace, Springburn.
1876, Mar. 21:	James (*Member of Council.*)	Mollison,	Lloyd's Register, 36 Oswald Street, Glasgow.

1869, Dec. 21:	John	Montgomerie,	210 Great Northern Ter., Possil Park.
1883, Nov. 21:	Joseph	Moore,	East Finchley, London.
1862, Nov. 26:	Ralph	Moore, C.E.,	13 Clairmont Gardens, Glasgow.
1878, Apr. 23:	Robert H.	Moore,	Mount Blue Works, Camlachie, Glasgow.
1888, Mar. 20:	William	Morison,	25 St. Vincent Crescent, Glasgow.
G. 1878, Dec. 17: M. 1883, Jan. 23.	Robert	Morton,	53 Waterloo St., Glasgow.
1885, Mar. 24:	Edmund	Mott,	Board of Trade Surveyor, 7 York Street, Glasgow.
1864, Feb. 17:	Hugh	Muir,	7 Kelvingrove Ter., Glasgow.
1882, Jan. 24:	John G.	†Muir,	Newport House, Eardisby.
1870, Mar. 22:	Wm. T.	Mumford,	36 Oswald Street, Glasgow.
1882, Feb. 21:	George	Munro,	254 Bath Street, Glasgow.
1882, Dec. 19:	Robert D.	Munro,	141 Buchanan St., Glasgow.
Original:	James	Murdoch,	Shipbuilder, Port-Glasgow.
1880, Jan, 27:	William	Murdoch,	20 Carlton Place, Glasgow.
1886, Jan. 26:	James	Murray,	8 Brown Street, Glasgow.
1877, Jan. 23:	Robert	Murray,	25A Coltman Street, Hull.
1881, Jan. 25:	Henry M.	Napier,	Shipbuilder, Yoker, near Glasgow.
1857, Dec. 23:	John	†*Napier,	23 Portman Sq., London.
1881, Dec. 20:	Robert T.	†Napier,	Shipbuilder, Yoker, near Glasgow.
Original:	Walter M.	Neilson, *(Past President.)*	Queen's Hill, Kirkcudbrightshire.
1869, Nov. 23:	Theod. L.	Neish,	22 Holyrood Crescent, Glasgow.
A. 1865, Apr. 26: M. 1879, Oct. 28:	R. S.	*Newall, F.R.S., F.R.A.S., &c.,	Ferndene, Gateshead-on-Tyne.
1883, Dec. 18:	Thomas	Nicol,	Clydebank, near Glasgow.

1884, Dec. 23:	Wm. H.	Nisbet,	Mavisbank, Partickhill, Glasgow.
1887, Apr. 6:	William	Nish,	15 Govan Road, Glasgow.
1876, Dec. 19:	Richard	Niven, C.E.,	3 Park Terrace, Ayr.
1861, Dec. 11:	John	Norman,	475 New Keppochhill Road, Glasgow.
1886, Jan. 26:	George	Oldfield,	238 Dewsbury Road, Leeds.
1882, Jan. 24:	Robert S.	Oliver, C.E.,	Highland Railway Co., Inverness.
1860, Nov. 28:	John W.	Ormiston,	Douglas Gardens, Uddingston.
1885, Mar. 24:	Alex. T.	Orr,	Westfield, Helensburgh.
1867, Apr. 24:	T. R.	Oswald,	The Southampton Shipbuilding & Engineering Works, Southampton.
1882 Mar. 21:	Geo. S.	Packer, F.I.C.,	Hallside Steel Works, Newton, near Glasgow.
1883, Nov. 21:	W. L. C.	Paterson,	19 St. Vincent Crescent, Glasgow.
1887, Nov. 22:	Prof. George	Paton, C.E.,	Royal Agricultural College, Cirencester.
1877, Apr. 24:	Andrew	Paul,	Levenford Works, Dumbarton.
G. 1884, Feb. 26: M. 1886, Dec. 21:	Matthew	Paul, Jun.,	Levenford Works, Dumbarton.
1880, Nov. 2:	James M.	Pearson, C.E.,	Strand Street, Kilmarnock.
1866, Dec. 26:	Sir William	Pearce, Bart., M.P.,	Fairfield Shipyard, Govan, Glasgow.
1868, Dec. 23:	Eugène	Perignon, C.E.,	105 Rue Faubourg St. Honoré, Paris.
1887, Oct. 25:	Robert Band	Pope,	Leven Shipy'd, Dumbarton.
1887, Apr. 6:	Theodor J.	Poretchkin,	Russian Imperial Navy, c/o Blackley Young & Co., 103 Holm St., Glasgow.

	John	*Price,	6 Osborne Villas, Jesmond, Newcastle-on-Tyne.
1877, Nov. 20:	F. P.	Purvis,	Craig Villa, Dumbarton.
1868, Dec. 23:	Henry M.	Rait,	155 Fenchurch St.,London.
1873, Apr. 22:	Richard	Ramage,	Shipbuilder, Leith.
1872, Oct. 22:	David	Rankine,	75 West Nile St., Glasgow.
1886, Mar. 23:	John F.	Rankin,	Eagle Foundry, Greenock.
1881, Jan. 25:	Charles	Reid,	Lilymount, Kilmarnock.
1883, Nov. 21:	George W.	Reid,	Highland Railway, Inverness.
1868, Mar. 11:	James (*Past President.*)	Reid,	Locomotive Works, Springburn, Glasgow.
1869, Mar. 17:	James	Reid,	Shipbuilder, Port-Glasgow.
	John	*Reid,	Shipbuilder, Port-Glasgow.
1880, Apr. 27:	John	Rennie,	Ardrossan Shipbuilding Co., Ardrossan.
G. 1873, Dec. 23: M. 1881, Nov. 22:	Charles H.	Reynolds,	9 Hamilton Crescent, Partick, Glasgow.
1886, Apr. 27:	James	Riley,	Steel Company of Scotland, 23 Royal Exchange Sq., Glasgow
1876, Oct. 24:	Duncan	Robertson,	8 Brighton Place, Govan, Glasgow.
1873, Jan. 21:	John	Robertson,	Grange Knowe, Pollokshields, Glasgow.
1863, Nov. 25:	William	Robertson,C.E.,	123 St. Vincent Street, Glasgow.
1884, Apr. 22:	R. A.	Robertson,	42 Aytoun Road, Pollokshields, Glasgow.
1888, Apr. 24:	J. F.	Robinson,	Atlas Works, Springburn, Glasgow.
Original:	Hazltn. R. (*Past President.*)	*Robson,	14 Royal Cresct., Glasgow.
1877, Feb. 20:	Jno.MacDonald	Ross,	11 Queen's Cres., Glasgow.

1861, Dec. 11:	Richard G.	Ross,	21 Greenhead St., Glasgow.
G. 1864, Nov. 23: M. 1870, Jan. 18:	Alex.	Ross, C.E.,	Lynnwood, Alva.
Original:	David (*Past President.*)	*Rowan,	231 Elliot Street, Glasgow.
G. 1875, Dec. 21: M. 1885, Jan. 27:	James	Rowan,	231 Elliot Street, Glasgow.
1877, Oct. 30:	Alexander	Russell,	186 North Street, Glasgow.
G. 1858, Dec. 22: M. 1863, Mar. 4:	George	Russell,	Engineer, Motherwell.
1881, Feb. 22:	Joseph	Russell,	Shipbuilder, Port-Glasgow.
1876, Oct. 24:	Peter	Samson,	Board of Trade Offices, Downing Street, London, S.W.
1885, Feb. 24:	James	Samuel, Jun.,	238 Berkeley Street, Glasgow.
1883, Feb. 20:	John	Sanderson,	Lloyd's Registry, 36 Oswald Street, Glasgow.
1882, Dec. 19:	Prof. Jas.	Scorgie, F.C.S.,	Civil Engineering College, Poona, India.
1872, Jan. 30:	James E.	Scott,	52 Coal Exchange, London.
1881, Jan. 25:	John	Scott,	Whitebank Engine Works, Kirkcaldy.
1860, Nov. 28:	Thos. B.	*Seath,	42 Broomielaw, Glasgow.
1875, Jan. 26:	Alexander	Shanks,	Belgrade, Aytoun Road, Pollokshields, Glasgow.
1858, Nov. 24:	William	Simons,	Tighnabruaich, Argyleshire.
1862, Jan. 22:	Alexander (*Member of Council.*)	Simpson, C.E.,	175 Hope Street, Glasgow.
1887, Jan. 25:	Robert	Simpson, B.Sc.,	175 Hope St., Glasgow.
G. 1877, Mar. 20: M. 1887, Dec. 20:	Nisbet	Sinclair,	27 La Crosse Terrace, Hillhead.
1871, Mar. 28:	Hugh	Smellie,	Belmont Grange Terrace, Kilmarnock.
Original:	Alexander	Smith,	57 Cook Street, Glasgow.

1880, Nov. 2:	Alexr. D.	Smith,	85 Maxwell Road, Pollokshields, Glasgow.
1869, Mar. 17:	David S.	Smith,	Hellenic Steam Navigation Co., Syra, Greece.
1871, Dec. 11:	Hugh	Smith,	Possil Engine Works, Possil Road.
1887, Oct. 25:	John Weir	Smith,	Fundicão do Bowman, Pernambuco, Brazil.
1870, Feb. 22:	Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn, Glasgow.
1887, Jan. 25:	Peter A.	Somervail,	35 Burnbank Gardens, Glasgow.
1883, Oct. 23:	Andrew	Sproul,	10 Virginia St., Greenock.
1886, Feb. 23:	George	Stanbury,	81 Brisbane St., Greenock.
1883, Dec. 18:	Alex. E.	†Stephen,	12 Park Terrace, Glasgow.
	John	†*Stephen,	Linthouse, Govan, Glasgow.
1881, Nov. 22:	Alex.	Steven,	Provanside, Glasgow.
1867, Jan. 30:	Duncan	Stewart,	47 Summer Street, Glasgow.
1874, Oct. 27:	Peter	Stewart,	53 Renfield Street, Glasgow.
G. 1873, Dec. 23: M. 1882, Oct. 24:	W. B.	Stewart,	18 Newton Place, Glasgow.
Original:	Patrick	Stirling,	The Great Northern Railway, Doncaster.
1881, Jan. 25:	Walter	Stoddart,	Caledonian Railway, Carstairs.
1877, Jan. 23:	James	Syme,	8 Glenavon Ter., Partick, Glasgow.
1879, Oct. 28:	James	Tait, C.E.,	Wishaw.
1882, Apr. 25:	Alex. M.	Taylor,	Java Cottage, Lenzie.
1885, Apr. 28:	Peter	Taylor,	62 Queen Street, Renfrew.
1879, Mar. 25:	Staveley	Taylor,	Russell & Co., Shipbuilders, Greenock.

