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IN SCOTLAND

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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 AND SHIPBUILDERS
IN SCOTLAND.
(INCORPORATED.)

THIRTY-NINTH SESSION, 1895-96.

Inaugural Address.

By Sir William Arrol, LL.D., M.P., President.

Delivered 22nd October, 1895.

Gentlemen—

I have to thank you for the great honour you have done me in asking me to take the chair of this Institution. I have been a member of this Institution for a number of years, although not taking any active share in its management. I have, however, given every encouragement that I possibly could to those of my assistants who are in the habit of coming to the Institution and reading papers and taking an interest in the papers generally. I have been much interested in looking over these papers before they came here, and assisting in their preparation as well as possible. I am sorry that I never have had the time to come here and take advantage of this Institution in connection with the engineering works of the country. My lines were generally fixed in another branch of engineering and continuing hard at a business which grew rapidly and which required me to devote the whole of my time to it. Although I must make that my apology for not having taken any part directly in the proceedings of this Institution, as I ought to have done, it is incumbent upon every person who is engaged in the trade and commerce of the country to do something to assist others to follow us, and we ought to do the best we can for our own interests and the interests of our fellow men. It is not only our interest to assist in such an Institution as this; it is our duty as well as our interest to do so. I have, therefore, to thank you for the great honour you have done me in placing me in this chair—a position which I feel I am unable to fill, because so many eminent men have already filled this chair; but, gentlemen, I shall do what I possibly can, by every means in my power, to advance the interests of the Institution. I did not prepare any special address, because there have been so many eminent men specially qualified in the various branches of engineering, such as your late President, who could take up everything connected with engineering and shipbuilding. I, practically as an outsider, have taken part in a branch of engineering more as a contractor than as an engineer, and it is rather difficult for me to fix on any subject which would be interesting to you, but perhaps at the close of the session I may be able to bring something before you which will be interesting and profitable to the younger members of our Society. Gentlemen, the Institution now enters upon its 39th session, and at the close of last session in April, 1895, the numbers of the various classes upon its roll were as follows:—Honorary Members, 9; Life Members, 17; Life Associate, 1; Ordinary Members, 473; Associates, 32; Graduates, 237, making a total of 769. During last session 1 new Life Member, 34 Ordinary Members, 4 Associates, 28 Graduates, making a total of 67, have been added to the roll. We have during the same period lost several members by death, whose names and a short notice of their careers will be found in the volume for the session just published. The Institution is also in a prosperous condition financially, the capital account having increased by £240. The papers read last session were numerous and varied, and the discussions well sustained.

The Council earnestly hope that the members will support them in their endeavour to provide suitable and plentiful papers during the coming session. Already several members have offered to contribute, and the dates of the reading of their papers have been fixed. It is most desirable that members proposing to read papers should at once communicate with the Secretary, so that the dates of reading may be suitably arranged. The Institution is now in touch with all the leading Engineering Associations, both at home and abroad, exchanging transactions with them and with all the principal Engineering Journals. The list of exchanges as published in the transactions shows that there are fully 70 such exchanges. Our members are now in all parts of the globe, and the extending influence of the Institution is seen in the numerous letters received by the Secretary with reference to copies of papers read or information as to membership. Gentlemen, there has been nothing outstanding of any great magnitude to attract attention for the last four or five years, but still there have been very important undertakings going on around us in Glasgow which call for some attention at our hands. We are apt to get familiar with those great undertakings when they are at our own doors and seeing them from day to day, but it is necessary, perhaps, that we should take some notice of them so as to enable us to get certain facts from some of those who are engaged in these undertakings in order to bring them before the Institution. In the first place, I would say that the Cessnock Dock on the Clyde is entitled to our special notice and consideration. The Cessnock Dock is no doubt one of the most magnificent docks in the country. When that dock is finished, I question if there will be another dock which will be better equipped than it. There is also the Graving Dock alongside of it, another important undertaking in connection with the Clyde. I have no doubt that we will have full particulars of these docks put before this Institution from some of those engineers who are engaged upon these works. I have no doubt that some of them have been here already in sections, but I presume that we will have complete papers put upon the proceedings of the Institution by the time the docks are finished. Then there is another great undertaking, the Underground Central Railway, belonging to the Caledonian Railway Company. That is a very important undertaking in many ways. In the first place, it is very important to the great masses of our working classes and to contractors and those who require labour in such a district as this, because, when you find a company, such as the Caledonian Railway or any great company, spending such an amount of money in our midst, it is a very important thing for Glasgow indeed, because, once that money is spent, it is a guarantee that there will be a certain amount of employment for a great number of men wherever that money has been spent. Now, although this Underground Railway comes in for a great deal of abuse about Glasgow, it is a very important undertaking, and gives facilities which will enable people to get in and about Glasgow after it is made. It has been a very arduous undertaking. I have no doubt that the Caledonian Railway Company, had they to do it now, would never have touched it, because, gentlemen, I have always said about individuals as well as undertakings that the longer we keep above ground the better. We know pretty well what there is above ground and we can calculate on what is going on above the surface, but we know very little about what we are going to meet when we go down below. At the same time, after it is completed, I think it will be a great benefit both to the Railway Company and to the citizens of Glasgow. In the first place, it will enable the Railway Company to manipulate their traffic and manage it with a greater freedom, and therefore reduce their working expenses. The whole of their local traffic will be converted into circular traffic, which will circle round the town and relieve the Central Station from all local traffic and enable them to deal better with the main line traffic, which will be a great benefit to the Caledonian Railway Company and at the same time be a great benefit to the public of Glasgow in every way. The only drawback that I see is one that will come back more on the citizens, and that is, that there will be a perfect block on Argyle Street and the lower part of the town when all these great railway stations are pouring out their passengers within 300 yards into one street. How the street traffic is going to be managed when all these railways are opened is a problem for the Council and for civil engineers to try and solve. The next thing that I would draw attention to is the Subway which is being made in the west-end of Glasgow. This is another great and important undertaking. Of course it is one of those things which are being made underground too. Whether the public will appreciate so much underground work I am at a loss to say, but it is a very important undertaking which shows a great amount of courage in the people who have spent so much money in putting an underground Subway all round the west-end of Glasgow for the purpose of trying to get a fair remuneration for the capital they have spent. I hope that this great undertaking will be a paying concern to the people who have had the courage to make it, and a benefit to the public in giving us facilities which will enable us to get round about Glasgow easier than we can do at present. There is another work in Glasgow, and I think there is very little attention drawn to it. I don't know but what it may come to be a very important undertaking indeed, and that is the Harbour Tunnel at Finnieston. It is now open, and traffic is passing through it every day, but whether it will be a commercial success or not, it is in the right direction in giving us another means of getting across the river without requiring to go through the crowded streets of the city. Our City of Glasgow now is pretty much like the two legs of a pitchfork, and you require to get round about it before you can get to the opposite ends of the prongs, and it is a great drawback. When produce has to be carted round about from Partick to Govan it causes a great amount of expense and makes everything dear, and increases the oncost of everything that has to be transferred. Now, in this time when the keen competition of life is so great, it is the duty of the Corporation to enable people to get their goods transferred from the one side of the river to the other at the cheapest possible rate it can be done, so that it is absolutely necessary that the people of Govan and Partick should have communication from both sides of the river. Although they are not in the City of Glasgow—and I think the sooner they belong to Glasgow the better for their own interests and ours—we look upon them all as one community, because we are equally interested in the various districts of Glasgow, and although some of us may live on the one side of the river and have our works on the other, we don't know when we may shift over to the other side, and it is absolutely necessary that we have communication in the lower part of the river as freely as we have in the upper. Then, the next important work which I would draw attention to is the Corporation Water Works and other water works in various parts of the country. There have been some papers read in connection with this subject, but in passing I think it is a very important thing that we should get a record of the great underground works that the Corporation have had in connection with the reservoir at Milngavie. There has been a very important undertaking there in connection with the puddled dyke or puddled wall, which will be a very interesting subject for a paper, because water engineering at the present day is one of the most important subjects which the public are interested in, for the simple reason that the water is disappearing from the most of the country districts in Mid-Lanarkshire and wherever there are coal workings. The water supply in these districts disappears or is diminished in such a way that the public have great difficulty in finding much water in connection with their houses. I know that some of the farmers in Lanarkshire at the present moment have the greatest difficulty on account of the want of water, and I am afraid that many of these districts will become depopulated owing to the disappearance of the water. Some of you, I dare say, will have heard of this unfortunate thing in connection with the water works in Upper-Lanarkshire, which is identically the same thing which Mr. Gale has had to contend with. They have gone to an enormous depth at Glengavell, and after spending I don't know how many thousands of pounds in trying to find a foundation they have not found one yet. In fact, I believe the works are practically abandoned, or it is proposed to abandon them after spending so much money. You see the importance of having a section of this great puddled wall which Mr Gale found it necessary to put down in connection with the Corporation Water Works. Well, gentlemen, these are some of the things in connection with our district of the country, and the next subject I would draw attention to is the Sewage Works in the east-end of the town. That important undertaking has evidently proved a success—so much so, that the Corporation intend to apply it to the north side of the river. This is one of the things which our far-seeing Mr Carrick, who used to be Master of Works, kept before him, because he took the opportunity when the Caledonian Railway Company intended to go underground to re-arrange the whole of the sewage at the east-end of the town in such a way that practically the Town Council have got the Caledonian Railway Company to re-arrange the whole of their sewage for nothing, and it enabled the Council to carry out this experiment at a cost of something like £150,000 less had the Central Underground Railway not been made. The purification of the Clyde will be a very important thing for Glasgow, and I think it is absolutely necessary that it should be undertaken as soon as possible. There is no doubt that it will cost a great amount of money. The rivers round about Glasgow are, no doubt, in a very filthy condition, and are getting worse year by year. Our large cities and great manufacturing centres are spread out all over the country, and it is very difficult to get drainage. It is absolutely necessary that the purification of the Clyde and its tributaries should be taken up at the earliest possible moment, and not only the Corporation of Glasgow but every other Corporation should be compelled to contribute their share and purify their own part in order to enable the rivers to be used by the people lower down. Well, gentlemen, I don't know that there is very much more to say. With reference to the principal undertakings that have been going on in the country, there was one in connection with the Tower Bridge which was opened lately. That was a very important undertaking that I had something to do with. That bridge is now open and working, and I am glad to say it is giving every satisfaction to the public, for whom it was built. There is another great bridge talked about—the Channel Bridge. It has been mentioned, and a Company has been formed, and they are spending a certain amount of money year by year, but I don't think that any person in this room will live to see a Channel Bridge. They may live to see it started, but I don't think they will live to see it finished. It is a very simple thing to design a bridge for the Channel to cross the Straits, but I don't think any sane man would undertake such a contract and live to see it finished. At least I don't think I would undertake to do it. I was asked to meet the French engineers three or four times during last year to discuss the matter, as they seemed sanguine that the thing would be started. I said to the director who came to me about it, that before anything practical could be done in such a great undertaking as this the first thing to do was to get the two Governments to settle the international question before they went to Parliament or asked any person to put their money in such an undertaking. The bridge was intended to be a bridge pretty much in the style of the Forth Bridge. The cylinders were to be put down and the piers to be put down pretty much as I did those on the Tay, and the plans were evidently taken on the same lines. The bridge was to be put down somewhat after that style, but the difficulty is whether it would be a wise and prudent thing to put a bridge in the midst of a channel, such as the English Channel, between England and France. I would say, as a practical man, that it would not be prudent for all the traffic that ever could be run across it. Supposing trains were going as close as they could to one another, it would never pay on this side of time, and it would never give a return. Then there is the danger to shipping. That would be so great that it would be almost impossible to prevent ships getting dashed against some of the piers, and there would be an enormous number of wrecks every winter if such a bridge was ever put up. It would also be impossible to transmit a sufficient amount of goods to France to make such a bridge pay in any shape or form, because if you take the railway freight from London to this end of the bridge it would be more than taking them all the way to France in ships, and it is practically impossible to make it pay. I will only mention one more matter and then we will proceed to the other business, and it is in connection with the finishing of a very large undertaking in London, or rather the practical completion of it, and that is the tunnel underneath the Thames. You are aware that they have been making a tunnel under the Thames for the purpose of enabling the traffic to be carried further down the river for a mile and a half under the Tower Bridge down at Blackwall. They are making it 30 feet in diameter for the purpose of carrying through the street traffic, pretty much the same as the tunnel made by Brunel three-quarters of a century before. That tunnel has been carried through practically the same as the Hudson Tunnel at New York, and it has been carried through very successfully, and now they have joined and got it completed right through under the river and on to the north side of the river. I am very pleased that it has been such a successful thing, because my interest in it is this, that the whole staff that has been carrying it through was composed of some of our young men who were brought up at the Forth Bridge. Some of these young engineers have read papers upon the subject. I do not know that there is much more to say, further than the fact that marine engineering on the Clyde is still in a position that we would like to see improved, and we would like to see shipbuilding on the Clyde better than we have it at present, or have had for a considerable length of time. There is no doubt we would all like a considerable amount more work going on on the Clyde than at present. Things are not over busy in a number of the yards, but it is a very difficult thing to keep those large shipbuilding yards turning out vessels as fast as they can build them. Our late President and the other large shipbuilders on the Clyde would be very pleased to have a large number of ships and engines turned out for the purpose of keeping their employees going; but there are two sides to this question, which is coming to be a very important question in this country, and that is the keen competition of life in which we are all interested, because a great amount of shipbuilding on the Clyde re-acts on some other trade in the country. We are all keenly interested in this competition, and everyone is doing the best he can. Every shipbuilder wants to build as many vessels as he can, and every shipowner wants to run as many as he can and get as large cargoes as he can. This is a matter that is very interesting to us as a nation, but there are other people who are not so much interested in it. We have a great agricultural depression, which looks as if it were going to swamp the whole of our agricultural interest in this country, and when you look at it in the proper light, what is causing this great agricultural depression but our great prosperity on the Clyde. The reason is this, that there are so many employees in this country requiring employment. There are so many shipowners or shipping agents who want to be always starting lines of steamers and running to every place in the world, and they are keenly competing for cargoes. The shipbuilder keenly competes for building ships, and the shipowner for cargoes. Shipowners will carry a cargo for little or nothing, and bring the foreign produce to our shores at the lowest possible rate, and the competition has driven our poor farmers down to the very lowest that they can exist at. The depression in the agricultural interests is far more than we can realise in this country, but we who are living in the large cities are getting the benefit of this keen competition in which we live, because we must have it to feed our working-classes as cheaply as we possibly can. Without the foreign grain we would need to pay more for our food, and it is very important that we should have those cheap food products. We are getting all this benefit at the expense of the poor agriculturist, but we as a nation cannot exist without the keen competition in which we are interested. It is all in our interest, and we must find another solution. We as shipbuilders and engineers must try to get as many ships as we can, and find out some other remedy for the agricultural interest. With these remarks I propose that we now go on with the rest of the business for the evening.

Mr JOHN INGLIS said he believed it was his privilege to ask the meeting to accord a very hearty vote of thanks to Sir William Arrol for his address. They were all familiar with the great works that

Sir William Arrol had executed and the great difficulties he had overcome, and that every engineer with an ambitious project looked to him as a man who would be able to bring it to a successful conclusion. They considered him a man of deeds rather than of words, but they were also glad to hear him tell them about his great deeds. They looked forward with much interest to the account he had promised to give later on of some of these feats of construction, and in the meantime he proposed that they give the President a hearty vote of thanks for his address.

The vote of thanks was heartily accorded.

On the "Extension of the Loch Katrine Water Works."

By Mr. James M. Gale, M.Inst.C.E.

The discussion on this paper was resumed on 22nd October, 1895.

The **President** stated that Mr Gale was not present. He would ask Professor Barr if he had anything further to say.