1873, Dec. 23:	E. L.	Tessier,	Veritas Office, 29 Waterloo Street, Glasgow.
1885, Jan. 27:	George W.	Thode,	107 Hope Street, Glasgow.
1887, Apr. 26:	Arthur W.	Thomson, B.Sc.,	79 West Regent Street, Glasgow.
1882, Apr. 25:	Geo. P.	Thomson,	Clydebank, Dumbartonshire.
1883, Dec. 18:	George	Thomson,	9 Buckingham Ter., Partick, Glasgow.
1886, Mar. 23:	James	Thomson, Jun.,	Leven Shipyard, Dumbarton.
1874, Nov. 24:	Prof. James (*Past President.*)	Thomson, C.E., LL.D., F.R.SS.L. & E.,	2 Florentine Gardens, Hillhead Street, Glasgow,
1868, Feb. 12:	James M.	Thomson,	36 Finnieston St., Glasgow.
1882, Mar. 21:	James R.	Thomson,	Clydebank, Dumbartonshire.
1868, May 20:	John	Thomson,	36 Finnieston St., Glasgow.
1875, Jan. 26:	Robert S.	Thomson,	3 Melrose Street, Queen's Crescent, Glasgow.
1864, Feb. 17:	W. R. M.	Thomson,	96 Buchanan St., Glasgow.
1878, May 14:	W. B.	Thompson,	Ellengowan, Dundee.
Original:	Thomas C.	Thorburn,	35 Hamilton Square, Birkenhead.
1874, Oct. 27:	Prof. R. H.	Thurston, M.E., C.E.,	Sibley College, Cornell University, Ithaca, N.Y., U.S.A.
1875, Nov. 23:	John (*Member of Council.*)	Turnbull, Jun.,	Consulting Engineer, 255 Bath Street, Glasgow.
1876, Nov. 21:	Alexander	Turnbull,	15 Whitehill Terrace, Dennistoun, Glasgow.
1880, Apr. 27:	John	Tweedy,	Neptune Works, Newcastle-on-Tyne.
1865, Apr. 26:	W. W.	Urquhart,	Blackness Foundry, Dundee.
1883, Jan. 23:	Peter	Wallace,	Shipyard, Troon.

1885, Mar. 24:	W. Carlile	Wallace,	Loaning Villa, Cardross.
1886, Jan. 26:	John (*Member of Council.*)	Ward,	LevenShipyard, Dumbarton
1875, Mar. 23:	G. L. (*Member of Council.*)	Watson,	108 W. Regent St., Glasgow.
1864, Mar. 16:	W. Renny (*Member of Council.*)	Watson,	16 Woodlands Ter., Glasgow.
G. 1875, Dec. 21: M. 1886, Oct. 26:	R. G.	Webb,	c/o Fleming & Co., Bombay.
G. 1878, Dec. 17: M. 1887, Nov. 22:	Robert L.	Weighton, M.A.,	St. Peter's, Newcastle-on-Tyne.
	John	*Weild,	Underwriter, Exchange, Glasgow.
1874, Dec. 22:	George	Weir, M.E.,	18 Millbrae Cres., Langside, Glasgow.
1874, Dec. 22:	James	Weir, M.E.,	Silver Bank, Cambuslang, near Glasgow.
G. 1876, Dec. 19: M. 1884, Feb. 26:	Thomas D.	Weir, C.E.,	———
1869, Feb. 17:	Thomas M.	Welsh,	63 St. Vincent Cres., Glasgow.
1868, Dec. 23:	Henry H.	West,	14 Castle Street, Liverpool.
1883, Feb. 20:	Richard S.	White,	Shipbuilder, Armstrong, Mitchell, & Co., Newcastle on-Tyne.
1888, Mar. 20:	George	Whitehall,	c/o Walsh, Lorett, & Co., Bombay.
1887, Apr. 6:	James	Whitehead,	52 Rose Street, Glasgow.
1884, Nov. 25:	John	Wildridge,	ConsultingEngineer,Sydney, N.S.W., Australia.
1876, Oct. 24:	Francis W.	Willcox,	45 West Sunniside, Sunderland.
1884, Dec. 23:	James	Williamson,	Barclay, Curle, & Co., Whiteinch.
1883, Feb. 20:	Robert	Williamson,	Lang & Williamson, Engineers, &c., Newport, Mon.

1878, Oct. 29:	Thomas	Williamson,	Clyde Bridge Steel Works, Rutherglen.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.
1868, Dec. 23:	James	Wilson, C.E.,	Water Works, Greenock.
1870, Feb. 22:	John	Wilson,	165 Onslow Drive, Dennistoun, Glasgow.
1887, Oct. 25:	David	Wilson,	Arecibo, Porto Rico, West Indies.
1858, Jan. 20:	Thomas	†*Wingate,	Viewfield, Partick.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.

ASSOCIATES.

	Thomas	*Aitken,	8 Commercial Street, Leith.
1883, Oct. 28:	John	Barr,	Secretary to Glenfield Co., Kilmarnock.
1882, Dec. 19:	Wm.	Begg,	Gartfern, High Crosshill, Rutherglen.
1884, Dec. 23:	W. S. C.	Blackley,	10 Hamilton Crescent, Partick.
1876, Jan. 25:	John	Brown, B.Sc.,	11 Somerset Place, Glasgow.
1865, Jan. 18:	John	Bryce,	Sweethope Cottage, N. Milton Road, Dunoon.
1880, Dec. 21:	John	Cassells,	56 Cook Street, Glasgow.
1870, Dec. 20:	Joseph J.	Coleman, F.C.S.,	Ardarroch, Bearsden, by Glasgow.
1885, Feb. 24:	Robert	Darling,	5 Summerside Place, Leith.

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

1859, Nov. 23:	Sir A. Orr	Ewing, Bart., M.P.,	2 W. Regent Street, Glasgow.
1885, Mar. 24:	James S.	Gardner,	52 North Frederick Street, Glasgow.
1863, Mar. 18:	Robert	Gardner,	52 North Frederick Street. Glasgow.
1860, Jan. 18:	George T.	Hendry,	79 Gt. Clyde St., Glasgow.
1882, Oct. 24:	Wm. A.	Kinghorn,	6 Colebrooke St., Hillhead, Glasgow.
1864, Dec. 21:	Anderson	Kirkwood, LL.D.,	7 Melville Ter., Stirling.
1878, Oct. 29:	John	Langlands,	88 Gt. Clyde St., Glasgow.
1884, Feb. 26:	C. R.	Lemkes,	198 Hope Street, Glasgow.
1888, Jan. 24:	Thos. S.	M'Innes,	8 Buchanan Street, Glasgow.
1886, Jan. 26:	Capt. Dun.	M'Pherson,	142 Pollok Street, Glasgow.
1873, Feb. 18:	John	Mayer, F.C.S.	2 Clarinda Terrace, Pollokshields, Glasgow.
1874, Mar. 24:	James B.	Mercer,	Broughton Copper Works, Manchester.
	George	*Miller,	1 Wellesley Place, Glasgow.
1865, Dec. 20:	John	Morgan,	Springfield House, Bishopbriggs, Glasgow.
1883. Dec. 18:	W. M'Ivor	Morison,	Mayfield, Marine Place, Rothesay.
	James S.	*Napier,	33 Oswald Street, Glasgow.
	John	Phillips,	17 Anderston Quay, Glasgow.

1869, Nov. 23:	Capt. John	Rankine,	31 Airlie Terrace, Pollokshields, Glasgow.
1867, Dec. 11:	William H.	Richardson,	19 Kyle Street, Glasgow.
1882, Dec. 19:	Colin Wm.	Scott,	30 Buchanan St., Glasgow.
1888, Jan. 24:	Samuel	Smillie,	71 Lancefield St., Glasgow.
1876, Jan. 25:	George	Smith,	45 West Nile St., Glasgow.
	John	*Smith,	Aberdeen Steam Navigation Co., Aberdeen.
	Malcolm M'N.	*Walker,	45 Clyde Place, Glasgow.
	H. J.	*Watson,	5 Oswald Street, Glasgow.
1882, Dec. 19:	John D.	Young,	141 Buchanan St., Glasgow.
	William	*Young,	Galbraith Street, Stobcross, Glasgow.

GRADUATES.

1882, Nov. 28:	William H.	Agnew,	Laird & Coy., Birkenhead.
1880, Nov. 2:	James	Aitken,	2 Lawn Villas, Harringay Road, W. Green, Foltenham, London, N.
1888, Jan. 24:	Hugh W.	Aitken,	Netherlea, Pollokshields.
1885, Dec. 22:	John Henry	Alexander,	Dubrah, near Gawalior, Central India.
1888, Jan. 24:	James	Allan,	144 Buccleuch St., Glasgow.
1888, Apr. 24:	Richard W.	Allan,	1 Maxwell Street, Partick.
1880, Feb. 24:	George	Almond,	Belmont, Bolton, Lancashire.
1888, Apr. 24:	Harry D. D.	Barman,	91 North Hanover Street, Glasgow.
1885, Dec. 22:	Peter M'L.	Baxter,	8 Mansfield Place, Blythswood Square, Glasgow.

1887, Apr. 26: Thomas Bell, Little Park Cottage, Yoker.
1885, Mar. 24: Alexander Bishop, 3 Germiston St., Glasgow.
1885, Oct. 27: Archibald Blair, 12 Arthur Street, Glasgow.
1883, Dec. 18: David Blair, Allan Line Works, Mavisbank Quay, Glasgow.
1884, Jan. 22: George Blair, Jun., 6 Alfred Terrace, Hillhead, Glasgow.
1884, Jan. 22: Henry Maclellan Blair, Clutha Ironworks, Vermont Street, Glasgow.
1885, Oct. 27: William C. Borrowman, 15 Breadalbane Street, Glasgow.
1888, Jan. 24: Mark Brand, B.Sc., Faulds Park, Baillieston.
1878, Dec. 17: Rowland Brittain, ———
1886, Oct. 26: James Brown, 89 North Frederick Street, Glasgow.
1883, Apr. 24: Arthur R. Brown, 5 Prince of Wales Terrace, Hillhead.
1879, Feb. 25: Alex. T. Brown, 6 Olrig Terrace, Glencairn Drive, Pollokshields, Glasgow.
1883, Dec. 18: Eben. H. Brown, 15 Moor Ter., Hartlepool.
1881, Jan. 25: Matthew T. Brown, B.Sc., 194 St. Vincent Street, Glasgow.
1885, Dec. 22: Hugh Brown, 194 St. Vincent Street, Glasgow.
1888, Mar. 20: James Brown, 12 Dalhousie St., Glasgow.
1886, Oct. 26: J. B. Buchanan, 5 Hope Street, Glasgow.
1876, Dec. 19: Lindsay Burnet, Moore Park Boiler Works, Govan, Glasgow.

1888, Jan. 24: Angus Campbell, 31 Elderslie St., Glasgow.
1884, Feb. 26: John Cleland, B.Sc., Woodhead Cottage, Old Monkland.
1881, Nov. 22: Alfred A. R. Clinkskill, 1 Holland Place, Glasgow.
1884, Feb. 26: Alexander Conner, 9 Scott Street, Glasgow.

1885, Dec. 22: Benjamin Conner, 9 Scott Street, Glasgow.
1884, Jan. 22: Alex. M. Copeland, Bellahouston Farm, Paisley Road, Glasgow.
1880, Dec. 21: Sinclair Couper, 15 Ibrox Terrace, Paisley Road, Glasgow.
1885, Oct. 27: Francis Coutts, 96 Shamrock St., Glasgow.
1880, Nov. 23: James M. Croom, ————
1882, Feb. 21: Wm. S. Cumming, Blackhill, by Parkhead, Glasgow.