Professor **Barr** said he did not think that he had anything further to say on the paper. A report of some remarks that he had already made on this paper appeared in the last volume of the proceedings, but he would like to state that he had not corrected the draft sent him for revision. As would be gathered from the report, the revision meant the thinking out of what it was that he had said, and that he had not found time to do when the draft reached him. With regard to the paper, he had no doubt that most of the members of the Institution would feel with him that they must take what Mr Gale had written regarding these works as the best information that could be given, and as something quite beyond their criticism. The papers which Mr Gale had given to the Institution in former years had attracted a great deal of attention. With this addition, and possibly with the addition suggested by the President, describing in more detail that wonderful puddle trench which no doubt many of the members had had the pleasure and interest of seeing, these papers would form in themselves one of the most valuable treatises they had on the subject of water-works engineering. He thought that the Institution was exceedingly fortunate in having had the honour of publishing such a valuable record of great works accomplished.

"*A New Departure in Steam Engine Economy, with a Description and Tests of Field's Combined Steam and Hot Air Engine.*"

By Professor ANDREW JAMIESON, M.Inst.C.E., F.R.S.E., etc.,
Of the Glasgow and West of Scotland Technical College.

The discussion on this paper was resumed on 22nd October, 1895.

Mr E. HALL-BROWN said, Professor Jamieson had given them an account of a test of what he calls "a new departure in steam engine economy," viz., Field's combined steam and hot-air engine, but, so far as he could judge, Professor Jamieson's test seemed to have omitted the very important point that *it is* a hot-air engine as well as a steam engine, and he merely gave the consumption (as determined by him) of steam. He said that "as we were not specially studying the economy of the boilers as steam generators, I will not put any stress on the coal burned per pound of water evaporated, but rather on the steam used per H.P. hour." The facts seemed to be these:— They had an engine using in the first instance steam generated in in a very uneconomical boiler; under these circumstances they were told that the engine consumed 31 lbs. of steam per I.H.P. hour; afterwards this engine was altered according to Field's system by putting an air heater in the flues, whereby some of the heat formerly escaping to the chimney was caught, and the heated air so obtained was used in the engine. It would therefore be seen that in the first case the engine had one source of heat, viz., the steam, and in the second case, two sources, viz., steam and hot air. Instead of heating the air, a second boiler might have been fitted and the steam so obtained from the heat of the escaping gases used in the engine, thus reducing the consumption of coal; or a more efficient boiler might have been fitted with the same result. Whether this would have been as economical (looking at the question of the coal used per B.H.P. hour) as the Field arrangement they had not sufficient data in the paper to say, but it would seem that with a fairly good boiler, and the engine using 31 lbs. steam per I.H.P. hour—say 37·4 lbs. per B.H.P. hour—the coal per B.H.P. hour could easily have been reduced to 3·56 lbs. In this connection it might be pointed out that the boiler would be more pressed for steam in Professor Kennedy's test than in Professor Jamieson's, and consequently the steam might not be maintained at 113 lbs. per square inch in the earlier test, but might fall much below that point; if so, the comparison became less favourable for the Field engine, and the probability, that a more economical boiler would have given equally good results, stronger. This was a point which he would like to draw Professor Jamieson's attention to, and that it would add greatly to the value of the paper if he could append a table of results from Professor Kennedy's test.

In the general arrangement given by Professor Jamieson he showed a steam superhearer, S.S. It was not clearly shown where the heat was taken from, he presumed from the flues. Would Professor Jamieson inform them if this superheater was in use during Professor Kennedy's test, and, if so, the degree of superheating in his tests, and those of Professor Kennedy? If in use in both tests, the steam should have been more superheated during the later test, as there was less steam passing through it.

The indicator diagrams shown in the paper were very remarkable in many ways, but he would only point out that the steam pressure in the cylinder was at least equal to, if not greater than, that in the boiler (this was also stated in the table), and that the exhaust took place exactly at atmospheric pressure in spite of the fact that hot air was being blown into the cylinder during exhaust. Personally he had never been able to obtain correct diagrams showing these results.

Regarding the tabulated results given by Professor Jamieson he had little to say, beyond that the boiler efficiency seemed to have fallen off very much in the second day's trial when the evaporation was only 7·9 lbs. from and at 212 degrees, as against 8·9 lbs. on the first day.

The question of the consumption of hot air was an interesting one, and it was unfortunate that it had been practically overlooked in the paper, but Professor Jamieson gave in his remarks an estimate based upon the cylinder capacity of the engine. He assumed that the cylinder was half filled with hot air at 1 lb. per square inch and 550 degrees F. Now if the cylinder was half filled only, he could not agree with Professor Jamieson's remarks on page 7 of the paper, that "consequently the whole internal surface of the cylinder was heated up to a temperature far exceeding that of the steam, thus preventing the possibility of condensation, etc." He was of the opinion that to heat the cylinder thoroughly it would be necessary not to half fill it with hot air only, but to blow hot air through it and out of the exhaust ports. Possibly this was the case, as a very considerable quantity of heat would be required to account for the fall in consumption from 31 lbs. to 18 lbs. If he was right in this, the quantity of air actually heated would be largely in excess of that given by Professor Jamieson, and consequently the heat abstracted from the gases would be much greater than his estimate. Taking Professor Jamieson's figures however, he made a slip in saying that 2½ lbs. of steam per minute was equal to about ⅛ of a H.P. As a matter of fact, in the Field engine cylinder it would be equivalent to

$$\frac{2{\cdot}5 \times 60}{1{\cdot}2 \times 18} = 6{\cdot}96\text{—nearly 7 I.H.P.}$$

He would not go into the figures of the heat actually transmitted to the air, as this could only be an estimate, and might vary, from the figures given by Professor Jamieson, to three or four times that amount.

Only one other point he would mention was that although the consumption of steam at the light load was very favourable, it was more than counter-balanced by the low B.H.P.

It was always interesting to hear of a new thing, and this Field engine had been no exception; but he thought that most practical engineers would agree with him that the merits of the invention would require to be more clearly seen than they were at present before it was largely adopted even in the few situations to which it was applicable.

Professor JAMIESON replied to the remarks of Mr E. Hall-Brown, that he had tabulated all his observations just as they were taken down, and had described faithfully all the testing apparatus provided for his use by Messrs Field & Company. He agreed with Mr Brown that it would have been both interesting and instructive to have ascertained the exact amount of heated air which was admitted into the cylinder of Field's engine, and he regretted that no means were placed at his disposal for obtaining the same. He believed that the superheater was in use when Professor Kennedy tested the engine (both before and after its conversion), and that his estimate in each case was that the quantity of priming water was entirely negligible, being on the average less than 0·2 per cent. Of course, the boilers were more pressed for steam *to produce the same power before* the conversion into Field's system than afterwards; but in each case there was no difficulty in maintaining the steam at the desired pressure. He was sorry that he did not possess a table of the results obtained by Professor Kennedy, but he understood that his report distinctly and entirely attributed the improved economy in the weight of steam used per I.H.P. to the application of Field's system; for, the efficiency of the boilers worked out very nearly the same before and after the conversion of the engine. Of course, the efficiency of the boilers fell when working light as in the author's second day's trial. Any one who had carefully tested boilers for their steam and coal consumpt had experienced similar results; for the efficiency of a boiler would rise up to a certain point with the demand for steam, and it then gradually fell if forced beyond that point. The fact that the observed steam pressures by the two boiler gauges were the same as the pressures as registered by the indicator (in one instance 1 lb. less) went to show how faithfully these pressures were recorded; for the same assistant who noted the two boiler gauges also took the indicator cards, and of course some minutes elapsed between these respective observations. As stated in the paper, the spring of the "Wayne" indicator was most carefully tested after the cards had been taken and that of the "Crosby" indicator had been previously found to be correct. Referring to the indicator cards of the first day's trial, the atmospheric line should have been traced by the zincographer's artist about $\frac{1}{32}$-inch below the exhaust line. With this exception, the figures were very exact reproductions of the original diagrams. Of course, the statement that 2½ lbs. of water converted into steam *per minute* from and at 212 degrees Fah. was only equivalent to "one-eighth of a horse-power," was evidently an error in the re-writing of his (Professor Jamieson's) MSS. by an assistant for *eight horse-power.* Since—

$$\frac{2\frac{1}{2} \times 60}{18 \cdot 6} = 8 \text{ H.P.}$$

To be more exact, he might have said that the total heat absorbed in raising 1 lb. of steam from water at 60 degrees Fah. to steam at 113·4 lbs. pressure per square inch by gauge was 1160 B.T.U. But it was found by the first day's trial that the Field engine only required 18·6 lbs. of the steam per hour, and that if the cylinder was but half-filled with hot air at each stroke then 20 lbs. of this heated air would be required, or an expenditure of 2332·4 B.T.U. every minute. Hence—

$$\frac{2332 \cdot 4 \times 60}{1160 \times 18 \cdot 6} = 6\tfrac{1}{2} \text{ nearly.}$$

Or, to half-fill the cylinder at each stroke with air of 550 degrees Fah. requires the trapping of heat from the waste gases equivalent to nearly 6½ H.P., *i.e.*, just 4¾ per cent., which was certainly not a large amount when they considered the advantages otherwise derived from the use of this heated air. There could be no doubt that the boilers were not arranged on the most economical principle, but they represented very fairly what had been hitherto the average practice in this country. Further (as mentioned in the paper), the engine had a very low mechanical efficiency. Nevertheless, with these apparent defects he did think that it had now been clearly demonstrated that the admixture of hot air with exhaust steam greatly reduced initial condensation and consequent waste of steam in the cylinder of an engine.

On "Propeller Diagrams.

By Mr ROBERT CAIRD, Member of Council.

SEE PLATES I. AND II.

Received 5th ; Read 26th November, 1895.

MR R. E. FROUDE'S 1886 paper, read before the Institution of Naval Architects, marked an epoch in the investigation of the properties and behaviour of the screw propeller.

As is well known, he experimented extensively with model propellers, and presented in graphic form, in a series of plates which accompanied his paper, the results obtained with screws of 0·68 feet diameter, set at 1·225, 1·4, 1·8, and 2·2 pitch ratio, advancing through the water at a velocity of 206 feet per minute.

These diagrams were very involved and difficult to use. So much so that in 1892 Mr Froude read a supplementary paper, throwing over the old forms and substituting a new set of curves, which have the merit, not only of being easily and quickly applied, but of giving the data sought for in an eminently comprehensive and lucid form.

The curves which I now submit have been constructed from the 1886 Froude diagrams and entirely without reference to and independently of the 1892 paper. In fact these curves and Froude's later ones arrive at the same conclusions by different methods.

It may be useful to quote his fundamental propositions laid down in his 1886 paper, which are :—

(1) The performance of any given screw advancing at a given speed through the water and turning at various numbers

of revolutions per minute (*i.e.*, with varying slip-ratio) may be represented by a diagram where the abscissæ indicate values of slip-ratio: the ordinates of B B the the corresponding thrusts: and the ordinates of A A the corresponding efficiencies.

(2) With given slip-ratio the thrust of a given screw varies as the square of the speed of advance through the water.

(3) With given slip-ratio and given speed of advance and with given design of screw, the thrust varies as the square of the dimension of the screw.

(4) With given slip-ratio and given design of screw the efficiency is unaffected by variations of speed or of size of screw.

(5) (Consequent on preceding.)

A single diagram will represent the performance of any number of screws of given design but of differing sizes advancing at any variety of speeds through the water, if the ordinates of the thrust curve are taken to represent

$$\frac{T}{D^2V_1^2},$$

where T = thrust; D = diameter of screw; V_1 = speed of advance.

As a result of the experiments referred to, Froude found that with constant slip-ratio the thrust varied as $\frac{D}{P} - 0{\cdot}17$; and, with constant efficiency, as $\left(\frac{D}{P}\right)^{0\cdot8}$.

Or, expressed in equations:

$$\frac{T}{D^2V_1^2} = C\left(\frac{D}{P} - 0{\cdot}17\right).$$ C being constant when s is constant.

$$\frac{T}{D^2V_1^2} = B\left(\frac{D}{P}\right)^{0\cdot8}.$$ B ,, ,, e_2 ,,

His notation being in tens of feet for D, and tens of knots for V_1, $\frac{T}{D^2V_1^2}$ becomes $\frac{T}{\left(\frac{D}{10}\right)^2\left(\frac{V_1}{10}\right)^2}$; and, putting N for this value, we get

$$C = \frac{N}{\left(\frac{D}{P} - 0{\cdot}17\right)}. \qquad \text{(I.)}$$

$$B = \left(\frac{P}{D}\right)^{0{\cdot}8}.\,N. \qquad \text{(II.)}$$

From Froude's Fig. 4 values of N have been very carefully measured and, together with the corresponding diameter and pitch ratios, substituted for the symbols in the above equations, which have then been solved for C and B. These values of C and B are given *in extenso* so that the accuracy of the measurements may be tested.

For s = 0·10	C = 2·17
" " = 0·15	" = 3·45
" " = 0·20	" = 5·00
" " = 0·25	" = 6·93
" " = 0·30	" = 9·40
" " = 0·35	" = 12·60
" " = 0·40	" = 17·00
" " = 0·45	" = 22·52

For abscissa value	2	B = 0·553
" "	4	" = 1·140
" "	6	" = 1·850
" "	8	" = 2·700
" "	10	" = 3·730
" "	12	" = 5·060
" "	14	" = 6·860
" "	16	" = 9·152

Of course the whole practical value of the curves now submitted depends upon the accuracy with which, first, the original curves have been constructed, and, second, the data contained in them have been extracted.

The results show Froude's work to be beyond praise.

From these data our Q and W curves have been built up: and in explanation of the form given to them I may say that it was thought desirable to eliminate the assumptions of an arbitrary wake factor and of an arbitrary propulsive co-efficient—assumptions which Froude made in 1886, and which he has retained in his 1892 paper. The disc area has been taken instead of D^2. Otherwise the material to be treated, whether for purposes of design or of analysis, is in much the same terms as those employed by Froude.

The speed of advance of the propeller, or V_1, has to be fixed sooner or later, and it is, I think, better to do so before using the curves than afterwards by the method of correction.

In the absence of other data, Froude's own scale in Fig. 8, or better as given by D. W. Taylor, in his "Resistance of Ships and Screw Propulsion," will be found useful.*

I have found it very fairly exact for top speeds in the cases we have analysed. By top speeds I mean the highest speeds attained in ordinary practice having regard to the fulness of the ships propelled. Mr Hök, in his admirable paper read before the North East Coast Institute in 1893, gave, in tabular form, the suggested top speed for 100 feet models with reference to their block co-efficients. I give the same results, in graphic form, in Diagram 3, the abscissæ being block co-efficients and the ordinates $\dfrac{V}{\left(\frac{L}{100}\right)^{\frac{1}{2}}}$, or the square root of one-hundredth of the length of the actual ship divided into the actual speed.

And it is just as easy to determine the propulsive co-efficient at the outset, in cases of design, as after getting out the dimension and pitch of the screw. The determination is, of course, a matter of experience. In trial analysis, when the nett resistance and I.H.P. are known, ϱ is readily calculated.

The reason for taking disc area instead of D^2 was that the disc constant is very commonly used in the literature of the screw

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* The equations of the mean wake lines are :—

For single screws, $w = 0{\cdot}44\,\omega - 0{\cdot}02$

For twin screws, $w = 0{\cdot}57\,\omega - 0{\cdot}20$

ω being block co-efficient.

propeller, and it is well to retain as many familiar expressions as possible in treating so abstruse a subject.

It will be noticed that Froude's abscissa values may be done away with entirely by plotting the efficiency curve directly on values of W as abscissæ; and as W is used only for the determination of the efficiency it is a more convenient form.