1884, Jan. 22: James Dalziel, 20 Kelvinhaugh Street, Glasgow.
1886, Mar. 23: Thomas Danks, Local Board Offices, Pentre Rhondda, Pontypridd, Wales.
1881, Mar. 22: David Davidson, Helenslee, Radnor Park, Dalmuir.
1885, Feb. 24: William S. Dawson, ————
1883, Dec. 18: William Denholm, 3 Merkland Street, Partick, Glasgow.
1883, Feb. 10: Lewis M. T. Deveria, Perry, Cutbill, de Lungo, & Co., Porto Cabello, *via* Laguayra, Venezuela.
1886, Nov. 23: Thomas Dick, 2 Belmont St., Clydebank.
1888, Mar. 20: B. B. Donald, 9 Balgray Ter., Springburn.
1882, Oct. 24: Daniel Douglas, Earle's Shipbuilding Co., Hull.
1883, Oct. 23: Harry W. Downes, 8 South Crescent, Hartlepool.
1886, Nov. 23: George F. Duncan, Ardenclutha, Port-Glasgow.
1884, Jan. 22: William Dunlop, 31 Hartington Street, Barrow-in-Furness.

1885, Mar. 24: Robert Elliot, B.Sc., The Engineers' Club, 10 Hare Street, Calcutta.

1878, Jan. 22:	James R.	Faill,	7 Winton Drive, Kelvinside.
1882, Feb. 21:	Albert E.	Fairman,	Stewartville, Helensburgh.
1880, Dec. 21:	Henry M.	Fellows,	Westbourne Lodge, Great Yarmouth.
1884, Jan. 22:	Thomas G.	Ferguson,	14 Queen's Cres., Glasgow.
1881, Feb. 22:	William	Ferguson,	Larkfield, Partick.
1885, Jan. 27:	Wm. D.	Ferguson,	33 Kelvingrove St., Gl'gow.
1881, Nov. 22:	Charles J.	Findlay,	10 Belmont Cres., Hillhead, Glasgow.
1888, Oct. 23:	Duncan	Finlayson,	15 Copeland Road, Govan, Glasgow.
1869, Oct. 26:	F. P.	Fletcher,	89 North Frederick Street, Glasgow.
1886, Apr. 27:	John I.	Fraser,	13 Sandyford Pl., Glasgow.

1885, Oct. 27:	Henry G.	Gannaway,	17 Caroline Street, Jarrow-on-Tyne.
1886, Dec. 21:	Charles S.	Geddes,	495 St. Vincent Street, Glasgow.
1874, Feb. 24:	James	Gillespie,	21 Minerva St., Glasgow.
1884, Dec. 23:	D. C.	Glen, Jun.,	14 Annfield Pl., Glasgow.
1885, Jan. 27:	Alex. M.	Gordon,	2 Hawarden Place, Ibrox, Glasgow.
1882, Jan. 24:	Arthur B.	Gowan,	3 Anderson Street, Port-Glasgow.
1884, Feb. 26:	Alexander	Gracie,	9 Great George Street, Hillhead, Glasgow.
1887, Jan. 25:	Edmund J.	Gumprecht,	Langdale, Dowanhill Gardens, Glasgow.

1881, Dec. 20:	Andrew	Hamilton,	2 Belmar Terrace, Pollokshields, Glasgow.
1887, Dec. 20:	Cecil P.	Harrington,	Broadfield, Port-Glasgow.
1881, Feb. 22:	James	Harvey,	2 Cambridge Terrace, Pollokshields.

1883, Feb. 20: David	Henderson,	Cardross Bank Villa, Cardross.
1882, Nov. 28: F. N.	Henderson,	11 Princes Terrace, Dowanhill, Glasgow.
1882, Feb. 21: Wm. S.	Herriot,	Leonora, Demerara.
1887, Feb. 22: George R.	Hingelberg,	———
1881, Jan. 25: A. C.	Holms, Jun.,	Hope Park, Partick, Glasgow.
1884, Dec. 23: John	Howarth,	37 Bentinck St., Glasgow.
1886, Oct. 26: Gilbert M.	Hunter,	3 Germiston St., Glasgow.
1888, Jan. 24: Daniel L.	Hutchison,	6 Belhaven Terrace, Kelvinside.
1883, Jan. 23: John A.	Inglis,	23 Park Circus, Glasgow.
1885, Feb. 24: John	Inglis,	Bonnington Brae, Edinburgh.
1873, Dec. 23: David	Johnston,	12 York Street, Glasgow.
1886, Nov. 23: Daniel	Kemp,	128 West Graham Street, Glasgow.
1883, Feb, 20: Eben. D.	Kemp,	Overbridge, Govan, Glasgow.
1886, Dec. 21: Donald	King,	6 Drummond St., Glasgow.
1886, Jan. 26: John	King,	8 Hamilton Street, Partick, Glasgow.
1888, Apr. 24: R. E.	Kinghorn,	12 Bute Gardens, Hillhead.
1885, Feb. 24: John	Lang,	5 Ruthven Street, Kelvinside, Glasgow.
1887, Oct. 25: Robert	Lawrie,	12 Scotia Street, Glasgow.
1886, Jan. 26: John	Lee,	Bleachfield House, Kilwinning.
1886, Dec. 21: Robert	Lee, Jun.,	2 Minard Terrace, Partickhill, Glasgow.

1883, Nov. 21:	William R.	Lester,	2 Donne Terrace, North Woodside, Glasgow.
1885, Mar. 24:	William	Linton,	————
1885, Mar. 24:	Fred.	Lobnitz,	2 Park Terrace, Govan.
1884, Dec. 23:	Robert	Logan,	3 Hayburn Cres., Partick, Glasgow.
1880, Nov. 2:	Patrick F.	M'Callum,	Fairbank Cottage, Helensburgh.
1881, Dec. 20:	Hugh	M'Coll,	Fabricade, Portilla, White & Co., Sevilla, Spain.
1883, Dec. 18:	Peter	M'Coll,	Stewartville Place, Partick, Glasgow.
1888, Apr. 24:	John Campbell	M'Culloch,	3 Germiston St., Glasgow.
1883, Dec. 18:	John	MacDonald,	293 New City Road, Glasgow.
1882, Oct. 24:	James L.	Macfarlane,	Meadowbank, Torrance.
1887, Jan. 25:	Dugald	M'Farlane,	54 Kelvingrove St., Glasgow.
1887, Jan. 25:	David L.	M'Geachen,	56 Paterson Street, S.S.
1886, Dec. 21:	William	MacGlashan,	134 St. Vincent Street, Glasgow.
1886, Dec. 21:	John	Macgregor,	Caven Crescent, Newton-Stewart.
1883, Dec. 18:	John Bow	M'Gregor,	13 Clarendon St., Partick, Glasgow.
1886, Dec. 21:	James	Mack,	3 Germiston Street, Glasgow.
1880, Feb. 24:	Neil	M'Kechnie,	8 Glenavon Terrace, Crow Road, Partick, Glasgow.
1881, Oct. 25:	James	Mackenzie,	c/o D. Rollo & Sons, 10 Fulton Street, Liverpool.
1883, Jan. 23:	Thos. B.	Mackenzie,	342 Duke Street, Glasgow.
1883, Feb. 26:	Robert	M'Kinnell,	56 Dundas Street, S.S., Glasgow.

1883, Dec. 19: Colin D.,	M'Lachlan,	3 Rosehill Terrace, South-Queensferry.
1882, Dec. 19: Peter	M'Lean,	Waverley Ironworks, Galashiels.
1885, Jan. 27: John	M'Millan,	26 Ashton Ter., Glasgow.
1886, Dec. 21: Andrew	M'Vitae,	385 Dumbarton Road, Glasgow.
1887, Feb. 22: Cree	Maitland,	4 Hampton Court Terrace, Renfrew Street, Glasgow.
1885, Oct. 27: John M.	Malloch,	Carron Iron Works, Falkirk.
1884, Dec. 23: Robert	Mansel, Jun.,	4 Clyde View, Partick, Glasgow.
1884, Dec. 23: W. J.	Marshall,	3 Minerva Street, Glasgow.
1882, Jan. 24: Robt. Alex.	Middleton,	9 Carmichael St., Govan, Glasgow.
1884, Nov. 25: Thomas	Millar,	Sir W. G. Armstrong, Mitchell, & Co., Ld., Walker Shipyard, Newcastle-on-Tyne.
1880, Feb. 24: Robert	Miller,	13 Park Grove Terrace, W., Glasgow.
1883, Dec. 18: Charles W.	Milne,	5 Park Terrace, Langlands Road, Govan.
1881, Jan. 25: Ernest W.	Moir.	Forth Bridge Works, South Queensferry.
1882, Feb. 21: C. J.	Morch,	Horten, Norway.
1882, Nov. 28: M. J.	Morrison, B.Sc.,	8 Annfield Ter., Partick, Glasgow.
1885, Dec. 22: William B.	Morrison,	90 Great Mersey St., L'pool.
1884, Feb. 26: Andrew	Munro,	629 Govan Road, Govan, Glasgow.
1878, May 14: Angus	Murray,	4 Sutherland Ter., Dowanhill, Glasgow.
1887, Dec. 20: David	Myles,	Neptune Engine Works, Walker-on-Tyne.

1883, Dec. 18: James L. Napier, 308 St. Vincent Street, Glasgow.

1886, Jan. 26: Thomas Nicholson, 6 Annfield Place, Glasgow.

1888, Jan. 24: James V. Paterson, 187 Bath Street, Glasgow.

1879, Nov. 25: Alex. R. Paton, Redthorn, Partick, Glasgow.

1886, Jan. 26: Samuel Paxton, 4 Lorne Terrace, Pollokshields.

1887, Nov. 22: James Peacock, 75 Wilton Street, Glasgow.

1873, Dec. 23: Edward C. Peck, Yarrow & Co., Poplar, London, E.

1881, Oct. 25: William T. Philp, 284 Bath Street, Glasgow.

1887, Apr. 6: John C. Preston, 27 Town Hall, Brisbane, Queensland.

1885, Jan. 27: James L. Proudfoot, Lanemark, New Cumnock.

1885, Feb. 24: John T. Ramage, The Hawthorn's, Bonnington, Edinburgh.

1880, Nov. 2: Matthew Rankine, 3 Wilton Crescent, Glasgow.

1886, Dec. 21: Andrew T. Reid, 10 Woodside Terrace, Glasgow.

1883, Nov. 21: Hugh Reid, 10 Woodside Terrace, Glasgow.

1884, Dec. 23: James G. Reid, 40 Glasgow Rd., Dumbarton.

1886, Dec. 21: John Reid, 10 Woodside Terrace, Glasgow.

1884, Feb. 26: Walter Reid, 118 Ingleby Drive, Glasgow.

1887, Oct. 25: David H. Reid, 144 Renfrew St., Glasgow.

1886, Oct. 26: Alexander Robertson, 111 Kenmure Street, Pollokshields.

1886, Apr. 27: Robert Robertson, B.Sc., Ardrossan Harbour Offices.

1887, Dec. 20: Matthew Robin, 69 Paisley Road West, Glasgow.