The construction of the curves is as follows:—

Transposing equations I. and II. and restoring the original symbols for N, we have:

$$\frac{1}{C} = \left(\frac{D}{P} - 0{\cdot}17\right) \cdot \frac{\left(\frac{D}{10}\right)^2 \left(\frac{V_1}{10}\right)}{T}. \qquad (1)$$

and

$$\frac{1}{B} = \left(\frac{D}{P}\right)^{0{\cdot}8} \cdot \frac{\left(\frac{D}{10}\right)^2 \left(\frac{V_1}{10}\right)^2}{T} \qquad (2)$$

Reducing T to T.H.P. and expressing velocities in terms of knots per hour; at the same time substituting for D^2 its equivalent $\frac{A}{0{\cdot}7854}$, these equations assume the forms of

$$\frac{1142}{C} = \left[\frac{D}{P} - 0{\cdot}17\right] \frac{AV_1{}^3}{\text{T.H.P.}} \qquad (3)$$

and

$$\frac{1142}{B} = \left(\frac{D}{P}\right)^{0{\cdot}8} \cdot \frac{AV_1{}^3}{\text{T.H.P.}} \qquad (4)$$

The ordinates of the Q curve are $\frac{1142}{C}$, and those of the W curve $\frac{1142}{B}$, or the reciprocals of C and B multiplied by a constant, 1142. The final forms of these equations are:

$$Q = \left[\frac{D}{P} - 0{\cdot}17\right] \frac{A\,(1 - w)^3\,V^3}{\text{E.H.P.}} \cdot e_2. \qquad (5)$$

$$W = \left(\frac{D}{P}\right)^{0{\cdot}8} \cdot \frac{A\,(1 - w)^3\,V^3}{\text{E.H.P.}} \cdot e_2. \qquad (6)$$

Or, as the expression $\frac{A\,(1 - w)^3\,V^3}{\text{E.H.P.}} \cdot e_2$ is common to both equations, denote it by C_A, and we have:

$$Q = \left(\frac{D}{P} - 0{\cdot}17\right) C_A. \qquad \text{(III.)}$$

$$W = \left(\frac{D}{P}\right)^{0\cdot 8} . C_A. \qquad \text{(IV.)}$$

These final modifications will at once be seen to be merely a substitution for V_1, of its equivalent $(1 - w) V$, and the introduction of E.H.P. and e_3 into the formula in place of T.H.P.

As Froude has pointed out T.H.P. = E.H.P. when e_3, or hull efficiency, = 1·00, and in design that is the condition generally assumed. The formulæ as above are correct for four-bladed screws; for three-bladed C_A is to be multiplied by 0·865, and for two-bladed by 0·65.

These curves are applicable in cases both of design and of analysis, as the following explanations will demonstrate:—*

DESIGN.

There is one pitch, and one pitch only, which will satisfy the conditions of any case where I.H.P., revolutions, speed of advance, and diameter of screw are given.

I say diameter of screw, because as that is generally fixed by conditions imposed by the draught of the ship to be propelled, it may be treated as one of the data. But if a range be permissible it is, of course, a simple matter to work out the problem for several diameters and select that one which corresponds to the highest efficiency.

To find Q it is necessary to have recourse to a mathematical device, the solution being partly algebraical and partly geometrical.

If we turn to the relation of speed, real slip, pitch, and revolutions, *i.e.*,

$$P = \frac{101\frac{1}{3}\, V\,(1 - w)}{R\,(1 - s)}, \qquad (1)$$

divide by D and invert, we get

$$\frac{D}{P} = \frac{(1 - s)}{101\frac{1}{3}} \cdot \left[\frac{DR}{V\,(1 - w)}\right] \qquad (2)$$

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* The equation of the Q curve is

$$Q = \frac{64}{s} - 92.$$

Or, as the expression within large brackets is the well known revolution constant, let us call it C_R and write

$$\frac{D}{P} = \frac{(1 - s)}{101\frac{1}{3}} \cdot C_R. \qquad (3)$$

Substituting this value for $\frac{D}{P}$ in the Q equation, viz.:

$$Q = \left[\frac{D}{P} - 0{\cdot}17\right] C_A \qquad (4)$$

we have

$$Q = \frac{C_A \cdot C_R}{101\frac{1}{3}} (1 - s) - 0{\cdot}17\, C_A. \qquad (V.)$$

This, in any given case, is the equation of a straight line referred to the same axes of co-ordinates as the Q curve.

Now, the co-ordinates of Q and s have to satisfy both the Q curve and equation V in any problem, and they can only do so at a common point, namely, the intersection of the straight line with the curve.

The method of application is as follows:—Solve equation Q for two values of s, say for $s = 0{\cdot}0$ and $s = 0{\cdot}5$; spot those values of Q on Diagram I., and draw a straight line connecting the spots and cutting the Q curve. The point of intersection gives the true value of Q and the corresponding abscissa that of s.

Having found Q and s,

$$\frac{P}{D} = \frac{1}{\frac{Q}{C_A} + 0{\cdot}17}$$

$$\therefore P = \frac{D}{\frac{Q}{C_A} + 0{\cdot}17}. \qquad (VI.)$$

The work at this point is easily checked by calculating the apparent slip-ratio from its relation to real slip-ratio and wake, and comparing it with its value calculated from its relation to speed, pitch, and revolutions. That is:

$$s^1 = \frac{s - w}{1 - w}.$$

$$\text{and } s^1 = 1 \quad \frac{101\frac{1}{3}\, V}{PR}$$

The pitch being determined, the value of W is calculated from the equation.

$$W = \frac{C_A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \qquad \text{(VII.)}$$

and the efficiency read off the W diagram.

ANALYSIS.

The difficulty we meet at the very outset in using these or any other curves for analysis arises from the indeterminate character of such factors as w and e_3.

Had we no means of getting over this initial difficulty the curves would be of little use for exact analysis; fortunately by means of a device analogous to that of the "cutting line" in Design we can arrive at very valuable results.

Hull efficiency is one of the three efficiencies of which the propulsive co-efficient is composed, viz. :—

$$\varrho = e_1 \times e_2 \times e_3.$$

So that

$$e_3 = \frac{\varrho}{e_1 \times e_2}. \qquad (1)$$

Now

$$W = \frac{C_A}{\left(\frac{P}{D}\right)^{0{\cdot}8}}$$

$$= \frac{A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \cdot \frac{(1 - w)^3\, V^3}{\text{E.H.P.}} \cdot e_3.$$

Substituting for e_3 its value in (1).

$$W = \frac{A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \cdot \frac{(1 - w)^3\, V^3}{\text{E.H.P.}} \cdot \frac{\varrho}{e_1 \cdot e_2}.$$

$$= \frac{A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \cdot \frac{(1 - w)^3\, V^3}{\frac{\text{E.H.P.}}{\varrho} \times e_1 \times e_2}$$

$$= \frac{A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \cdot \frac{(1 - w)^3\, V^3}{e_1\, \text{I.H.P.}\, e_2}$$

Solving for e_2, we have:

$$e_2 = \frac{A}{\left(\frac{P}{D}\right)^{0\cdot8}} \cdot \frac{(1-w)^3\,V^3}{e_1\ \text{I.H.P.}\ W}. \qquad (2)$$

To eliminate w, take the relation:

$$\text{PR} = \frac{101\frac{1}{3}\ (1-w)\ V}{1-s}.$$

$$\left(\frac{3\ P}{304}\right) R = \frac{(1-w)\ V}{1-s}.$$

$$\therefore (1-w)^3\ V^3 = \left(\frac{3\ P}{304}\right) . R^3\ (1-s)^3.$$

Substituting this in (2) it becomes:

$$e_2 = \frac{A}{\left(\frac{P}{D}\right)^{0\cdot8}} \cdot \left(\frac{3\ P}{304}\right)^3 \cdot \frac{R^3}{e_1\ \text{I.H.P.}} \cdot \frac{(1-s)^3}{W}. \qquad \text{(VIII.)}$$

This is the equation of a curve referred to the axes of Diagram 2, which will be found to cut the curve of e_2.

The method of procedure is to solve equation VIII. for three arbitrary values of W selected, so that one shall be greater and one less than the value experience would lead us to expect, and let the third value be intermediate between these two.

Spot the values so obtained on diagram 2 and sweep a fair curve through them cutting the e_2 curve. The point of intersection gives the true e_2 value and the corresponding abscissa the exact value of W.

Q and w are then easily calculated from the equations

$$Q = \left[\frac{D}{P} - 0\cdot17\right] \left(\frac{P}{D}\right)^{0\cdot8} . W.$$

$$\text{and } w = \frac{s - s^1}{1 - s^1}.$$

An example is worked out in Appendix B.

The data from which the examples in the appendices are worked out have been taken from Mr Martin's paper on "The Trials of the Dutch Opium Cruiser 'Argus,'" and, in order that the information may be in as accessible a form as possible, I give a diagram of the results of one of the progressive trials. (Diagram 4.)

It contains a curve of E.H.P., the model having been tried in the Royal Naval Tank at Amsterdam.

In pursuing these investigations I have had brought home to me more and more forcibly the necessity for experimental data such as can only be furnished by a well equipped tank.

T.H.P. or E.H.P. can only be arrived at, with any satisfactory degree of accuracy, by means of tank trials; and the complex problem of the strange relations between thrust deduction and wake gain will ever remain, so far as I can conceive, not only insoluble but unassailable, unless it can be brought under such observation and subjected to such treatment as an experimental tank alone renders possible. And that is, to my mind, equivalent to saying that only in and through such methods can we reach a thorough understanding of the action of the screw propeller.

In conclusion, I wish to express my indebtedness to Mr John Anderson for very able assistance in the preparation of this paper, and particularly in working out the cutting line for the determination of the Q value in design and the cutting curve for the determination of e_2 in analysis.

SYMBOLS.

A = Disc area of propeller in square feet.
D = Diameter ,, ,, ,, ,,
P = Pitch ,, ,, ,, ,,
T = Thrust ,, ,, ,, tons.
R = Revolutions of ,, per minute.
s = Real slip-ratio of ,,
s^1 = Apparent slip-ratio of propeller.
w = Wake factor.
V = Actual speed of ship in knots per hour.
w V = ,, ,, wake ,, ,, ,, ,,
$(1 - w)$ V = V_1 ,, ,, screw in ,, ,, ,, through the wake current in which it works.
t = Thrust deduction factor.
T.H.P. = Thrust horse power.
E.H.P. = Effective ,, ,,
I.H.P. = Indicated horse ,,
e_1 = Engine efficiency.
e_2 = Screw ,,
e_3 = Hull ,,
ϱ = Propulsive ,,

APPENDIX A.

Example for Design.

Data. $V = 16.$ $\quad$ $E.H.P. = 640.$ $\quad$ $w = 0{\cdot}26.$

$R = 205.$ $\quad$ $D = 7{\cdot}5$ feet. $\quad$ $e_3 = 1{\cdot}00.$

Formulæ.

$$Q = \frac{C_A \cdot C_R}{101\frac{1}{3}}(1 - s) - 0{\cdot}17\, C_A.$$

$$C_A = \frac{A\,(1 - w)^3\, V^3}{E.H.P.} \cdot e_3.$$

$$C_R = \frac{DR}{(1 - w)\,V} \cdot$$

$$P = \frac{D}{\frac{Q}{C_A} + 0{\cdot}17}.$$

Calculating from the data we get:

$$C_A = 114{\cdot}6. \qquad C_R = 130.$$

$$Q = 127{\cdot}5 \text{ when } s = 0{\cdot}0.$$

$$Q = 54{\cdot}0 \quad ,, \quad s = 0{\cdot}5.$$

Applying the straight line on diagram I. we get the point of intersection at $Q = 70$, and consequently $s = 0{\cdot}39$.

$$P = \frac{7{\cdot}5}{\frac{70}{114{\cdot}6} + 0{\cdot}17} = 9{\cdot}6 \text{ feet.}$$

Checking by apparent slip:

$$s^1 = \frac{s - w}{1 - w} = \frac{0{\cdot}39 - 0{\cdot}26}{1 - 0{\cdot}26} = 0{\cdot}175.$$

$$s^1 = 1 - \frac{101\frac{1}{3}\,V}{PR} = 1 - \frac{101\frac{1}{3} \times 16}{9{\cdot}6 \times 205} = 0{\cdot}176.$$

$$W = \frac{C_A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} = \frac{114{\cdot}6}{1{\cdot}21} = 94{\cdot}71.$$

$$\therefore e_2 = 0{\cdot}61.$$

The actual pitch in the case of the "Argus" is 9·25 feet, the difference being due to the fact that the wake co-efficient works out at 0·24 instead of 0·26, and e_3 at 1·093 instead of unity.

APPENDIX B.

Example of Analysis.

Data. $D = 7{\cdot}5$ feet : $P = 9{\cdot}25$ feet : $V = 16.$
$s^1 = 0{\cdot}142$: I.H.P. $= 1024$: $e_1 = 0{\cdot}85.$
$\varrho = 0{\cdot}595.$ $R = 205.$

Formulæ.

$$e_2 = \frac{A}{\left(\frac{P}{D}\right)^{0{\cdot}8}} \cdot \left(\frac{3\,P}{304}\right)^3 \cdot \frac{R^3}{e_1 \text{ I.H.P.}} \cdot \frac{(1 - s)^3}{W}$$

$$= \left(\frac{44{\cdot}18}{1{\cdot}19}\right) \cdot (0{\cdot}00076) \cdot \left(\frac{8615125}{871{\cdot}25}\right) \cdot \frac{(1 - s)^3}{W}.$$

$$= 278{\cdot}85 \times \frac{(1 - s)^3}{W}$$

$$Q = \left(\frac{D}{P} - 0{\cdot}17\right) \left(\frac{P}{D}\right)^{0{\cdot}8} . \ W.$$

$$= 0{\cdot}64 \times 1{\cdot}19 \times W.$$

$$= 0{\cdot}762 \times W.$$

If $W = 150$: $Q = 114{\cdot}3$: $s = 0{\cdot}31$
and $e_2 = 0{\cdot}61.$
If $W = 100$: $Q = 76{\cdot}2$: $s = 0{\cdot}38$
and $e_2 = 0{\cdot}67.$
If $W = 80$: $Q = 61$: $s = 0{\cdot}415$
and $e_2 = 0{\cdot}6975.$

A curve swept through these points of e_2 plotted on diagram II. intersects the e_2 curve at

$W = 118$: $Q = 90$: $s = 0{\cdot}35$
and $e_2 = 0{\cdot}642$

$$w = \frac{s - s^1}{1 - s^1} = \frac{0{\cdot}35 - 0{\cdot}142}{1{\cdot}000 - 0{\cdot}142} = 0{\cdot}242.$$

Thrust Efficiency $(e_1 \times e_2) = 0{\cdot}85 \times 0{\cdot}642 = 0{\cdot}546$

e_3 or Hull „ $\left(\frac{\varrho}{e_1 \times e_2}\right) = \frac{0{\cdot}595}{0{\cdot}546} = 1{\cdot}09$

t, or Thrust Deduction factor $= 1 - e_3 \times (1 - w) = 1 - 1{\cdot}09 \times 0{\cdot}758 = 0{\cdot}174.$

It was agreed to postpone the discussion upon this paper till next meeting, and on the motion of the President a hearty vote of thanks was given to Mr Caird for his paper.

The discussion of this paper took place on 24th December, 1895.

Mr **James Howden** said this admirably arranged paper by Mr Robert Caird on "Propeller Diagrams" raised issues on a rather complicated and abstruse subject. Having given, in former years, considerable attention to the action of screw propellers and the phenomena attending their working, he wished to offer some remarks on the points raised in Mr Caird's paper. It might be described as the eulogy of Mr R. E. Froude, or, at least, of his paper, read at the I.N.A. in 1886, on "The Determination of the most Suitable Dimensions for Screw Propellers." Mr Caird had characterised the teaching of this paper of Mr Froude as beyond praise, and as marking an epoch in the investigation of the properties and behaviour of the screw propeller. Mr Caird in his paper had therefore set himself the task of producing curves representing the performances of screws, these curves being constructed from Mr Froude's diagrams and formulæ given in his paper of 1886, but by a different method than that used by Mr Froude to represent the same effects in his later paper of 1892. It might be taken for granted that any paper by Mr R. E. Froude must contain valuable and ingenious matter, presented with much literary excellence. In his paper of 1886 there were investigations of an original and instructive character, but that the sum total of the paper merited the estimate given of it by Mr Caird he must decidedly take leave to question, because it was in a great measure based on insufficient data and misleading conceptions, and the conclusions derived therefrom were incorrect, and consequently the paper did not fulfil its professed object, "The Determination of the most Suitable Dimensions for Screw Propellers." The formulæ on which these curves were constructed left out of consideration some essential factors on which the determination of the most suitable dimensions of a screw propeller for any given case depended. Further, Mr Froude deduced from the performances of certain small model screws of about 8 inches in diameter, of special shape, working under special and limited conditions, the means of determining the dimensions of screws for ships of the most divergent character. The propeller, in fact, in his treatment became, as it were, a law unto itself, while the ship and *its* character, in determining the character and the proportions of the screw, were practically ignored. Again, Mr Froude gave values to slip and pitch ratios taken from one size and character of screw working under like conditions as fixed factors for determining the proportions of all other screws, giving to these most variable and in a sense accidental factors a value and power in this determination far beyond that which they actually possessed. A still further objection was that the principles on which Mr Froude based his propositions were incorrect and at variance with experience. He said, in Section 133 of his paper, "The leading propositions concerning the efficiency of screws in undisturbed water, which I am going to put forward, are primarily based on the reasoning of the late Dr Froude's paper, read before this Institution (I.N.A.) in 1878, entitled 'On the Elementary Relation between Pitch, Slip and Propulsive Efficiency.' These propositions have been corroborated by the results of very numerous experiments on model screws made at Torquay, they are also corroborated (as I gather from Mr Sydney Barnaby's work on 'Marine Propellers,') by the results of an entirely independent set of experiments therein referred to." Before referring to these theories and investigations of Dr Froude and Mr Barnaby, it would be well to mention here that they, as well as Mr R. E. Froude, had had their ideas on this subject strongly influenced by an erroneous estimate made by the late Professor Rankine of the extent of the motion given to the water in propulsion from a given slip. The weight of Professor Rankine's authority had been so great as to lead all the eminent men who had written since then on this subject to accept without investigation his theory as correct, for the error had been repeated by Professor Cotterill, Dr Wm. Froude, Mr R. E. Froude, Professor Greenhill, and many others, and here they found Mr Robert Caird, amongst these eminent men, taking his views from Mr R. E. Froude, a follower and defender of Dr Rankine's theory, though with various modifications. All these held on one to the other, like links in a chain, and the whole to Professor Rankine. Before referring more particularly to the points in the investigations and theories of Dr Froude and Mr Barnaby, referred to by Mr R. E. Froude, he (Mr Howden) would return to the propositions in the 1886 paper of Mr Froude as given by Mr Caird, and show why the fifth proposition, which embodied the previous four propositions, did not fulfil the purpose for which Mr Froude wrote his paper. This proposition was, "A single diagram will represent the performance of any number of screws of given design, but of different sizes, advancing at any variety of speeds through the water if the ordinates of the thrust curve were taken to represent $\frac{T}{D^2V_1^2}$ where $T =$ thrust; $D =$ diameter of screw; $V_1 =$ speed of ship's advance." To show the undue value given to the diameter of the screw in this formula in determining efficiencies or any values represented by ordinates of the thrust curve, he gave two examples where, with exactly the same thrust and the same speed of ship, but with a difference in diameter of screw, which difference in actual practice could, by a slight variation in disposition of surface merely, without altering area, give a greater thrust than the screw with the greater diameter—that is, the engines with the same revolutions gave thereby a greater speed to the ship. Suppose, for easier comparison, that the screw of smaller diameter gave only the *same* speed, the T and V_1 of the formula remained the same in value in both the following equations (see Plate II^A.):—

(1) With larger screw, let $T = 12{,}000$ lbs., ozs., or any other unit of weight, $D = 12$ feet, $V_1 = 10$ knots, then $\frac{T}{D^2V_1^2} = \cdot 83$.

(2) With smaller screw, with T and V_1 as in (1), let $D = 10$ feet, then $\frac{T}{D^2V_1^2} = 1 \cdot 2$.

In these two examples, with the same actual thrust and speed, by the simple alteration of diameter of screw the ordinates of the thrust curves actually varied as much as nearly 45 per cent. What value could such formulæ, so inadequate, be for determining the most suitable dimensions of screw propellers? He would say, little or nothing. They were, indeed, entirely misleading, for instead of such diagrams as they gave, representing the performances of any number of screws of different sizes at any variety of speed, as was claimed by Mr R. E. Froude and Mr Caird, they were only applicable to the size and character of the propeller used in the experiments for one particular case and with one particular ship, and almost limited to one particular speed. He could only refer briefly to the basis of Professor Rankine's theory, which had led so many eminent men astray, on the action of the screw propeller. It was necessary to understand this theory in order to comprehend the reasoning of Mr R. E. Froude and other writers of this school. The fundamental error of Professor Rankine's theory lay in his taking the *total slip* of a screw blade in a revolution as being made by the blade from starting, and from neglecting the fact that the actual water moved by the blade directly was merely the slip of the whole revolution divided by the number of times the breadth of the blade was contained in the helical circle of revolution. This description would be easily understood by the following diagrams (see Plate II^{A}.). Starting with this fundamental mistake, Professor Rankine postulated for a basis of reaction a column of water equal in diameter to that of the diameter of the screw, and in length equal, with a small reduction only, to that of the advance of the ship per revolution + the slip. This column was driven astern in a mass, = the slip per revolution. By the application of the usual formula $\frac{Wv}{g}$ to the movement of this column, the thrust was obtained, and consequently from the thrust and the velocity of the ship the T.H.P. was obtained. Unfortunately it so happened that this formula, with the values of W and v, found from Professor Rankine's formula, as described, was applied to the case of the "Warrior," with a propeller 24 feet in diameter, which, on trial, made 12 per cent. slip at 54 revolutions, and which, with certain allowances made by Professor Rankine for friction and working in disturbed water, gave an I.H.P. very nearly equal to the actual I.H.P. obtained on the trial of this ship. Professor Rankine did not appear to have made further investigations, but it was evident that on his own formula the accidental coincidence which occurred in this ship would have been entirely upset if the diameter of the propeller had been reduced to 20 feet, or had the slip been 6 % instead of 12% all which, with a more suitable propeller, could have been effected. In an actual example of a steamer given in his (Mr Howden's) paper (read at this Institution in 1878), to which he applied Professor Rankine's formula at 10, 20, and 30 per cent. slips, all being slips made by this steamer at sea under varying conditions of weather, it was shown that with 60 revolutions at 10 per cent. slip and at 14·8 knots per hour the thrust horse power was 1635; at 20 per cent. slip, when making 13·15 knots with the same revolutions, the T.H.P. rose by the formula to 3051; while at 30 per cent. slip, and making 11·51 knots' speed at same revolutions, the T.H.P. was as high as 3673. This showed that by this theory a speed of 14·8 knots at 10 per cent. slip was obtained with considerably less than half the power taken to give 11·51 knots' speed when the slip was 30 per cent. Mr Caird had given an example in the "Argus" as a case, he supposed, for he had not examined it, in support of Mr Froude's theory. He would recommend Mr Caird to beware of coincidences. Dr Froude's paper of 1878 on "The Elementary Relations between Pitch, Slip and Propulsive Efficiency," on which Mr Froude said his 1886 paper was primarily based, was, though based on a different view than Rankine's, quite as much in error. To explain Dr Froude's ideas he would read parts of three paragraphs from his paper on "Various Theories of the Screw Propeller," read at the Institute of Naval Architects in 1890, in review of Dr Froude's and other theories.

"There are several points in the reasoning employed by Dr Froude in setting forth the principles supposed to govern the screw's action which, I venture to say, must necessarily lead to erroneous conclusions, notably, 'that to reduce the slip from 10 per cent. to 5 per cent. would require at least a doubled area, and from 10 per cent. to 2½ per cent. we should approximately need to double the diameter of the propeller.' An essential omission also in the consideration of the effect of the increase of slip is that of neglecting, as I have repeatedly mentioned, the effect of the breadth of the blade on the slip motion. Had this essential point been observed, and the actual motions of the water under various slips been ascertained, conclusions very nearly the reverse of those come to would, I believe, have been arrived at. The supposed comparatively smaller loss in friction arising from the greatly increased area supposed by Dr Froude to be necessary to reduce slip, and which, with views minimising the detrimental effect of slip, led him to the general conclusion 'that instead of its being correct to regard a large amount of slip as a proof of waste of power, the opposite conclusion is the true one. To assert that a screw works with unusually little slip is to give a proof that it is working with a large waste of power.'

"The efficiency of a propeller, so far as giving a larger or smaller slip is concerned, does not depend altogether, and it may not even chiefly, on the amount of surface, but on the disposition of that surface and the pitch employed. Two propellers may have exactly the same surface, but one may with the same power propel the vessel under the same conditions with half the slip of the other and with an increased speed.

"Another important disadvantage in connection with the increase of slip overlooked by Dr Froude should be noticed, that is, the reduced progress of the ship. A speed of screw of 15 miles per hour is reduced to 14·25 miles with 5 per cent. slip, to 13·5 with 10 per cent., and to 10·5 miles with 30 per cent. slip.

"If then 60 revolutions give 15 miles without slip, the same revolutions will give 14·25 miles' speed with 5 per cent. slip, but it will take 81·5 revolutions to give 14·5 miles' speed with 30 per cent. slip. Should, however, the pitch be increased in order to give 14·25 miles' speed with 60 revolutions and 30 per cent. slip, as Dr Froude would evidently have recommended, then an equal disadvantage would be encountered, as the pitch in this case would have to be increased from 25 feet to 34 feet. The much greater resistance which a slip of 30 per cent. would make with a pitch of 34 feet compared with that from 5 per cent. on 25 feet pitch is made apparent by the diagrams, Figs. 12 and 13."

Mr Froude in his paper of 1886 refers to similar experiments made by Mr Barnaby which corroborated his own results. As Mr Froude does not give any account in his paper how his experiments were made, it is necessary to ascertain from Mr Barnaby, in his remarks at the discussion of Mr Froude's paper in 1886, and in his own paper, read at the Institute of Civil Engineers in 1890, how Mr Froude's experiments were carried out.

Mr Barnaby explains that his experiments were made by or at the instance of Mr Thornycroft in 1883, Mr Barnaby assisting him. A steam launch was employed, which was driven by a screw in the stern in the usual manner at 4½ knots' speed, but the screw from which the thrust and efficiency diagrams were made up, and from which, with Mr Froude's collaboration, Mr Barnaby formulated the rules for propeller, was one of 9 inches diameter and 10 feet 3 inches pitch, and placed in the bow of the boat and driven by an apparatus designed by Mr Froude. This screw gave a negative thrust until its revolutions exceeded 530, after which positive thrust was recorded —that is, when its pitch by revolutions exceeded the speed of 4½ knots given by the screw propelling the launch. As little thrust was given on the dynamometer attached to this small screw when working at little above the speed of the boat, and when consequently there was little slip, it was concluded by Mr Froude and Mr Barnaby that a screw working with little slip was a wasteful screw and of low efficiency, and, on the other hand, that when much slip was made and a much larger thrust obtained the efficiency was correspondingly greater.

It is impossible to go into any fuller description of these experiments here; suffice it to say that the diagrams constructed therefrom by Mr Froude, and the practical rules given by Mr Barnaby for finding the most suitable relations between diameter, pitch, and revolutions of a propeller, are all based on the performances of a screw which did not propel the vessel, and therefore were utterly incapable of giving any instructive guidance, or of being made use of for "determining the most suitable dimensions for screw propellers," the object contemplated by Mr Froude in his paper of 1886, which Mr Caird has now brought before this Institution.

He regretted the limited time at his disposal had not allowed him to put the matter in better form than in the remarks he had now made.

Mr THOM said the paper now under discussion at the North-East Coast Institution of Engineers and Shipbuilders by Mr J. D. Young says:—"Experimental constants, such as those obtained by Mr R. E. Froude, can be readily transformed and operated with under the law of comparison, as also can the equations suggested by Mr Thom and adopted by Mr Barnaby and others." Mr Thom said he would like to show, from a few examples of constants taken from known steamers, the importance of working from the surface or projected area as well as from the disc area, although surface is not mentioned or taken into consideration in Mr Caird's paper.

	$\frac{\text{Disc area} \times \text{speed}^3}{\text{I.H.P.}}$	$\frac{\text{Projected area} \times \text{speed}^3}{\text{I.H.P.}}$
"City of Rome,"	220 ...	69
"Furnessia,"	220 ...	69
"Kowshing,"	171 ...	69
H.M.S. "Iris," twin-screw,	459 ...	136
Swift 3-bladed „	225 ...	61½
„ 4-bladed „	225 ...	58

By means of these formulæ it could be shown whether the proposed propeller would be efficient or not. If these constants had been tried on the proposed original propellers of H.M.S. "Iris" it would have been seen they were too large, and had too much surface. As the "Iris" was a twin-screw steamer, he had added the results from two for comparison. He preferred to compare propellers from the projected area looking fore and aft, as it remains nearer a constant than the other dimentions, because, if the pitch ratio is small, it shows more surface in proportion and that a smaller propeller can do the work, and if the usual diameter cannot be got, the surface can be added, as shown by constants from light draught steamer "Kowshing." There are other considerations besides speed to be taken into consideration in designing propellers. They should be suitable for all weathers, which makes it impossible to fulfil the conditions laid down on page 26, which says there is one pitch only suitable for a given speed and I.H.P., because with the same I.H.P. the speed will be different according to the weather and condition of vessel, so that constants should be found from experience most suitable for the trade the vessel is in.

Mr E. HALL-BROWN said he trusted that the question of the screw propeller which had been so often raised, and which had been, and was being, so fully investigated, would not remain much longer in the domain of rule of thumb, as it was in our drawing offices at present. The usual way of "designing" a propeller was to take a somewhat similar vessel which did fairly well on trial or at sea, and from it, as a model, another propeller was deduced by Mr Thom's formula or other means. They had no real knowledge as to whether the former propeller was the best possible for the ship; indeed it may have really given very poor results; all that could be said was that the gross result was as good as was expected. It was only by careful analysis, assisted, if possible, as Mr Caird pointed out, by land experiments, that they could improve the propeller, and he thought they ought to welcome Mr Caird's paper as a help towards that result. He trusted that the question of the propeller would not be allowed to drop, as it had so frequently done, after so much labour and thought had been expended upon it, simply because engineers would not exert themselves to take advantage of the work of investigation which had been already done. The object of Mr Barnaby's experiments was to determine for a given propeller the best ratio of slip. This was done by allowing the propeller to move at a certain speed through the water, and measuring the effective thrust, the power used to drive the screw, and the number of revolutions of the screw. The useful work is the thrust multiplied by the speed through still water—*i.e.*, the speed of the launch; and this, divided by the work absorbed in driving the screw, gives the efficiency. When the pitch × revolutions of the screw was equal to the speed of the launch, there would be no thrust; and the power required to drive the screw would be that required to overcome the slight friction only of the apparatus. The slip of the screw and the efficiency would be nothing. As the revolutions were increased the thrust would increase, and useful work would be done; at the same time the work required to drive the screw would increase, and the slip would also increase. Taking the useful work (thrust × speed of launch) and the work required to drive the screw, it was found that the useful work increased more rapidly than the power required to drive the screw up to a certain point. In other words, the efficiency increased up to a certain point. After that the efficiency began to fall, but it fell slowly as the slip was increased beyond the point of maximum efficiency. This shows that the efficiency of a screw increases with an increase of slip, up to a certain point, and thereafter begins to decrease. There is no ambiguity about this result, and the fact that the propeller did not drive the boat is certainly no reason for doubting its correctness. The boat was only a vehicle for carrying the apparatus, and had it been in front of the screw it would have disturbed the water, and the results would have been unreliable.