1888, Feb. 21: Leslie S.	Robinson,	Engine Works, Dumbarton.
1882, Nov. 28: J. M‘E.	Ross,	Ravensleigh, Dowanhill Gardens, Glasgow.
1888, Jan. 24: John A.	Rudd,	6 Beadalbane St., Glasgow.
1887, Apr. 6: Joseph W.	Russell,	12 Newton Street, Glasgow.
1884, Mar. 25: J. B.	Sanderson,	15 India Street, Glasgow.
1885, Oct. 27: Alexander	Scobie,	Culdees, Partickhill, Glasgow.
1879, Mar. 25: John	Scobie,	c/o Senores Funes & Bialet, Calle Constitucion, Cordova, Argentine Republic.
1886, Dec. 21: Walter	Scott,	28 Rowancraig Place, Glasgow Road, Dumbarton.
1886, Mar. 23: Thomas R.	Seath,	Sunny Oaks, Laugbank.
1886, Mar. 23: William Y.	Seath,	Sunny Oaks, Langbank.
1880, Apr. 27: Archibald	Sharp,	26 Melrose Gardens, West Kensington Park, London, W.
1882, Oct. 24: John	Sharp,	461 St. Vincent St., Glasgow.
1883, Dec. 18: George	Simpson,	13 Maxwell Street, Partick, Glasgow.
1884, Mar. 25: Russell	Sinclair,	2 West Quay, Greenock.
1882, Nov. 28: Geo. H.	Slight, Jun.,	84 George St., Edinburgh.
1881, Nov. 22: John A.	Steven,	12 Royal Crescent, Glasgow.
1881, Jan. 25: William	Stevenson,	25 Argyle Place, Partick.
1873, Dec. 23: John	Stewart,	270 New City Road, Glasgow.
1875, Dec. 21: Andrew	Stirling,	Engine Works, Dumbarton.
1888, Jan. 24: Archd.	Stodart,	Netherton, Newton Mearns.
1884, Dec. 23: David W.	Sturrock,	11 Florence Pl., Glasgow.
1886, Dec. 21: James R.	Symington,	204 St. Vincent St., Glasgow.

1880, Dec. 21: Stanley	Tatham,	Northern Counties Club, Newcastle-on-Tyne.
1883, Dec. 18: Lewis	Taylor,	12 Hillsborough Terrace, Hillhead, Glasgow.
1882, Nov. 28: William	Taylor,	57 St. Vincent Cres., Glasgow.
1880, Nov. 23: George	Thomson,	Athlone Villa, Southwick, Birmingham.
1874, Feb. 24: George C.	Thomson,	39 Kersland Terrace, Hillhead, Glasgow.
1884, Dec. 23: John	Thomson,	3 Hillsborough Square, Hillhead.
1884, Dec 23: William	Thomson,	3 Hillsborough Square, Hillhead.
1885, Oct. 27: Peter	Tod,	℅ Paul & Co., Engineers, Dumbarton.
1887, Jan. 25: David R.	Todd,	107 Hope Street, Glasgow.
1885, Feb. 24: Charles H.	Wannop,	12 Derby Street, Glasgow.
1884, Feb. 26: William	Warrington,	23 Miller Street, Glasgow.
1881, Mar. 22: Robert	Watson,	1 Glencairn Drive, Pollokshields, Glasgow.
1880, Apr. 27: Robert D.	Watt,	s.s. "Tsinan," ℅ Butterfield & Swire, Hong Kong, China.
1884, Apr. 22: John	Weir,	Ramage & Ferguson, Shipbuilders, Leith.
1885, Nov. 24: James	Welsh,	51 St. Vincent Crescent, Glasgow.
1882, Nov. 28: Geo. B.	Wemyss,	134 Blythswood Terrace, Glasgow.
1883, Dec. 18: John	Whitehead,	Cragie Road, Kilmarnock.
1877, Jan. 23: Robt. John	Wight,	7 Berlin Place, Pollokshields, Glasgow.
1886, Apr. 27: Percy F. C.	Willcox,	————

1883, Jan. 23:	John	Wilson,	175 North Street, Glasgow.
1883, Dec. 18:	David	Wood,	124 West Nile Street, Glasgow.
1888, Apr. 24:	Alex.	Woodburn,	3 Germiston St., Glasgow.
1887, Oct. 25:	James Brown	Wyllie,	23 Miller Street, Glasgow.
1888, Jan. 24:	Andrew Orr	Wyper,	7 Bowmont Gardens, Kelvinside, Glasgow.
1888, Jan. 24:	J. Denholm	Young,	10 Kersland St., Hillhead, Glasgow.

INDEX.

William Munro, Printer, 80 Gordon Street, Glasgow.

PLATE I

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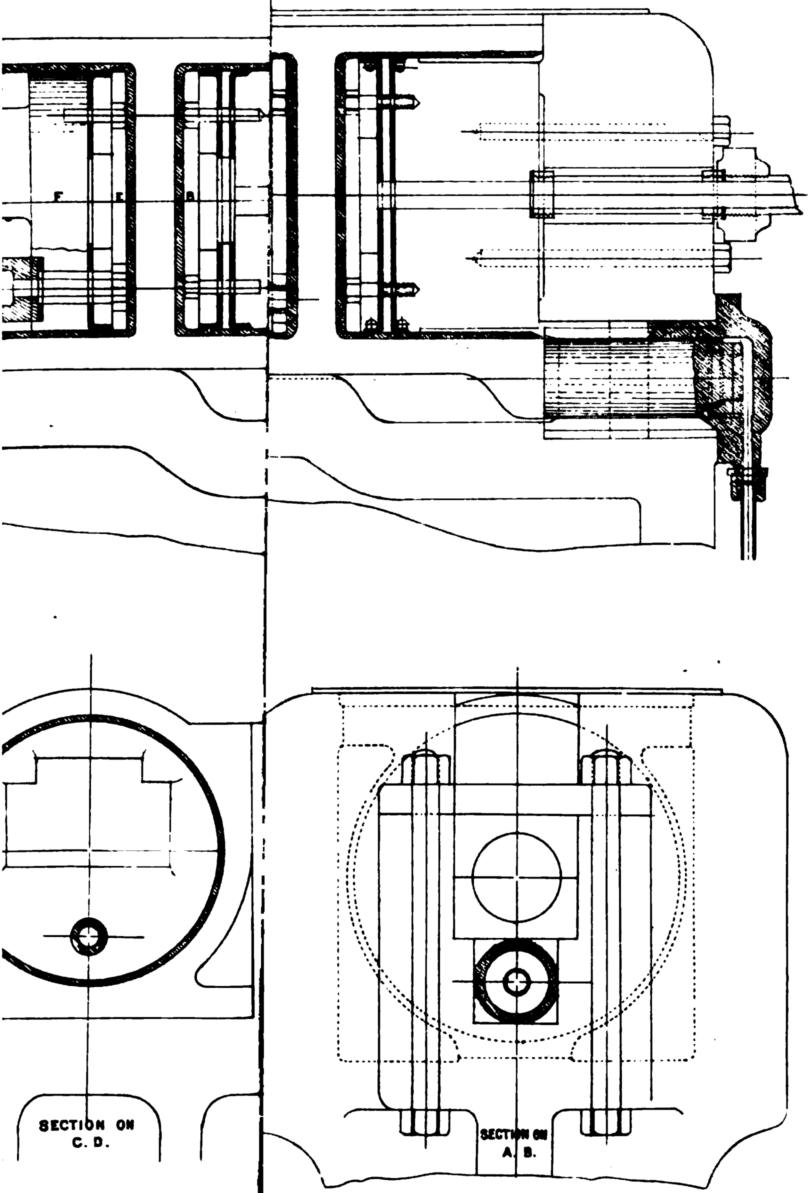

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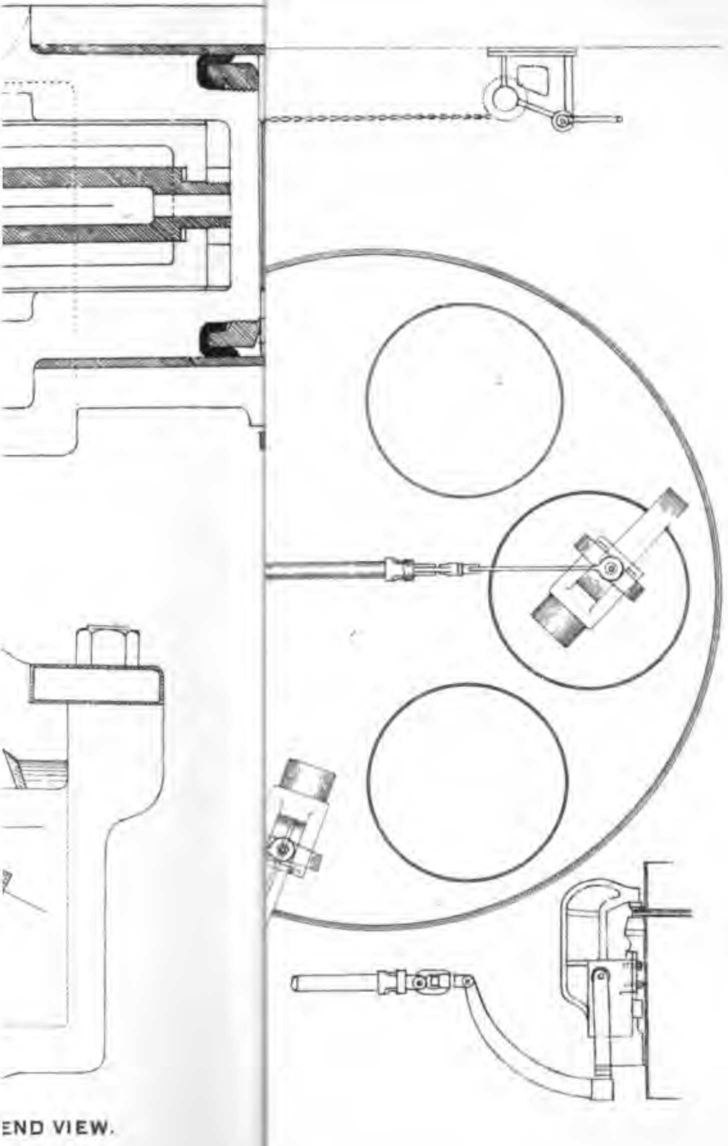
PLATE II



END VIEW.