Mr PURVIS thought that Mr Caird might be asked to explain a little more fully what he wanted to get at by his analysis. Mr Caird was very clear in his own mind about it, and in a private letter to him had made it rather more clear than in his paper; also, why he preferred to alter the form of the data as given by Mr Froude? At first he was inclined to think that Mr Caird was making complication more complicated, but on further consideration he did not think that was so. In some respects Mr Caird seemed to have improved on Mr Froude's own presentment of his data.

It was agreed that the discussion should be adjourned till next meeting.

The adjourned discussion of this paper took place on the 28th January, 1896.

Mr CAIRD said Mr Howden's remarks fell naturally into three categories. The first of them was a brief and not unsympathetic, if somewhat inaccurate, account of the paper he was criticising. The second was a concrete example which was intended to prove the fallacy of Froude's fifth proposition; and the third was in the form of copious quotations from previous papers of his own. He proposed to take up Mr Howden's third category first. Of Mr Howden's attack on Froude and on Rankine the most complete and conclusive refutation was to be found in the discussions which followed the papers to which Mr Howden referred. He would particularly direct the attention of any one interested to Mr Froude's remarks on Mr Howden's 1890 paper, read before the Institution of Naval Architects. It would be a work of mere supererogation to add anything to these remarks. Of the first category he did not propose to say anything—that was Mr Howden's *resumé* of his (Mr Caird's) paper—except to thank him for whatever was complimentary in his remarks. In the second, however, that was Mr Howden's disproof of the fifth proposition advanced by Mr Froude, there was very unexpectedly something to lay hold of. In the statement of that proposition which Mr Howden gave within inverted commas as a quotation from his (Mr Caird's) paper, he quite gratuitously, and he need scarcely say erroneously, interpolated the word "ship's" in the definition of the symbol V_1, making it mean speed of ship's advance through the water, instead of, as it was very clearly defined in the table of symbols on page 30, the actual speed of the screw through the wake current in which it worked. This had perhaps been done inadvertently, in which case it was to be regretted that carelessness should have led Mr Howden into so gross and palpable a blunder. It was this elementary misconception which had led Mr Howden to make the amazing statement that the ship and its character were practically ignored in Froude's treatment of the subject. Now for Mr Howden's concrete example. Let them bear in mind that it was given in order to demonstrate the undue importance which, according to Mr Howden, Mr Froude attached to diameter as affecting screw efficiency. Mr Howden had overlooked, or perhaps he had disregarded as accidents—he put it somewhat in that way—two elementary facts which appeared to him to be patent to the most ordinary intelligence: the first that the curve under criticism was for one pitch ratio only, and the second that it was plotted on slip ratio as a base. Bearing that in mind, let them look at Mr Howden's figures. His first case was that of a 12 foot, and his second that of a 10 foot propeller, the thrust and speed of advance remaining constant in both cases. Let them assume a pitch ratio of 1·1 for both. They could, of course, assume any pitch ratio they liked, remembering that each one had a separate curve. Then the ordinates, or $\frac{T}{D^2V_1^2}$ in the two cases, would be ordinates of Froude's curve for that pitch ratio, the abscissa of the one being 20 per cent., and the other 26 per cent., on the slip ratio scale, and the revolutions would be 94 in the case of the larger, and 124 in the case of the smaller screw. Was that not exactly what one would expect—namely, that the smaller screw would require 124 revolutions to maintain the same thrust as the larger screw with 94? Again, let them look at what Mr Howden said, just after his numerical example, as to the character of the model screw trials. He said that they were made with one particular ship, but, as a matter of fact, they were made with no ship at all. Mr Howden was doubtless thinking of Mr Barnaby's trials, which he had described further on as having been conducted in collaboration with Froude. That, as Mr Froude had written to him, was "a perfectly gratuitous mistake." Mr Howden said that the trials were "almost limited to one particular speed," and he granted him that and something more. He might leave out the word "almost" and say, as he had done in his paper, that the trials were conducted at 206 feet per minute. The trials were made for a series of slip ratios from 0 to 40 per cent., and Mr Howden would perhaps now see that these ratios were quite general, and applicable to any speed. Mr Howden supposed that he had selected the case of the "Argus" for analysis because it supported Froude's theory. He selected it because it was a published example, and because it contained that very rare curve, the curve of E.H.P., and for no other reason. If Mr Howden would be good enough to furnish him with any authenticated trial data, he would be very glad to analyse them for him, and assure him beforehand that the results could not fail to support what he called Froude's theory, provided always the screw blade was elliptical in form, and with an expanded area of about 9·4 per cent. of the disc area for each blade, and set at a pitch ratio within the limits named in this paper—namely, 1·225 to 2·2. He must enter a protest against the view that he had had any idea of presenting a complete and universal solution of all problems connected with the screw propeller—a view which the course of this discussion would almost point to as being held by some of the gentlemen who had done him the honour of criticising his paper. He quite appreciated Mr Thom's point, but it appeared to him that the substitution of projected area for disc area was that of one unit for another, and little if anything more, because in Mr Froude's experiments, the blade being of fixed design, its expanded area was a fixed percentage of the disc area. The projected area would of course vary with the pitch, but its introduction into the formula would only cause difficulty and complication, and it should be borne in mind that, to obtain the experimental results, as the pitch was varied, so the ratio of projected to disc area varied, and its effect upon thrust was implicit in the result. If he did not mention surface it did not follow that he did not take it into consideration; indeed, it was impossible to avoid it. The question of designing a propeller suitable for all weathers did not enter into the scope of this paper; and Mr Thom would excuse him if he pointed out that he imposed more conditions than a given speed and I.H.P., when he said that there was one pitch and one only which would satisfy them. He had to thank Mr Purvis for calling his attention to the incompleteness of his remarks on analysis. His idea was simply to place the method at the command of the members for their use, if they cared to use it, feeling certain that systematic analyses of trial results on the lines presented would of themselves open up new problems, and possibly lead to a simplification of the process. He had prepared a complete Analysis Diagram of the trial results of the "Argus" (see Plate VI., Fig. 5), which he would ask to have added as a supplement to the paper, and which he trusted would answer the purpose of showing the scope of the method. When the paper was written, he had the impression that Froude's 1892 method could not be applied to analysis, and it was only on Mr Purvis's suggestion that a manipulation of the formulæ by a device similar to that of the cutting curve revealed the possibility of so applying these curves. He had sent the solution to Mr Froude, who, while not having yet had time to examine it, had given him full authority to make any use of it he desired. Since then Mr Purvis had sent him an arrangement which was an improvement on what he sent to Mr Froude, and he had in view a still further abbreviation of the process. He would be very glad to communicate the complete results to the Institution either as a supplement to this paper or separately.

On "Period of Rolling of Vessels as an Index of Stability."

By Mr F. P. PURVIS.

Received 8th; Read 26th November, 1895.

VARIOUS attempts have, from time to time, been made to give captains information regarding the stability of their vessels, and to get from them in return information that may be usefully related to the behaviour of the vessels, and may be of service to the naval architect or shipbuilder when designing vessels of a somewhat similar character, or for somewhat similar service. Without giving any summary of these attempts, it may suffice here to mention the names of Mr Alex. Taylor, Dr Elgar, Mr A. Denny, and the late Mr Wm. Denny, all of whom have done much to bring stability questions from the region of theory to the region of practice.

These attempts to bring the knowledge of the seaman and the naval architect into closer alliance, with a view to mutual assistance, to the production of vessels that *can* be loaded with the best results as to stability and steadiness, and to actual loading, such as to bring about those best results, have all depended upon obtaining an inclination of the vessel by shifting weights from side to side, ascertaining the angle of heel caused by the said shifting, and deducing therefrom the metacentric height, or some value in which metacentric height forms the all important part.

My object on the present occasion is to point out the advantage of another measure, viz.—in still water—the period of rolling, or oscillation, as an alternative to the metacentric height for the purposes referred to. I hope to be able to show that period of oscillation is a measure which can be more easily arrived at than the metacentric height, and that it is at least quite as useful as metacentric height as an index of stability. Period of oscillation will, moreover, at once be admitted as a measure about which a seaman can freely speak without feeling he is going beyond his depth; in this respect at least it has an outstanding advantage over metacentric height.

In order to lay down a series of rules as to what the period of oscillation should be, or as to what can be deduced from the known period of a particular vessel, it is most necessary to have a large amount of experimental data to go upon. Such data, in the mercantile marine, is no doubt at present quite unavailable. From the records of British war vessels more is to be obtained; and, as I shall shortly show, still more is to be had from the records of French war vessels.

During the past summer, I have made the following notes from my own observation:—

	Dimensions.	Time of Single Roll or Half Period of Oscillation.*		
Mail steamer	320 × 35'0" × 19'6"	6·5	$B \times \frac{19}{100}$	B÷5·4
Cross channel steamer	260 × 34'0" × 16'9"	4·0	$B \times \frac{12}{100}$	B÷8·5
" "	231 × 31'3" × 16'0"	5·5	$B \times \frac{18}{100}$	B÷5·7
" "	189 × 29'0" × $\left.\begin{matrix}12'\\15'\end{matrix}\right\}$	3·8	$B \times \frac{13}{100}$	B ÷ 7·6
River paddle steamer	255 × 25'6" × 9'6"	3·3	$B \times \frac{13}{100}$	B÷7·7
" "	200 × 22'0" × 7'9"	3·0	$B \times \frac{14}{100}$	B÷7·3
" "	225 × 22'0" × 8'6"	4·2	$B \times \frac{19}{100}$	B÷5·3
" "	190 × 20'0" × 7'2"	3·0	$B \times \frac{15}{100}$	B÷6·7

In the last two columns of this table is given the relation between time of oscillation and the breadth of the vessel.

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* For the purposes of this paper, it has appeared to be convenient—even though less classic—to deal with half periods rather than with periods.

If sufficient data of this sort were available, and the behaviour of each vessel carefully recorded, it would be possible, I think, without any reference to metacentric height at all, to fix the relation which the period of oscillation ought to bear to the beam. As, in the present state of our knowledge, we have more data about metacentric heights than we have about periods, it seems best to trace the relation between these two, and from our accumulated knowledge regarding metacentric heights to deduce rules for period, if possible relating such period to some dimension of the vessel such as the beam.

Probably the largest number of vessels introduced into any one contribution bearing on the subject of period is to be found in a paper by M. Antoine, in vol. II. of "Naval Science," published in 1873. On page 74 of that volume will be found an average value of 130 for screw steamers; this 130 being

$$\frac{\text{Number of oscillations per minute} \times \text{breadth of steamer}}{\sqrt{\text{Metacentric height}}}$$

metres being the unit of length. Converting metres into feet the value 130 becomes 235; hence using feet as unit of length,

$$\frac{\text{Number of oscillations per minute} \times \text{beam}}{\sqrt{\text{Metacentric height}}} = 235$$

When the corresponding value is worked out for any steamers for which we possess sufficient data, results somewhat different from 235 are obtained. H.M.S. "Revenge" (metacentric height = 3·78, ½ period = 7·6, beam = 75 feet; see Sir Wm. H. White's paper, I.N.A., 1895) gives 305; H.M.S. "Greyhound" gives 257; the steamer "Daisy" (metacentric height = 3 feet, ½ period = 3·8, beam = 29 feet) gives 264. These differences of value are to be fully expected; an exact agreement* could occur only if the ratio of depth to breadth were the same in every case and all the arrangements of the vessels were exactly similar. For the purpose of this

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* For the theoretical considerations upon which the above value may be expected to be approximately constant, see Appendix.

paper, and dealing only with mercantile vessels of which the depth to the weather deck is not less than seven-tenths of the breadth, a value 250 is probably not very far from representing a fair average. From the expression—

$$\frac{\text{Number of oscillations per minute} \times \text{beam}}{\sqrt{\text{Metacentric height}}} = 250$$

it is easy to deduce the time (*i.e.* ½ period) of oscillation, viz.—

$$\text{Time} = \cdot 24 \times \frac{\text{Beam}}{\sqrt{\text{Metacentric height}}}$$

And from this two simple conclusions may be drawn: (1) since the breadth of any vessel is a known quantity, the time of oscillation and metacentric height for that vessel are practically convertible terms; if one is known the other can quite readily be deduced from it; (2) if it is regarded that metacentric height should be independent of size of vessel, then the time of oscillation must bear a constant ratio to the beam.

If then time of oscillation and metacentric height can be regarded as convertible terms, it is clear that obtaining the one is, for practical purposes, quite as satisfactory as obtaining the other; it only becomes a question which is the easier to obtain. A little consideration of all the circumstances will, I think, undoubtedly show us that this question is answered in favour of the time of oscillation. To obtain metacentric height it is necessary to have a calm day, everything on board (except the operations in connection with the inclining experiment) perfectly quiescent; then to have bilges perfectly dry; to shift a known weight through a known distance, and obtain, by very careful measurement, the angle of heel produced by that shift. To obtain time of oscillation, on the other hand, it is simply necessary to count the time of, say, ten single swings of the vessel under favourable circumstances, and divide that number by ten; a very slight roll is sufficient to allow of the count being made; facilities repeatedly occur in leaving a river or harbour; a passing steamer, or a turn of the helm gives a slight list, and a slight roll results; but slight as it is, it is quite sufficient to enable it and a few succeeding rolls to be timed by a watch; presence of bilge water, though not desirable in any but small quantities, does not vitiate the result; movement of the vessel, in the line ahead, need not be stopped; oscillation caused by waves would no doubt lead to a wrong conclusion, but observations can readily be obtained clear of this disturbing cause, and they are made so readily that if the first is not considered satisfactory it can be repeated almost *ad libitum.* No doubt the results obtained, however carefully, will always be subject to a percentage of error; but as with metacentric heights, so is it also with periods, that the margin line between safety and danger, or between comfort and discomfort, cannot be so nicely drawn that a small error of observation will throw the observer either to the one side or the other of that margin.

One frequently hears such a statement as that a certain vessel rolled very badly, and that if she had had more ballast in her bottom she would have behaved better. It is natural to ask, in such a case, whether the vessel had not too much ballast to begin with, and (as a means to judge of this) what was the metacentric height. If I have been able to justify my contention in the foregoing remarks, it would serve just the same purpose to ask what the time of oscillation was in still water. Nay, further, within the limits of type of vessel that I have indicated, we can lay down general rules as to what should be the relation between time of oscillation and breadth of steamer; for instance, in an ocean-going steamer of the tramp description, with plenty of freeboard, the time may be, beam × $\frac{24}{100}$, or, say, beam ÷ 4; in a coasting steamer, subject to a contingent of deck and other passengers, it should not be more than beam × $\frac{17}{100}$, or, say, beam ÷ 6; while in a river passenger boat it ought not to exceed beam × $\frac{12}{100}$, or, say, beam ÷ 8. These values of the time of oscillation nearly correspond respectively to metacentric heights of 1 foot, 2 feet, and 4 feet. In a sailing ship also the "time" should probably not be more than beam × $\frac{16}{100}$. If the various vessels have a "time" value much less than the above (in other words, if the swing is quicker), they will be found too stiff, and will roll heavily, especially when exposed in a seaway. If, on the other hand, the swing is slower, and the "time" in any case approaches, say, to beam × $\frac{32}{100}$, or, say, beam ÷ 3, the vessel will—even without any deck passengers—be found dangerously crank.