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PLATE III

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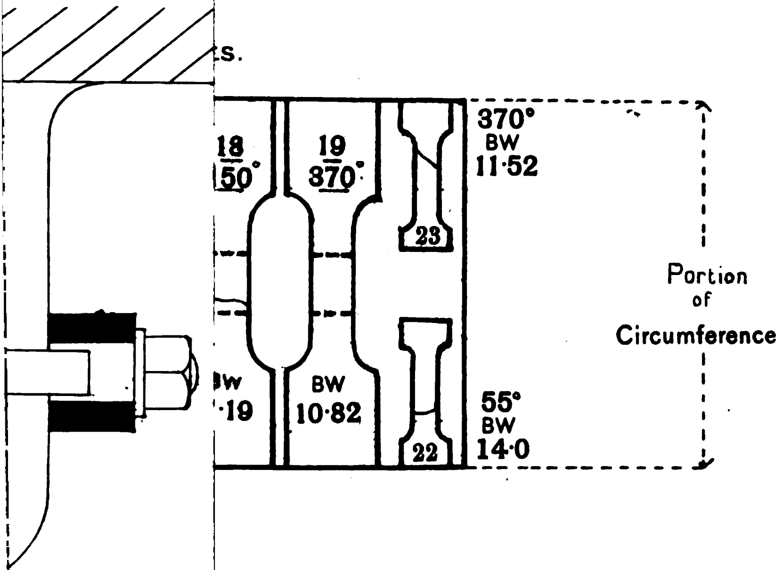

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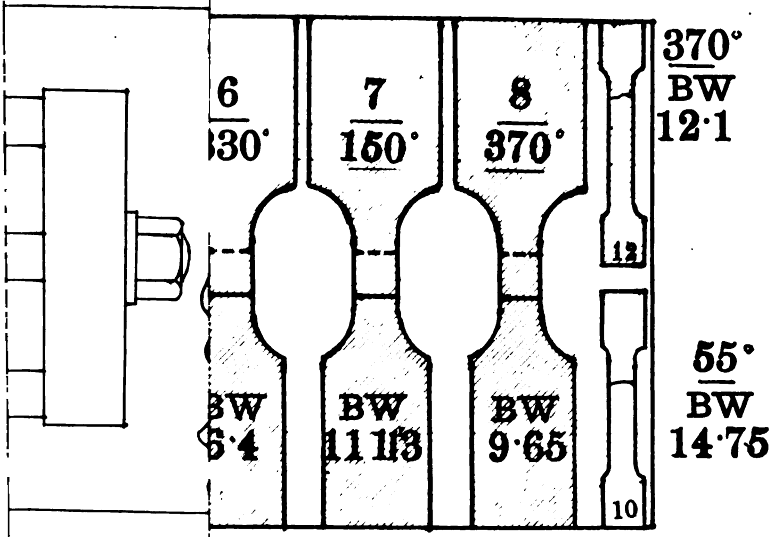

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Machure Macdonald & Co

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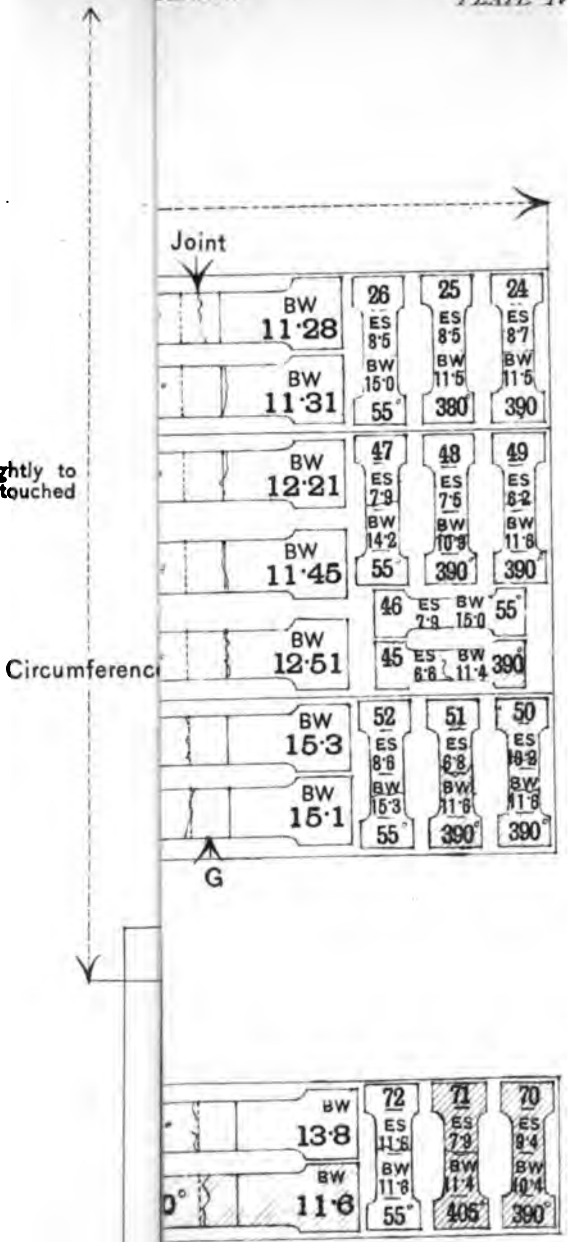

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EXPERIMENTS ON

PLATE V.

STRENGTHS ADDED IN

E SAKE OF COMPARISON.

RE STEAM PIPE BURST BY

NT TEMPERATURES.

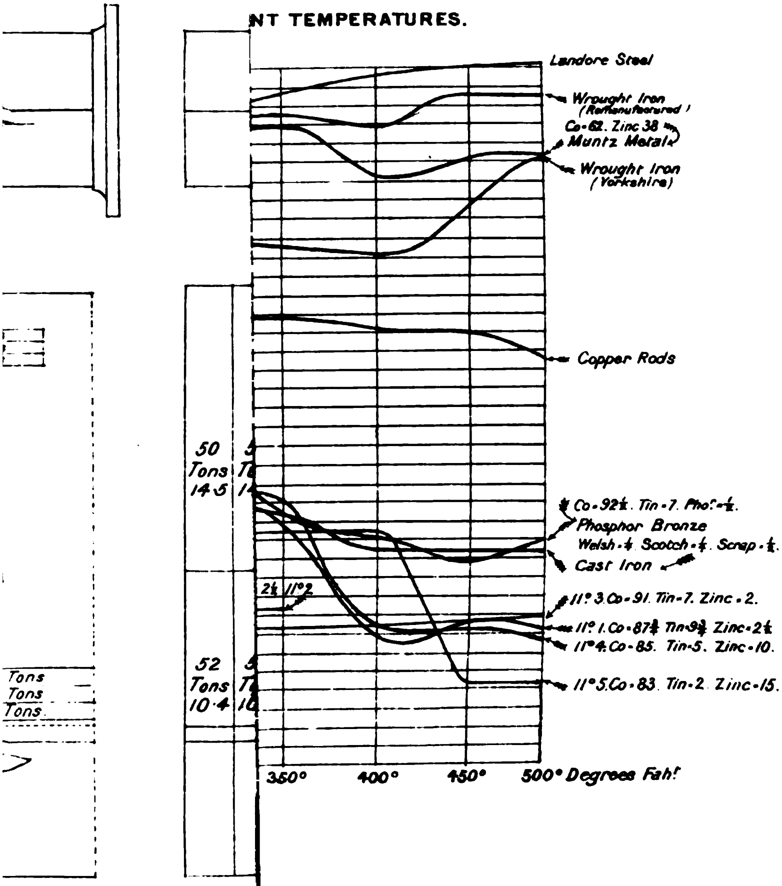

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PLATE VI

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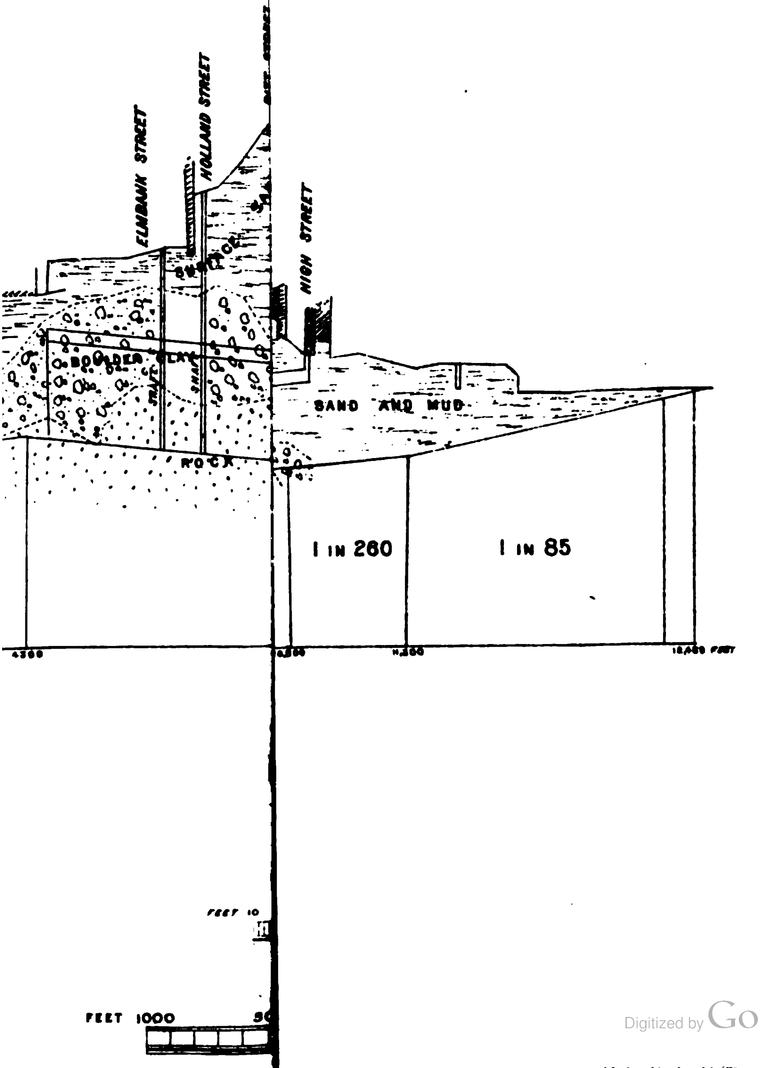

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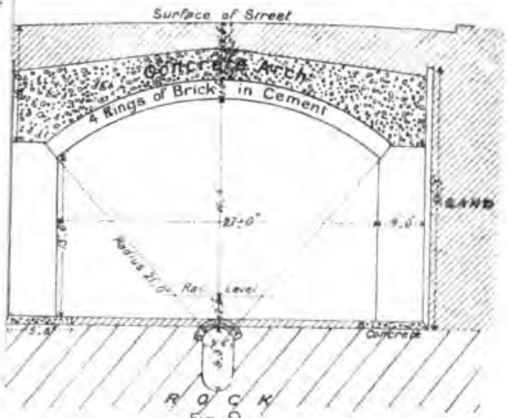

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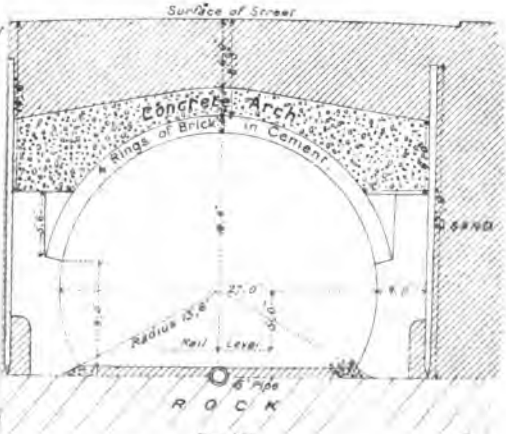

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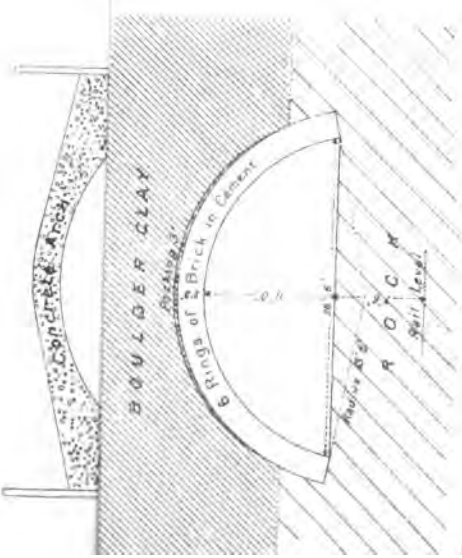

Fig 15.