My suggestion then is that all captains should be encouraged to take observations upon the time of oscillation, and should themselves relate them to the behaviour of their vessels, endeavouring to discover whether an increase or decrease of "time" from, say, beam ÷ 6 is the more efficacious in lessening the tendency to roll. By noting for themselves what the "time" is, alongside of the stowage and the behaviour of the vessel, they will find they have a standard of reference easily obtained, and valuable when obtained. If, going further, these "times" are made available for the use of others (*i.e.*, if captains will report them, and some one will be good enough to collect and tabulate them), we shall soon have a valuable set of data, showing for various classes of vessels what "time" is ascertained to be most satisfactory. Having such data, we should not improbably find that some of our views regarding proportions of steamers and other features which tell upon stability and upon time of oscillation, require some considerable modification. On this point I speak with some actual experience before me. Not so very long ago I should have said that a metacentric height of 1·5 feet was quite enough for a cross channel steamer, subject to a contingent of passengers or cattle; speaking to-day, I say that a metacentric height of 2·5 feet is not a bit too much; in other words, that a time of oscillation = beam × $\frac{15}{100}$, or beam ÷ 6·5 is not too little. The behaviour of the steamer "Louth," crossing from Liverpool to Dublin in the storm of the 21st and 22nd of last December, and from Dublin to Liverpool in the storm of the 29th of the same month, fully bears out this assertion; the metacentric height on both occasions being within a trifle of 2·5 feet. This behaviour does not stand alone, the subsequent behaviour—both of the "Louth" and the "Wicklow"—in anything like stormy weather, fully confirming the "Louth's" character for steadiness. It is far from my object to deduce a general conclusion from the behaviour of two steamers; but that behaviour, in view of the circumstances, is at least an argument for further observations. If it be established that in making further observations it is quite as satisfactory to deal with the time of oscillation as with the metacentric height, then there is no reason why, even in the present winter, our knowledge of what is required for channel steamers, and indeed for other classes of steamers as well, should not be greatly extended.

APPENDIX.

The two equations,

$$\frac{NB}{\sqrt{m}} = 250 \text{ and } T = \cdot 24\, \frac{B}{\sqrt{m}},$$

where N = number of oscillations per minute,
B = beam,
m = metacentric height,
T = half-period,

are of course obtainable one from the other by the simple consideration that $T = \frac{60}{N}$. The particular values 250 and ·24, or some other values, would be invariable for all vessels if transverse radius of gyration (K) bore always a constant ratio to the beam (say = c B). This can be easily shown from the ordinary equation connecting T with K and m.

$$T = \pi\, \frac{K}{\sqrt{mg}},$$

$$= \text{therefore } \frac{\pi c}{\sqrt{g}}\, \frac{B}{\sqrt{m}},$$

$$= \cdot 556\, c\, \frac{B}{\sqrt{m}}.$$

Taking ·24 as an approximate value for ·556 c amounts to assuming that $c = \frac{\cdot 24}{\cdot 556} = \cdot 432$.

I cannot pretend that $\frac{K}{B} = \cdot 432$ for all classes of vessels. Indeed, deducing its value for H.M.S. "Revenge," we get ·355, for the "Greyhound" ·42, for the "Daisy" ·413. It varies with the internal arrangements of the vessel, at least to some extent, but it varies far more with the ratio of breadth to depth, and with the rig.

Seeing, then, that $\frac{K}{B}$, or c, is not constant for different classes of vessels, it follows that, for constant values of m, T will not bear a constant ratio to B. But this does not nullify my contention that for vessels of a somewhat similar class there should be a fairly constant relation between time of oscillation and beam, nor my further contention that if time becomes unduly long in relation to beam, say more than one-third, a vessel becomes too crank. This may be seen from the general consideration that the causes which tend to diminish m, extra depth of vessel for instance in relation to beam, likewise affect c, so that in the extreme limit that should be allowed to T in relation to B, the values of c and m play each its part. I think, moreover, it will be found that the value (·432) I have assumed for c, giving $T = \cdot 24\frac{B}{\sqrt{m}}$, applies with nearest approximation to vessels of considerable depth in relation to breadth—*i.e.*, to vessels which may be expected to have a small value of m; so that, if the smallest allowable value of m be determined upon, the corresponding value of T is readily obtained; if m must not be less than ·5 feet, then $T = \frac{\cdot 24}{\sqrt{\cdot 5}}$, $B =$ about $\frac{B}{3}$, as taken in the paper.

In the after discussion,

Mr JOHN INGLIS asked what would be the effect of bilge keels in the experiments Mr Purvis recommended in the paper.

Mr PURVIS said the question as to the effect of bilge keels on period had been pretty well answered in Sir William White's paper and elsewhere. It appeared that the effect of bilge keels was not large. Sir William White gave the effect on the "Revenge" as an increase from 8·0 seconds (single swing) without bilge keels to 8·4 seconds with. A very similar result was obtained by Mr Froude a good many years ago with the "Greyhound," in which the addition of bilge keels made very little difference in the period. The effect on period and effect on rolling were of course two entirely different matters, as Mr Inglis would readily bear out. In Mr Froude's experiments there were two nearly similar vessels, the "Greyhound," fitted with bilge keels, and the "Perseus" without. The metacentric height was made identical, and the two were put simultaneously into a beam sea to get a good roll, with the result that the amount of the oscillation was very markedly different, the average roll of the "Greyhound" being only about half that of the "Perseus."

Mr **Pilcher** said there was one point which he thought should be noticed. It seemed to him that the ratios which Mr Purvis had given, showing what might be considered safe, and what might be considered unsafe periods of oscillation, would only hold in one particular system of loading, because if they had a system of loading in which they had a lot of light stuff in the middle and a lot of pig-iron at the sides, that would increase the radius very much and give a long period of roll. The same thing could not obtain in a man-of-war with main-deck guns. They could increase the period of roll with exactly the same stability by the men running out their guns. It would increase the period of gyration, although it would only imperceptibly interfere with the real stability of the vessel.

Mr **Purvis** said that Mr Pilcher certainly raised a real point, showing the necessity for further data. He did not attempt to claim that all ships ought to be taken in the same way, or that men-of-war should be taken as merchant ships, but if they examined any theoretical attempt to show the effect on period of alteration of radius of gyration, through lateral movements of weights, they would be struck with the comparatively insignificant nature of the result.

Mr **Thom** said the effect of the position of the weights might be very small laterally, but it was of great importance fore and aft. If they took a modern yacht, and distributed the weight over the full length of the yacht, she would plunge her bows right under in a seaway.

Mr **Purvis** said that no doubt that would be the case; longitudinally there was more scope for alteration of weights.

Mr W. D. **Archer** said that the point Mr Purvis had called attention to with regard to the necessity when making an inclining experiment of having calm weather and perfectly dry bilges was one of importance. This method that he had devised for measuring the metacentric height was very ingenious, and he thought might be very useful to master mariners. It had always appeared to him that an inclining experiment was too delicate for seamen to perform with tolerable accuracy. Any one who had made an inclining experiment knew how very difficult it was to get the data that they relied upon, and what trouble there was to get the water out of the bilges, and other things of that kind, and it seemed to him that Mr Purvis had suggested a valuable means of measuring the metacentric height by taking the period of roll.

The discussion of this paper was resumed on 24th December, 1895.

Mr **Purvis** further stated that he had received the following letter from Mr Hök, of Sunderland—"We went out this morning (25th November) with a steamer 340 by 44 feet 6 inches by 29 feet to upper deck, and I had a splendid opportunity of rolling her, not, of course, in still water, but among waves. The swell was somewhat irregular, but I had time to count the period on ten different occasions, so the mean value is probably not far from the truth. The steamer had 650 tons of water ballast and 1060 tons of coal in her; part of the coal was stored in the bridge, and for the rest empty. She is a large and full cargo steamer, was in ballast and bunkers, with a mean draught of 12 feet 8 inches. Her metacentric height during the experiment was 4·4 feet. The times of ten swings from side to side, taken while she was lying broadside on to the swell, were, during the ten experiments, respectively, 42, 37, 45, 42, 40, 43, 41, 43, 40, and 40 seconds, giving a mean ½ period of 4·13 seconds. Working out the value of $\frac{N \times B}{\sqrt{m}}$ it becomes 308 $\left(\text{or } T = \cdot 195 \frac{B}{\sqrt{m}}\right)$ which is almost the same as that of H.M.S. 'Revenge.' Coming to the general question, I have long thought that the seagoing qualities of steamers could never be determined by observing the metacentric height. I have always felt that the theory of rolling is out of gear, and the more I go to sea and the more I talk to sea captains the stronger is this my conviction. I believe that the seagoing qualities of ships can alone be settled experimentally and by considering the question from a dynamical point of view. And for this reason I think your paper is very valuable, and I hope it will give an impetus to experiments in the direction and for the purpose you require. Personally I shall certainly roll ships every time I get an opportunity, and on the North-East coast we have splendid opportunities to roll ships in a seaway and accumulate data tending to show the relation of the $\frac{1}{2}$ period to the metacentric height. I don't think that for given beam the product of the period squared and the metacentric height is a constant quantity. It may perhaps be as constant as the Admiralty speed constant, bnt nevertheless the expression is simple and may be of good use until something better is invented that is based on varied and sufficient experimental data."

Mr **Archibald Denny** writes:—I have carefully examined our records, and I enclose herewith a Table giving results of actual practice where both the period of oscillation and the metacentric height have been known.

Mr Purvis sent me his M.S., and I have already sent him some of these results.

The first line gives the actual half period of roll.

The second line the actual M.G.

The third line the period obtained from Mr Purvis' formula, knowing the beam and the M.G.

The fourth line is the reverse of the third, assuming the beam and period known, it gives the M.G. according to Mr Purvis' formula.

The fifth line corresponds to Mr Purvis' fractions given on p. 51.

From this Table it will be seen that the figure Mr Purvis has taken—namely, 250—is rather too much of a constant.

For vessel A, the first column was from a rolling experiment in the dock, which could only be more or less accurate, as the roll was caused by a strong wind.

The second and third columns were observations made by myself on an actual voyage, and which, I believe, are as accurate as any observations could be made.

The second vessel is shallower in proportion to beam than Mr Purvis anticipates in his paper.

The third vessel C, like A, has a depth of not less than $\frac{7}{10}$ths of beam.

D E F G H were shallow and broad.

K was a vessel falling within Mr Purvis' limits.

I am responsible for an instrument which I have called the M.G. meter, and with which inclining experiments can be made with facility. Several of these instruments have been supplied to ship captains. One captain, who has taken a special interest in this question, and who had previously used the pendulum described in my paper of 1887, read before the Institution of Naval Architects, writes as follows:—

"I beg to inform you that I heeled my ship for stability whilst at anchor (port anchor) in Suez roads on the 12th inst. I used your M.G. meter, which I placed on the after bulkhead in my room, for the observations.

"The weight used was 4 tons of cutch, and the distance through which it was moved was 26 feet. The result was as follows:—

Steamer upright, the micrometer screw read 1 inch (exactly).
Heel to port, 1·17 inch.
Heel to starboard, ·87 inch.
Mean adjustment of screw, ·15 inch.
The steamer's mean draught was 22 feet.

I then proceeded as follows:—

$$\text{Displacement}\ \frac{26 \times 2}{6143}\ \text{tons} \qquad \cdot 017\ \text{nearly.}$$

Notes on Mr Purvis's paper on "Rolling of Ships."

	"A"			"B"	'C"	"D"	"E"	"F"	"G"	"H"	"K"
½ period of roll ($\frac{\text{actual}}{\text{time}}$)	7·25	7·25	8·0	7·33	7·0	3·5	1·17	3·0	3·0	3·188	5·0
M.G.	2·12′	1·2′	·94′	1·22′	2·22′	4·45′	2·67′	6·86′	4·95′	7·34′	1·70′
"T" from formula $T = \frac{\cdot 24 \times \text{beam}}{\sqrt{\text{M.G.}}}$	7·41	9·76	11·08	6·11	7·73	4·09	1·32	2·20	2·60	2·12	6·99
M.G. from formula	2·19′	2·19′	1·80′	·84′	2·71′	6·10′	3·41′	3·68′	3·68	3·26	3·33
½ period (actual) ÷ B	·162	·162	·179	·262	·146	·097	·129	·125	·125	·133	·132
Condition of ship	Launching condition	Loaded at start of voyage	Loaded at completion of voyage	Light	Loaded	Loaded	Light	Partly loaded	Loaded	Partly loaded	Loaded
Type of ship	Large passenger ship			Small cross channel steamer	Large passenger steamer	Small full cargo steamer	Small launch	Sailing barge	"	"	Passenger steamer (Mediterranean)

I then shifted the scale E to ·15 and the straight edge G to ·017 on E, which gave me ·6 metacentric height nearly. I think that the first reading of the micrometer, ·17, would be likely to give the metacentric height more correctly than the mean of the two readings, as the shift of the two tons of cutch was done very quick, and the loose water in the ballast tanks would not have had time to run over to port and give an incorrect result. The whole observation only took twenty minutes to perform, and I hope to be able to get a couple of water tanks (to weigh about two tons each when full of salt water) which will enable me to take an observation in less than ten minutes when I get home."

From this it will be seen that he at least finds no difficulty in making the inclining experiment. The practice of this captain is to incline his vessel at least once, if not twice, a voyage (trading to and from the East), and he supplies us with diagrams showing the loading of his steamer with a greater accuracy than we have ever had from any other captain—in fact the accuracy is such that we are able to check his inclining experiment from our knowledge of the light centre of gravity.

In all the experiments he has sent us, which are very numerous now, there has never been more than one-tenth of a foot difference between him and us. It may interest the members of this Institution to know that this vessel, which is an ordinary cargo steamer of about 320 feet in length, habitually sails with an M.G. little if anything exceeding ·6 of a foot. The captain reports that she is an admirable sea boat under these circumstances, a light roller, and at the same time appears to him what he calls stiff—what a professional man would on the other hand call steady.

While I cannot, I am sorry to say, give evidence in support of Mr Purvis' contention, I shall endeavour to get all the data I can and study the question from his point of view, but I must say my experience leads me to believe that even a moderately well done inclining experiment will be more accurate than a rolling experiment.

In the case of vessel A I have turned up my diary of the voyage, and although the conditions for obtaining an accurate roll were exceptionally favourable, namely, a calm sea with a long swell, my diary says:—"Found ship most comfortable and easy; period 14 to 15 seconds." This refers to the second column, where the period has been taken 14½.

For the third column my note is—"Period appears to be for rolling about 16 or 17 seconds, say 16 seconds full." This experiment was made at the end of the voyage, after having burnt a known quantity of coal.

These figures were not put down until I had repeated the experiment over and over again with a stop-watch, carefully choosing rolls which I considered were uninfluenced by the motion of the sea at the moment.

I would also like to say that I have endeavoured to make actual rolling experiments in still water with a body of men running from side to side in the usual way, but in the several cases where I have attempted this I have found it quite impossible, and the time consumed would be much more than that taken up by an inclining experiment.

As to Mr Inglis' question, I have made numerous experiments in the tank on models with and without bilge keels. It may interest the Society to know the result of one of these in reference to the effect of bilge keels on the extinction diagram, of which a sample is sent herewith. (See Fig. 5, Plate II$^{\text{A}}$.)

Comparing the diagrams with and without bilge keels, there was a greater extinction with bilge keels, amounting to 48 per cent. of the angle from the end of the first single swing to the end of the seventh single swing. I also made experiments as to the effect of winging weights. The total displacement of the model was 243 lbs.; the weight was 20 lbs. placed first at centre, and afterwards 10 lbs. on each side, 7 inches out.

The period of roll with the weights in was 1·52 seconds, with the weights out 1·6 seconds, which, I think, confirms Mr Purvis' remark that winging weights, such as can be done in actual practice, has not a great effect upon merchant ships.

The difference in period between the same model with and without bilge keels is also quite negligible so far as my experiments show.

Please understand that although at present I prefer an inclining experiment both for accuracy and facility, I welcome Mr Purvis' paper as an addition to our knowledge, and shall certainly follow the matter up and endeavour by numerous experiments to get at the law relating M.G. and period, but the impossibility of making a rolling experiment in dock and the necessity of knowing the M.G. before leaving dock seems to me a serious drawback to the system.

It was agreed to adjourn the discussion.

The adjourned discussion of this paper took place on the 28th January, 1896.

Mr PURVIS wished to thank those who had spoken and those who had written with relation to his paper for what they had said about it, and especially for their promise to keep it before them for guidance in the future. Mr Archibald Denny's table on page 59 represented the most severe criticism that his paper had received, and, with their permission, he would like to put one or two figures upon the blackboard. Mr. Purvis then compared line 2 of Mr Denny's paper with line 4, remarking that Mr Denny's comparison amounted to saying that while by Mr Purvis' formula metacentric heights should be as in line 4, they did, from actual experiment, come out as in line 2.

		"A"			"B"	"C".	"D"	"E"	"F"	"G"	"H"	"K"
M.G	Line 4	2·19	2·19	1·80	·84	2·71	6·10	3·41	3·68	3·68	3·26	3 33
	Line 2	2·12	1·20	·94	1·22	2·22	4 45	2·67	6·86	4 95	7·34	1·70

Examining these figures, the second and third columns under heading A first called for remark. Mr Denny had written to Mr Purvis privately that one of the water-ballast tanks was partially filled with fresh water for boiling use. How he had corrected for this Mr Purvis did not clearly understand, but the case was certainly not one contemplated by his formula, and the comparison should, he thought, be struck out. This raised the general question of probably the greatest difficulty with which Mr Denny's method—the metacentric method—in the hands of the most experienced captain yet found out had to contend—viz., the presence of bilge water. Anyone who had had experience of inclining, even with all the resources of a shipyard, knew how easy it was to have his experiment vitiated by the presence of bilge water; Mr Denny was probably a little inclined to minimise this. Might it possibly be the case that in the steamers "C" and "K" there was more bilge water than the captains reported; the effect would be to make the metacentric height appear less than it actually was, and hence account for figures in line 2 coming less than in line 4. The other cases were outside the scope of what Mr Purvis' formula dealt with, but it was rather curious to take the cases "F," "G," and "H," where the discrepancy was very marked indeed; it showed to him, or to anybody else who might be using his formula, that it must not be applied beyond due limits. He thought he knew the boats to which the figures referred, and, if he was correct, they had an enormously heavy rig for the purpose of sailing across the Atlantic. The effect of the high masts and heavy rig was evidently to increase the radius of the gyration of rolling in comparison with the beam. As Mr Purvis' formula was based on the beam instead of on the radius of gyration, it would follow that any values worked from it would be too small when for any reason the radius of gyration was large.

On "Comparisons of Systems of Mechanical Draught."

By Mr JOHN THOM, M.I.N.A.

Received and Read 26th November, 1895.

WHEN I promised the Secretary to read a paper this session the subject was intended to be "Water Tube Boilers." From unforeseen circumstances, however, it is not advisable at present to give the results of the experiments made.

Instead, I have written a short paper, sufficient to start a discussion, on "Mechanical Draught," being led to choose this subject through having crossed the Atlantic three times in an official capacity, and each time in a vessel fitted with a different arrangement of mechanical draught.

My intention is to mention the results obtained from the arrangements adopted in these vessels, and other systems that have come under my own supervision.

And it will be instructive if other members will give their experience with any other arrangements.

The systems I took notes from were:—

First.—The closed stokehole, usual Admiralty system, gratings covered over, and air forced into the stokehole with fans, and air-locks for allowing men to enter and go out.

Second.—The well-known Howden system of forced draught, with the air heated on the way to the furnaces by the hot gases as they pass to the funnel.

Third.—The Ellis & Eaves arrangement of induced draught, with the air heated on the way to the furnaces, similar to Howden's system, but the fans in this instance are placed at the base of the funnel, and induce the gases to them (will be spoken of as suction draught in this paper).

Fourth.—The closed ash-pit arrangement, with fans discharging direct to the furnaces, and stokehole gratings open.

A The first arrangement mentioned, the closed stokehole, is still working satisfactorily after many years' use, and does not appear to injure the boilers as it is worked. The air pressure carried is ¾-inch in the stokehole, burning 25·9 lbs. of coal per square foot of grate, and giving 16·1 I.H.P. per square foot of grate, and ·372 I.H.P. per square foot of heating surface.

The result of a good passage with very good American coal was 1·6 lbs. of coal per I.H.P. per hour; with American coal the full power developed is only about 5 per cent. less than with Welsh coal.

This system is very simple, although the air-locks are inconvenient, and all the bunkers require to be air-tight, as the air would escape from the stokehole through them, as the bunker doors must always be left open (if there is any leakage the coal dust will be blown on deck). The inconvenience of air-locks is not so much felt in a large steamer, where the engineer remains a full watch in the stokehole. The stokehole is very dirty, especially with Welsh coal. The temperature of the stokehole was 116 degrees F., with the atmosphere at 62 degrees F. mean of voyage.

B Howden's, the second system, fitted in a sister vessel to the first, is a decided advantage in many respects. The stokehole can be left open to the engine-room, and is much cleaner, there is not so much dust flying about. Care must be taken to make the uptakes and casings air-tight, or the arrangement is not so effective, as the gases escape into the stokehole. This arrangement is worked with a shorter fire-bar and burning a greater quantity of coal per square foot of grate, owing to being able to carry a higher air pressure at the fires through having valves for shutting off the draught while firing.

Of course there are more complications on the boiler front which require attention, but there is an average saving of about 8 per cent. in the coal bill over the first system, due to the heated air and retarders.

This arrangement is not so suitable for American coal as it is for Welsh coal. The falling-off in full power, due to using American coal instead of Welsh, is about twice as much as it is in the vessel with the closed stokehole. The temperature of the stokehole is about the same as it is with the closed stokehole system—116 degrees, with tho atmosphere at 61 degrees. Taking the results from a good voyage with good Welsh coal, with 3¾-inches air pressure at the fans and 1½-inches at the ash-pits, burning 28·2 lbs. of coal per square foot of grate, that is with 18·6 I.H.P. per square foot of grate surface and ·393 I.H.P. per square foot of heating surface, the consumption is 1·52 lbs. of good Welsh coal per I.H.P. per hour.

C Gives the results from a more recent arrangement of Howden's system on trial. When indicating on trial 24·13 horse power per square foot of bar surface and ·577 per square foot of heating surface the temperature of the funnel gases was 496 degrees and air entering fires at 159 degrees, and 3⅛-in. W.G. pressure of air at fans, the heating surface of air heating tubes equals about ⅓ heating surface of boiler.

D The Ellis & Eaves arrangement is the latest system of mechanical draught, and has been developed at Messrs John Brown & Co.'s, Sheffield, where they have a large number of boilers working under this system.

This combination of Howden's and Martin's systems with Serve tubes makes a comfortable arrangement. The stokehole is open as with ordinary draught—in fact it is just ordinary draught intensified by the fans—the air before reaching the furnaces is drawn through horizontal air-heating tubes, the hot gases on their way to the funnel pass round outside these tubes so that the air is heated, as in Howden's arrangement on voyage mentioned, to 308 degrees F., the air drawn from above the boilers entering the air tubes at 117 degrees and at fan delivery or funnel base 395 degrees. The heating surface of air-heating tubes was about the same as total heating surface of main boiler, or three times greater in proportion than Howden's arrangement. There is, however, this advantage, the furnaces are under less pressure than the stokehole, and a certain quantity of cold air can be allowed to enter from the stokehole below the fire-bars; this sweetens the air in the stokehole, as the air that is taken away is replaced by pure air from above, and any leakages about the furnace fronts or casings act in the same way, drawing in air. The temperature of the stokehole was only 80 degrees.

A certain amount of cold air admitted under the fires does not appear to affect the economy much. When cold air is admitted in this manner there is less heated air drawn through the tubes, but the hot air which is drawn through them will be of higher temperature through having been longer in the tubes. The cold air admitted below the bars should help to keep them cool.

From experiments made at Sheffield, it was discovered that by raising the fire-bars a few inches at the back (instead of lowering them at the back in the usual way) the bars would allow the fires to be forced very much more severely, and would give no trouble when burning over 60 lbs. of coal per square foot of grate. Sloping the bars up towards the back has a further advantage, that it is easier to see that the whole of the grate is covered through the fire door, and there is no chance of the flame being blown in your face. Another advantage the arrangement in this vessel possessed was the control the engineer had of regulating the quantity of heated air admitted above and below the bars, with peep-holes to watch the result while regulating. With bituminous coal all the hot air would be put over the fires and the smoke almost entirely consumed.

The consumption per I.H.P. (on voyage) of which the particulars are given, was 1·41 lbs. per hour with soft coal (not South Wales coal), that equals ·539 I.H.P. per square foot of heating surface, and 17·13 I.H.P. per square foot of bar surface, and 24·2 lbs. of coal per square foot of grate, with 3¼-inch W.G. vacuum at fan and chimney, and 1-inch W.G. vacuum at ash-pit.

I should mention that in firing and cleaning fires, the action of opening the door automatically closed off the draught from the furnace and prevented the cold air from rushing in. At Sheffield they think this an unnecessary precaution, and I do not think it is adopted there.

They hold the opinion that with suction draught the heat impinging on the ends of the tubes and tube-plates is altogether different to what it is with forced draught. The adherents of suction draught say it sweeps clear of the ends of the tubes and enters in the centre, while with forced it impinges on the tube ends. Many other engineers maintain that the action is precisely the same in each case; the draught is due to the difference of pressure at the base of the funnel and at the furnace mouth. This is a point that should be noticed in the discussion; each speaker should give his opinion whether he believes suction and forced draught synonymous terms or not; if speakers are diffident, we should take a show of hands, as the discussion on Mr Martin's paper before the Institute of Naval Architects still left the point disputed.

From experience at Sheffield, from the same reason as given for saving tube ends, they advise the air space at the back of furnace between the bars to be reduced, as the draught is more intense at the back end of grate.

The fans are about double the capacity in the suction arrangement of draught compared with the other arrangements, due to the gases having expanded by the heat, and the gas from the coal burned having to pass through the fans.

Although double the capacity the adherents of suction draught maintain the fans do not require double the power, as the work done is much the same, whether the power is put at either end of the conduits, but the fans, being larger and heavier, have more friction, and are said to require 25 per cent. more power to work them in handling the lighter gases.

With suction draught it is quite possible where the fans draw from a common conduit to have much more fan power than necessary. In that case it may be found in some instances that one fan will not be doing any useful work, merely keeping the air from going back through it, but not discharging any gases, the other fan being capable of doing all the work required.

The air-heating tubes in this arrangement reduce the temperature of the gases to a point that can easily be handled by the fans.

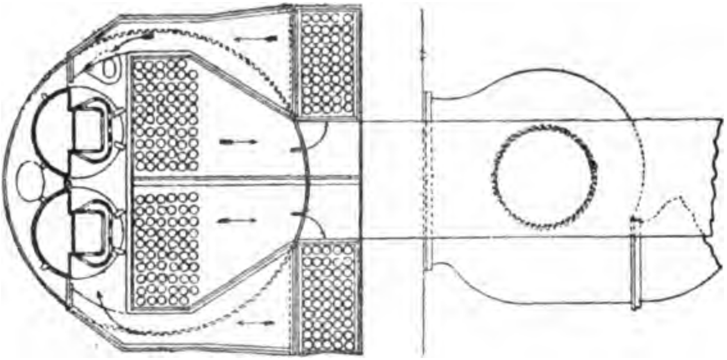
The bearings of the fan next the casing is kept cool by circulating water round the bottom bearings. These bearings should be made very long to prevent the fans wearing down; this refers to all fans. Good fans have the end bearings next fans over three times the diameter in length.

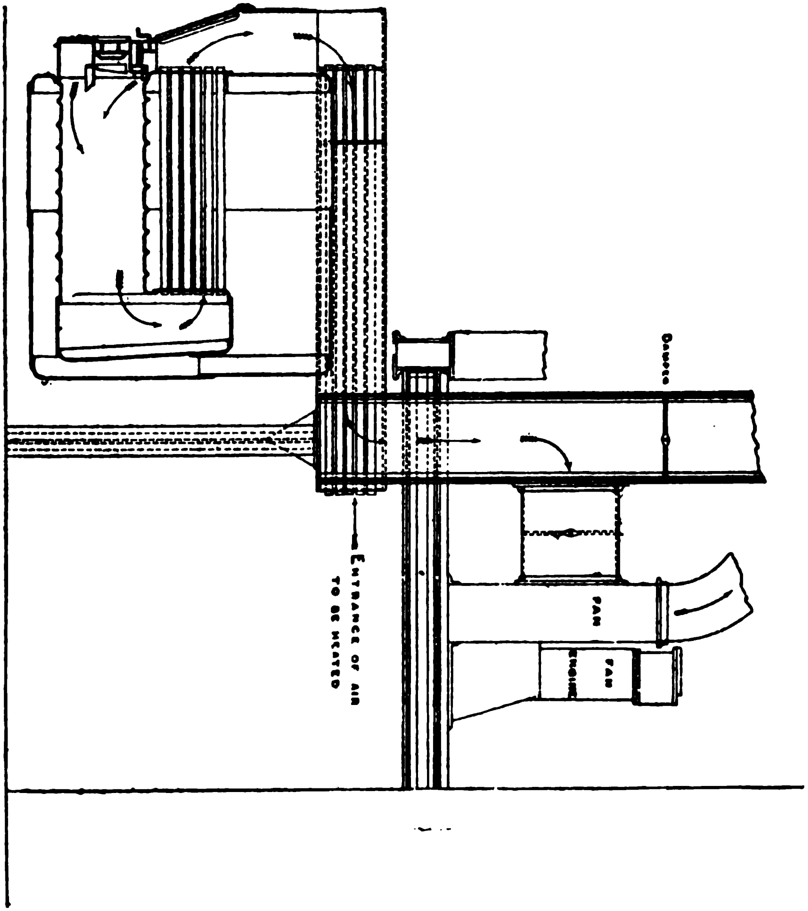
E The *Closed Ashpit System* is the fourth arrangement mentioned. Although perhaps the oldest, this is the least adopted, through the fear of using cold air under a high pressure. The arrangement works very well if properly designed. You can get a very high power from a light boiler, but you must take the precaution not to inject the air directly into the ashpit, only arrange it so that the air is circulating all over the furnace front, and let pressure into the furnace at various parts above and below the bars. The stokehole is quite open in this system, and it has this advantage over all the others, that you have merely to open the ashpit doors and stop the fans in order to work with natural draught. The fans draw from the engine-room or stokehole, as desired, and keep the engine-room and stokehole more comfortable than with natural draught. You will notice from the table that with this arrangement the power on trial was very high for the weight and heating surface—22·6 I.H.P. per square foot of bar surface and ·714 I.H.P. per square foot of heating surface, with 4 inches air pressure at fans and 2 at ashpits.

Under ordinary cruising conditions the power was reduced to 13·3 lbs. of coal per square foot of bar surface, and ·418 I.H.P. per square foot of heating surface. The consumption was 1·56 lbs. of Welsh coal per I.H.P. per hour, with 1¾-inches air pressure at fan. This arrangement has also been working satisfactorily for years.

The results given are from a similar arrangement to that so well worked out by Mr D. J. Dunlop, Port-Glasgow, and published in *Engineering*, March 18th, 1892, fitted in the yacht "Mira," which had the exciting race from Cloch round the Cumbraes with the yacht "Hermione."

The annexed figure shows Ellis & Eaves' combination. The other arrangements are so well known that drawings are unnecessary.




DAMPER
ENTRANCE OF AIR TO BE HEATED
FAN
FAN ENGINE

The figure shows the arrangement as adopted for land purposes at Sheffield. For marine work I think it would be advisable to draw the air through outside the tubes, and let the coal gases pass through the tubes; they could then be swept when overhauling in port from outside the heating-box, same as boiler tubes.

In further reference to the table of comparisons annexed, the first two refer to mail steamers kept continually working at full power. They are exactly the same in every respect, except the system of draught employed.

These two steamers when working under favourable conditions, the closed stokehole made the fastest passages with American coal and the Howden system the quickest with Welsh coal; but latterly the closed stokehole is quicker, taking all last season on an average, of six hours per passage. This vessel was not designed to suit Howden draught originally, but the boilers were designed to suit forced draught. The average consumption of average voyages with Welsh and American coal takes 10 per cent. more coal per I.H.P. than mentioned in table.

The furnaces with the closed stokehole arrangement stood quite as well as with Howden's draught, but the tubes began to leak at combustion chamber end, and the boilers had to be re-tubed at a much earlier date than with Howden's draught.