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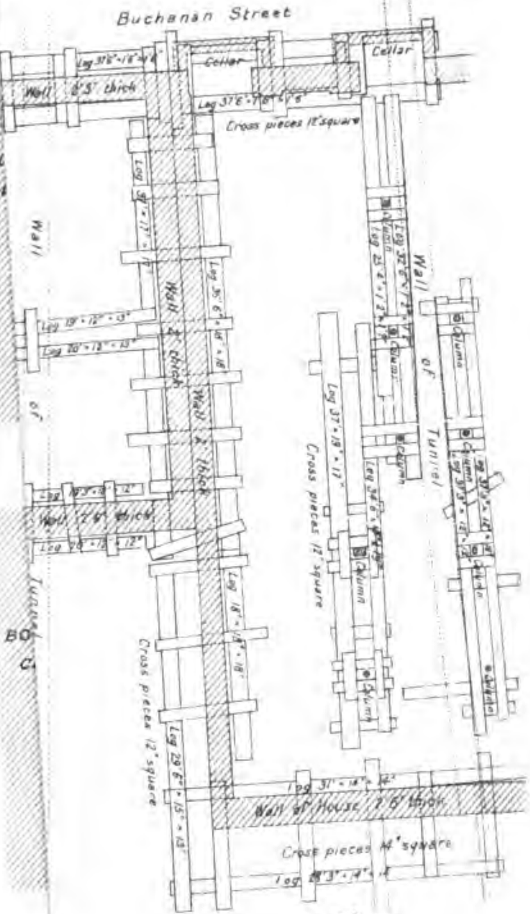

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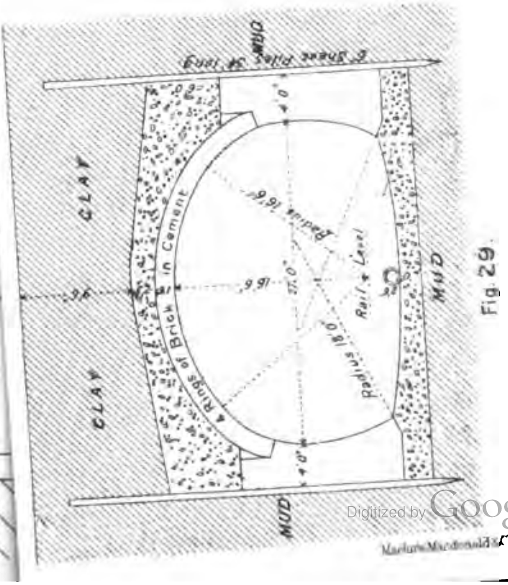

Fig 29.

Maclure&Macdonald Lith.

PLATE IX

EXPERIMENTS ON T

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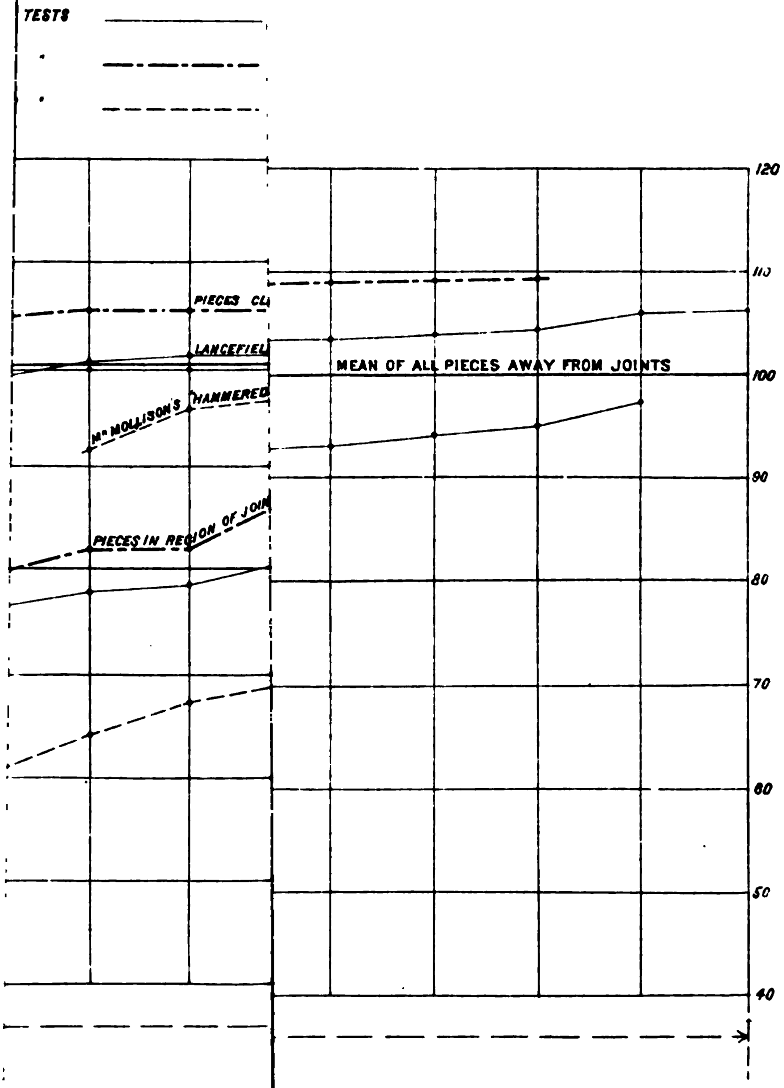


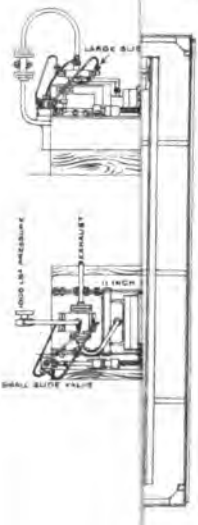
THE ERECTIO

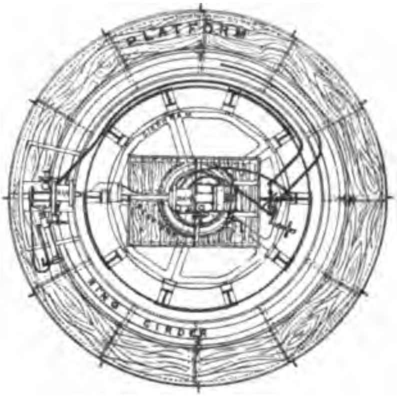
PLATE X

Fig. 3.

BE RIVETING MACHINE

FORTH BRIDGE





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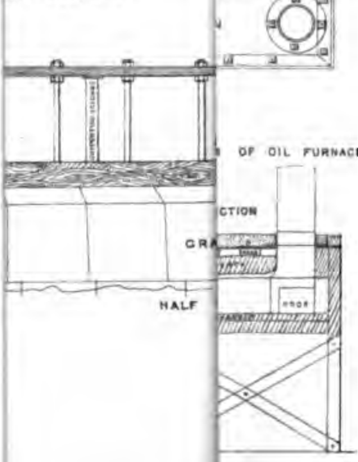

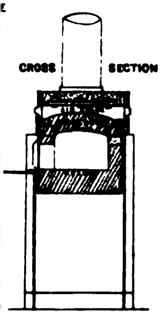

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PLATE XI

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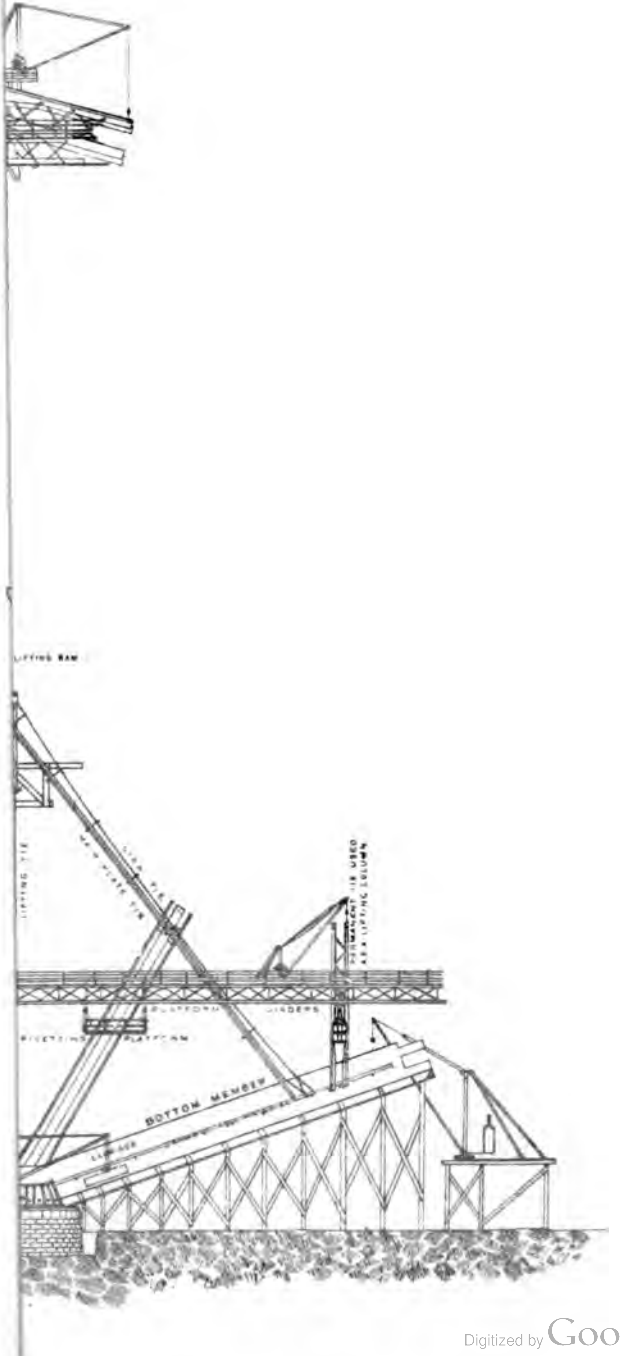

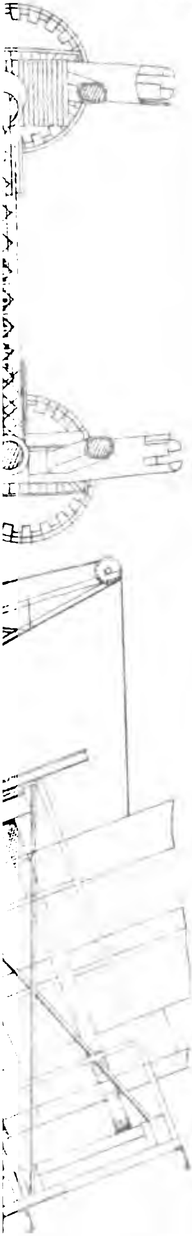

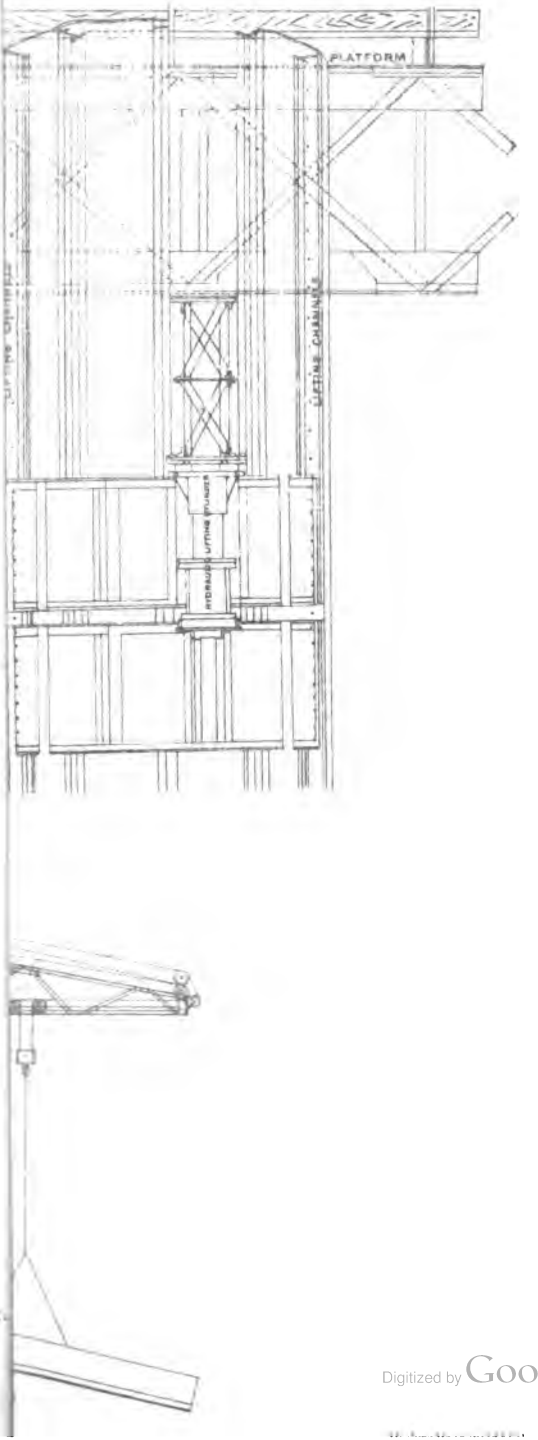

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DIST FIFE MAIN STEEL PIE

PLATE XIII

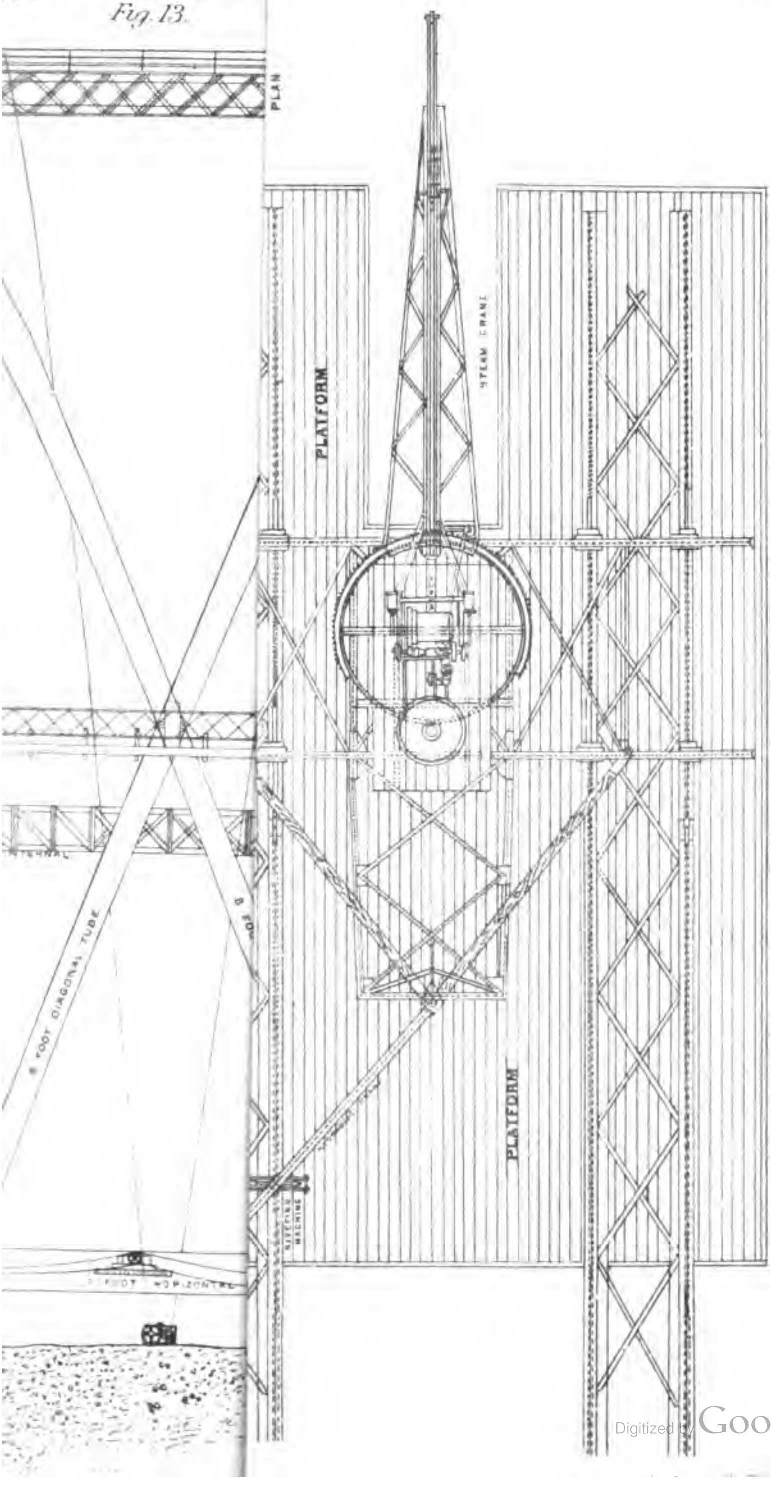
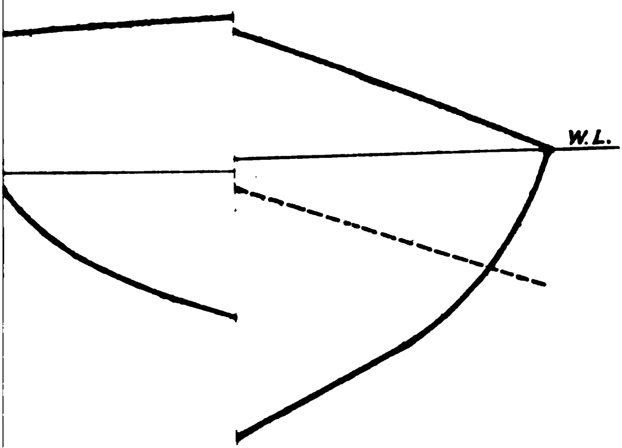
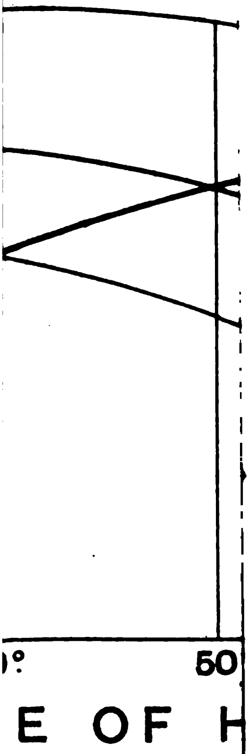


Fig. 13.

Fig. 1.





	A	B1	B2	B3
...	85	85	85	85
...	15	28	28	28
...	17 2	10 2	10 2	10 2
...	13 5	7 5	7 5	7 5
...	3 76	11 04	9 59	8 47
...	71	79	79	134½
...	80	60	55½	
ILS,	9	9	13½	13½
...	160	148	148	148

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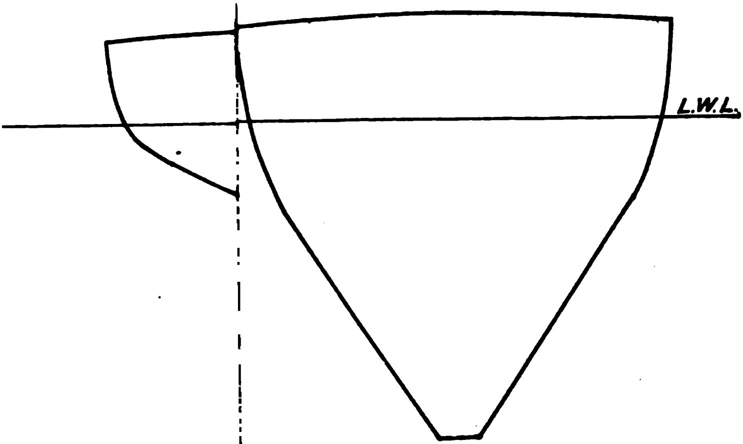
PLATE XV

K.



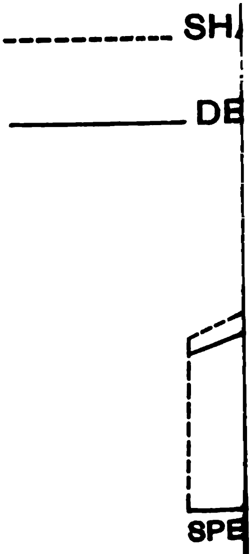


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PLATE XVI

C	D
·25	5
85	85
115	115
28·3	20
7·1	10
3·5	3·5
82	71
65	79·5
13	9·5
160	160

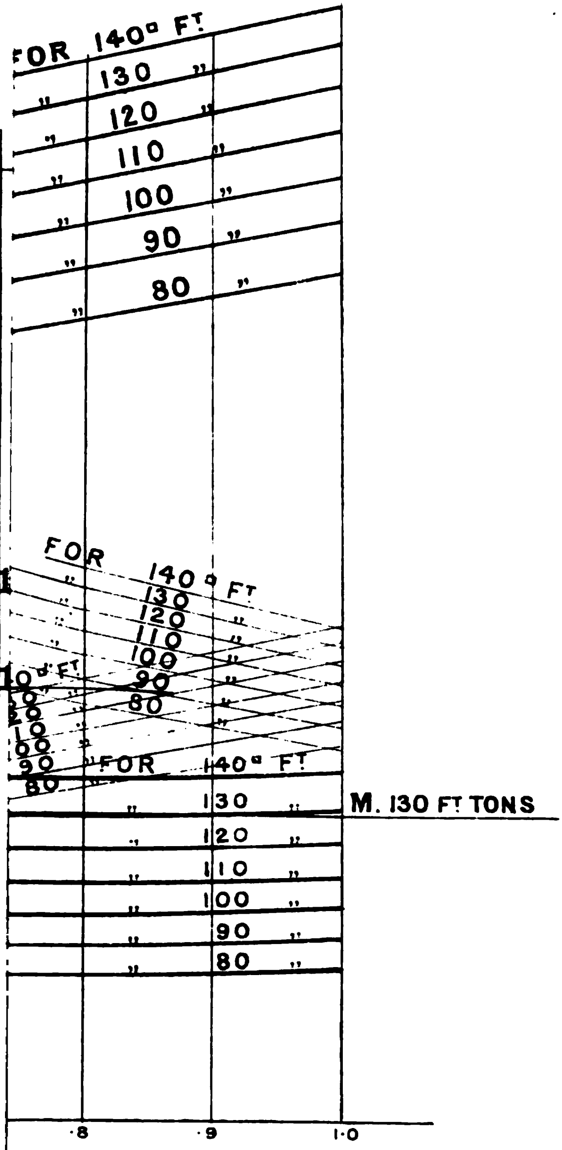

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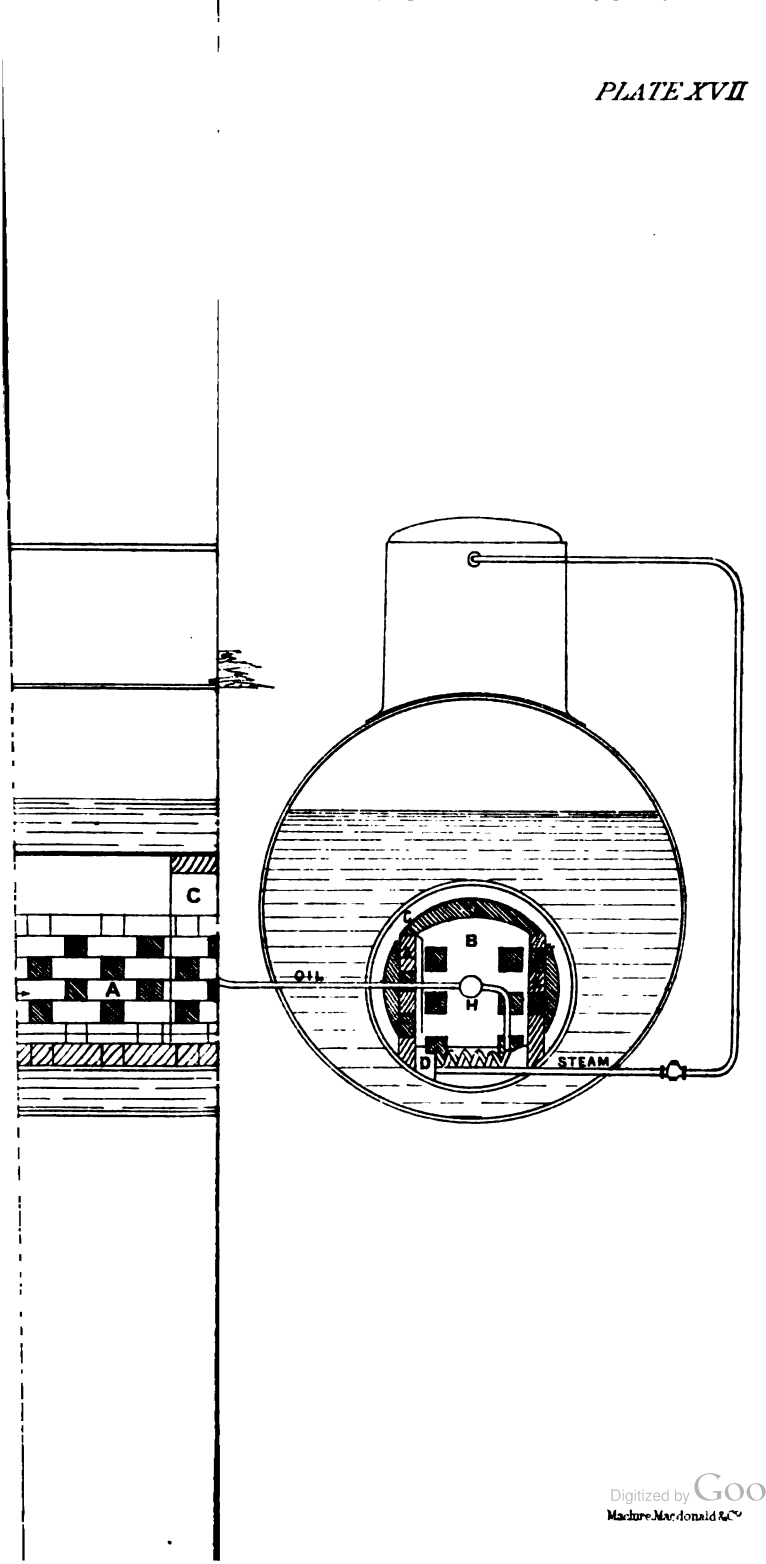
PLATE XVII



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APPLICATION

PLATE XVIII.

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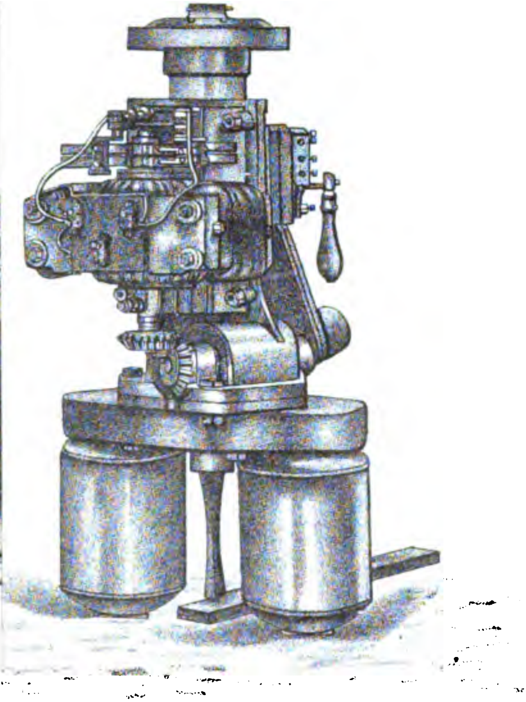


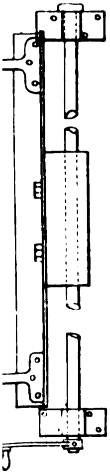
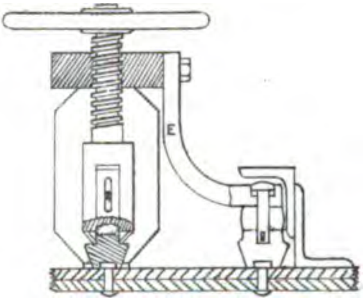


Fig. 8.



APP

PLATE XIX.

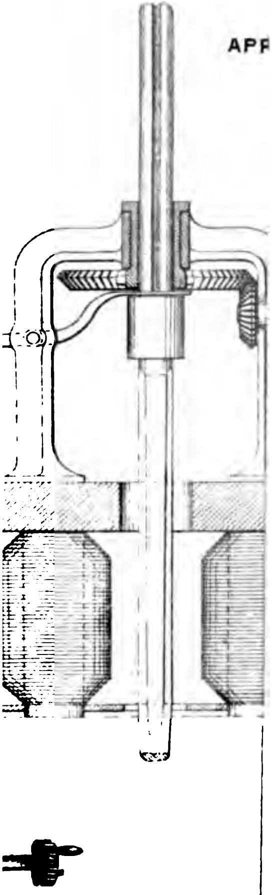
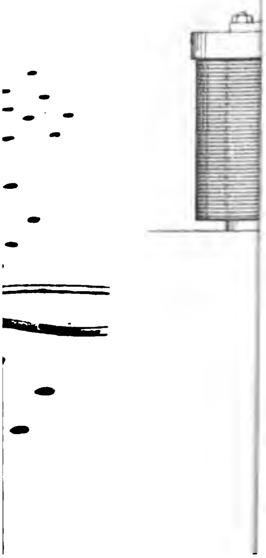


Fig. 1



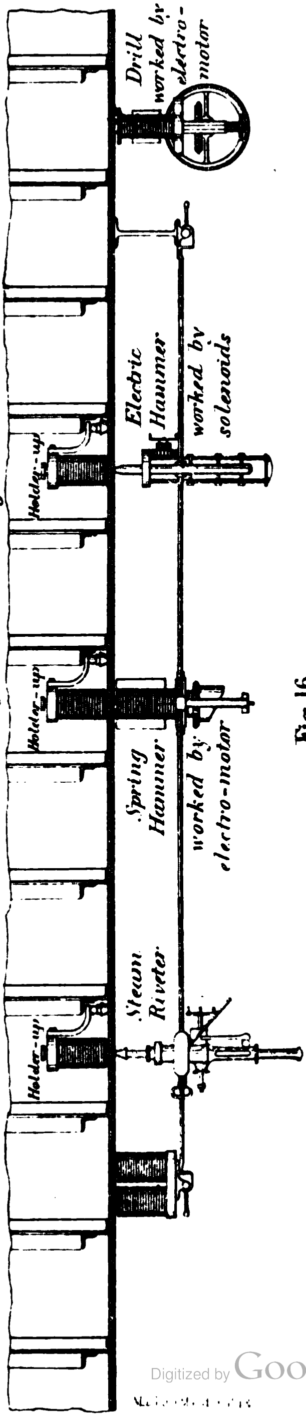


Fig 16.

LAYING

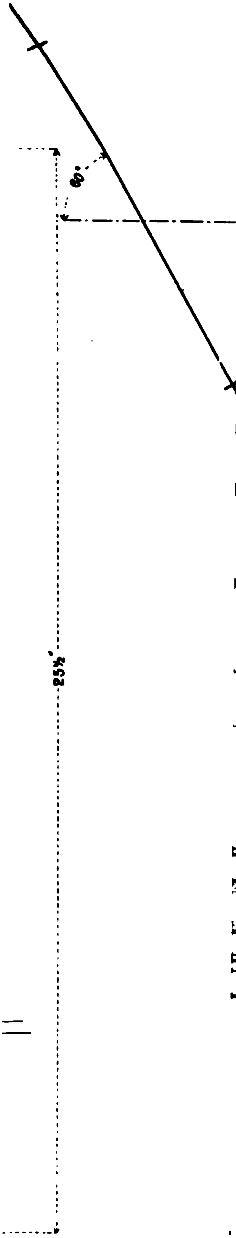
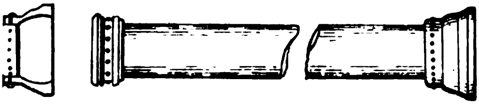


PLATE XX.

Fig. 1.



INT OF SUBMARINE PIPES

2.

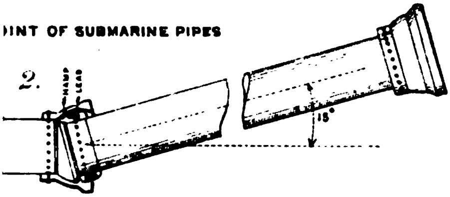
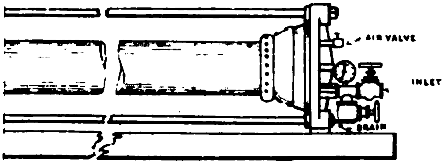


Fig. 5.



TESTING MACHINE

M. [illegible] Macdonald [illegible]

ONS AT SEA

PLATE XXI

n Ship." Thi

REFERENCES.

opened (after the accident) in bulkhead (b) low the water in compartment (F) to flow engine compartment, the vessel being provided ase of such accidents as the present) with a ate pipe from the interior of the vessel, for lying the condenser with water, enabled the neer to keep his own compartment clear and of F to the level of the hole (k), in which she arrived at Greenock.

form in engine-room, between bulkhead (a) the steam cylinders, supporting the bulkhead.

Scale for Figs. 1 and 2—$\frac{1}{250}$th

Scale for Fig. 3—$\frac{1}{118}$th