Altogether, it is a very creditable result for the Admiralty system where you can afford to carry weight for engines large enough for economical working with a good number of expansions.

The I.H.P. per ton of boilers machinery is almost as great in these two express vessels on ordinary work as the others on trial. This is where the human element comes in. The I.H.P. per ton of machnery is very nearly alike in the other examples.

The second two refer to swift cargo steamers of the same type.

The fifth column refers to a yacht of 1500 I.H.P., showing that a large H.P. can be obtained with this arrangement when necessary. With it natural draught can be adopted, and save the decks from the discharge of ashes caused by forced draught. This trouble is common to all forced draught arrangements mentioned when used to excess.

Generally, I have no doubt that examples might be obtained from any of these systems, showing a greater power obtained from the coal or from the weight, but the examples I have taken are from vessels under or about the same conditions for a fair comparison.

On trial, in the instances mentioned, the closed ashpit arrangement is much superior to all the others in I.H.P. per ton of machinery, and Ellis & Eaves' system show the most power per square foot of heating surface on voyage. This should be expected, as it is the only one fitted with Serve tubes, but I do not think the full advantage of these tubes has yet been taken in designing boilers. I have advised in boilers now building to reduce the number of tubes. In that way we get larger furnaces, and greater power from same dimensions of boiler, and depend on the head absorbing power of the Serve tube to make the heat distributing surface more effective. The Serve tubes will be worth paying for under these conditions. Howden's arrangement shows the greatest power per square foot of grate both at trial and on voyage, due to using shorter fire-bars.

From my own experience I know that each of the systems can be made to work very satisfactorily. The furnaces will not give trouble with any of these systems so long as the air is properly admitted, although, naturally, one would be led to suppose that the heated air would do the furnaces less damage.

The closed ashpit becomes similar to the closed stokehole system if in the closed ashpit system the air is kept circulating round the front and is admitted by holes above and below the bars, as mentioned before, with this advantage in favour of the closed ashpit, that when working with high air pressure the blast is shut off while firing,

If necessary, with either of these arrangements the opening of the fire door can be arranged to automatically close off the fan from the draught in the one case or to the funnel in the other. This would certainly increase the life of the tubes.

The tables show that the most economical arrangements are the heaviest, probably because of the air-heating tubes which are employed in these systems.

When the length of voyage is limited it becomes questionable whether the increased economy is worth obtaining when it is necessarily accompanied by the increasing weight. But in the case of a long voyage the smaller consumption will necessitate less coal to be carried, and so the total weight of boilers and coal will be less than when lighter systems are employed.

The fans themselves are the most important factor of any forced draught system. When the fans are too small they have to be overdriven, and soon come to grief. I have found that a good empirical rule for the capacity of the fan is—

$$\frac{\text{Width at periphery} \times \text{dia.} \times \text{cir., all in feet}}{3} = \text{cub. ft. of air per rev.}$$

Allow for 250 cubic feet of air per lb. of coal to allow for leakages, etc. Of course you will require to see that the speed of the fan periphery is suitable for the amount of air pressure to be carried, say

$$8\sqrt{68 \times \text{inches water gauge air pressure}}$$

= speed of fan tips in feet per second to balance inches water; multiply by 60 and divide by circumference of fan in feet = revolutions of fan per minute for forced draught.

If the proportioning of the fans is left to the fan-makers they are apt to supply fans which are much too small for the work required, in order to reduce the price.

If the fans are over double the capacity given by this rule they can be depended on to work in the funnel gases after they have been reduced in temperature by the air-heating tubes.

These air heating tubes have been the saving of the induced system. When the fans are put direct in the funnel, as originally fitted, it is quite probable that you might find only the stumps of the blades left after the trial when consuming a large amount of coal with small heating surface.

Another decided improvement was that adopted by Messrs J. & G. Thomson in the vessel from which the particulars are given, viz., in placing the fans on brackets on the casing of the vessel instead of on the hot uptakes, which soon heat up the fan base.

I should mention that all the arrangements mentioned are now fitted with retarders except the natural draught example. This seems to be an important factor in the economy derived from forced draught.

Some owners think it a greater invention than that of the triple-expansion engines, because fitting it to some of their steamers when the conditions were favourable the saving was as much as 10 per cent. of coal.

I should mention the consumption of coal per I.H.P. per hour is arrived at by reducing the I.H.P. calculated from the diagrams at the revolutions the engines were then working, to the power equal to the mean revolutions from the counters on the voyage as the cube of the revolutions and the total coal consumed between ports, according to the American navy practice.

I am sorry the particulars of log for column C were not to hand to correct these particulars before table was exhibited on wall. The consumption should be 1·54 lbs. instead of 1·4 per I.H.P. per hour, as originally stated. This shows the importance of taking the mean in this way. I am afraid the more accurate method will not be adopted by the superintendents here, as the report to the directors would immediately take a decided increase in consumption per I.H.P. per hour.

A friend proposed to add the particulars from a good modern ordinary draught steamer to the table for comparison at F; this I have done. All the steamers have the same style of feed-heater except E, which is not fitted with one.

	A Closed stokehole system.	B Howden's system.	C Howden's system.	D Suction system.	E Closed ashpit system	F Natural draught system.
Engines and working pressure - - -	Triple, 160 lbs.	Triple, 160 lbs.	Triple, 180 lbs.	Q'druple, 200 lbs.	Triple, 170 lbs.	Triple, 165 lbs.
I.H.P. per square foot of grate—trial - -	—	—	24·13	21·7	22·66	14·73
Do. do. voyage - -	16·1	18·6	16·96	17·13	13·3	10
I.H.P. per square foot of heating surface—trial	—	—	·577	·682	·714	·5
Do. do. voyage	·372	·393	·405	·539	·418	·346
I.H.P. per ton of boiler and appurtenances—trial	—	—	16·8	14·7	19·6	15·9
Do. do. voyage	13·71	13·71	11·8	11·6	11·51	11
Length of fire-bars - - - - - -	6′	5′ 3″	5′ 3″	5′ 9″	6′	5′ 6″
Lbs. coal per square foot of grate—voyage -	25·9	28·2	25·3	24·2	20·7	15·4
Lbs. coal per I.H.P. at time cards were taken -	—	—	1·4	—	—	—
Lbs. coal per I.H.P. per hour, mean of voyage -	1·6	1·52	1·54	1·41	1·56	1·53
Quality and purpose used for - - -	American, very good, used for propelling machinery only.	Welsh, good, used for propelling machinery only.	Soft coal, used in main boilers for all ship's purposes.	Soft coal, used in main boilers for all ship's purposes.	Welsh, used in main boilers for all ship's purposes.	Soft coal, used in main boilers for all ship's purposes.

The discussion of this paper took place on 24th December, 1895.

Mr Carlile Wallace said he had much pleasure in thanking Mr Thom for bringing this subject before the Institution. Mr Thom had had very exceptional opportunities of observing the working of the different forms of draught, having crossed the Atlantic in vessels fitted with Mr Howden's and other draughts, and the data which he gave on the subject were correspondingly valuable. Setting aside just now the question of economy, he was glad to see that Mr Thom spoke so favourably of the coolness of the stokeholes with the Ellis & Eaves' system of suction draught. From particulars received from one of the steamers crossing the Atlantic with the draught, the temperature never exceeded, even on the hottest days, 88 degrees Fah. This, compared with closed stokeholes or any other form of draught, was very favourable. Another thing he would like to point out was that with this form of draught it was possible to draw the air entering the heating tubes from the different holds of the ship by connecting them to the tube boxes by means of air ducts, thus forming an efficient means of ventilation, the fresh air entering the holds to take the place of that taken away; of course this method could only be used provided the air in passing through the holds did not become so vitiated as to be unfit for use in the fires. Another point which Mr Thom noticed was the almost entire absence of smoke with induced draught. In this respect it was only a matter of setting the hot air inlet valves so as to admit more or less hot air above the bars, depending on the kind of coal to be burned. In this connection he might say that the automatic valves spoken of by Mr Thom had the effect of causing smoke rather than otherwise, and it was found that no injury had been caused to the boilers in Sheffield by the absence of these valves, although they had now been under steam night and day for five years. Mr Thom wished the meeting to state very distinctly if they saw any difference between induced or suction draught and forced draught. With regard to this, it might be said that a draught was only a difference of pressure between the ashpit and the base of the funnel. It was due to this difference of pressure that the air entered the furnaces, and it did not matter whether the pressure was a plus or a minus one. He thought it was necessary to go a little further and follow the course of the gases as they passed through the boiler. In the case of forced draught they had an air pressure of, say, 1 inch of water underneath the bars. As the air had to force its way through the fuel, there would naturally be a reduced pressure above the bars, and so on through the tubes, the pressure steadily getting less and less and the speed of the gases getting slower as they reached the funnel. The tendency of this was that the heat which was generated in the furnace was not carried away to the other portions of the boiler, a large percentage of the work being done in the furnaces, giving less work to be done in the tubes and other heating surfaces of the boiler. In the case of the suction draught matters were, so to speak, reversed. Assuming ½-inch of vacuum under the bars, above the bars there would be an increased vacuum, and a still greater increase in the smoke-box, tending to carry away the heat from the furnace and distribute it over the other heating surfaces of the boiler, the speed of the gases increasing as they neared the fan. In case they raised the question that this increased speed of gases would tend to prevent the gases giving off their heat to the boiler, the most satisfactory answer was that the efficiency of the boilers with the induced draught was as high as 70 to 75 per cent., and the temperature of the waste gases at the fan inlet only 350 degrees Fah. when burning 30 lbs. of coal per square foot of grate. It had been stated by advocates of forced draught that the patentees claimed some supernatural power for the induced draught as regards the action of the gases on the tube plates. This was quite a mistake. All they said was that in sucking the heated gases through the tubes the tendency seemed naturally to be that they would impinge less severely upon the tube plates and ends of the tubes, and, as far as could be judged, from looking through a sight-hole into the combustion chamber on the side of one of the boilers in Sheffield, through which they could see the tube ends, this was borne out to a large extent. He would like to have said something with regard to the power required to drive the fans, but he would just mention that from the experiments made at Sheffield they found that from 10 to 11 indicated horse power of fan engine would burn 1000 lbs. of coal per hour at 30 to 35 lbs. per square foot of grate; and from further experiments made with forced draught they found that about 7 horse power did the same work at the same rate of burning per square foot. He did not wish to go further into that matter just now, as it was so late, but he would be glad to put his views in writing if such was the wish of the meeting so that they could be discussed at a future meeting. He might also mention that a vacuum of three inches of water at the fan inlet was found quite sufficient for ordinary rates of burning, even as high as 35 lbs. per square foot of grate. He quite agreed with Mr Thom in thinking that marine engine builders up to now had not taken sufficient advantage of the extra heating absorbing surface of Serve tubes in reducing the size of the boilers, and therefore the weight. The experiments at Sheffield showed that when burning coals at 60 lbs. per square foot grate they evaporated 16·8 lbs. of water per square foot of heating surface, calculated in the ordinary way, which in a good engine would give 1·2 I.H.P. In this case the boiler was fitted with Ellis & Eaves' induced draught, and the evaporation was 9·45 lbs. of water per lb. of Scotch coal. Assuming that the air heating saved 10 per cent., the evaporation with cold air under grate or closed stokeholes draught should be 8·5 lbs. per lb. of coal; based on these figures he would have no hesitation in designing boilers with Serve tubes and closed stokeholes to give on trial quite easily 1 I.H.P. per square foot of ordinary heating surface. He would like before sitting down to point out the special suitability of Ellis & Eaves' suction draught for electric lighting stations. By increasing the speed of the fans it was possible to increase the rate of burning from 12 lbs. to 50 lbs. per square foot without any serious loss of efficiency. Electrical engineers would fully appreciate the advantage which this gives in getting over the daily peak or meeting any sudden demand for extra light.

Mr HECTOR MACCOLL said he would like to say that they had fitted several steamers with the Howden system of forced draught with very great success. In the last instance the economy was such that he doubted whether the facts were correctly given. According to the log supplied by the owners, the vessel was running on a consumption of about 1·15 lbs. of coal per I.H.P. per hour, which, personally, he thought impossible. In any case, debiting the entire coal paid for to the engines, the consumption came out 1·4 lbs. per I.H.P. per hour, which every one would acknowledge to be a very good result. His own feeling was that the I.H.P. logged was in excess of the actual power exerted over the whole voyage, and, possibly, too great deductions were made for other purposes than propelling the ship. In connection with that he was pleased to see, in the results given by Mr Thom, that there could be no doubt apparently as to the disposition of the coal in the cases of A and B, because apparently the coal charged was that paid for, and that was really what the owner had to deal with; and as the coal appeared to have been consumed entirely by the propelling machinery, if the figures were correct there could be no difficulty about the facts or about the coal per I.H.P. per hour.

Mr MATTHEW PAUL, jun., writes—I much regret that I cannot be present at the discussion of Mr Thom's paper on "Mechanical Draught," on Tuesday evening, as the subject is one in which I am greatly interested. The paper is a very valuable contribution to the literature of the subject, for not every one has the means of securing reliable comparative results such as he gives, and the discussion of it ought to be of great interest. With reference to the remark on page 69 as to the capacity of fans for suction draught, it should be noted that, even if double the capacity of forced draught fans be required, the dimensions and weight of the fans do not increase in anything like the direct ratio of the capacities, but in a very much smaller proportion. With regard to the comparative power required, Mr Thom still makes far too liberal an allowance with 25 per cent. extra power for suction fans. The work done in discharging the hot gases from the chimney is exactly the same, whichever end of the boiler the fans are placed at, and is measured by the *weight*—not the volume—of gases passing through the fan per minute. With equal air supply, and at equal rates of combustion, it is clear, therefore, that the work done is exactly the same in exhausting as in forcing. The slightly greater weight of the larger fan cannot possibly increase the friction by 25 per cent. This is borne out by some suction fan experiments made recently, in which, to begin with, the same size of engine was fitted as for a forced draught fan of equal diameter, with the result that when working in the hot gases the revolutions were maintained with a mere fraction of the steam required for equal revolutions when working in air of atmospheric temperature. There must surely be some mistake in the statement of the empirical rule given on page 74 for determining the capacity of fans. In the first place, no rule which does not take account of the pressure of the air delivered can pretend to accuracy; but even assuming Mr Thom's formula to refer to air at 1 inch of water, the result is so remarkably low that it appears some multiplier must have been omitted. If not, then Mr Thom's data must have been taken from fans with an exceptionally low efficiency. With regard to the general question, there is no mention in Mr Thom's paper of Martin's system of induced draught, referred to by Mr Durston in his presidential address to the Marine Engineers, which has been fitted to H.M.S. "Magnificent" and "Torch" with apparently successful results, although the fans deal with the "unmitigated" gases at the imminent risk of the catastrophe referred to on p. 74. Patterson's system of suction draught, illustrated and described in *Engineering* recently, successfully obviates this contingency, with the minimum of complication, weight, space, and cost, and the results given in Professor Barr's report may be of interest in comparison with those given by Mr Thom. Assuming a consumpt of 15 lbs. steam per I.H.P. hour with triple engines, the results work out as follows :—

I.H.P. per square foot H.S.,	1st trial,	·56,	2nd trial,	·655
I.H.P. " " grate,	"	·20,	"	23.5
I.H.P. per ton of boiler and fittings,	"	·20,	"	23·5
Lbs. coal per square foot grate,	"	37·0,	"	48·5
Lbs. coal per I.H.P per hour,	"	1·85,	"	2·0

At the best. Mr Thom's comparative figures can only be approximate, as no attempt has been made to differentiate the engine and boiler efficiencies. The consumption of steam in all the examples is hardly likely to be the same, and the comparative boiler and draught efficiencies may for this reason be widely different from that shown by coal per I.H.P.

Further remarks on Mr Thom's paper by Mr W. Carlile Wallace, received 16th January, 1896.

From what has been already said on the subject, we may assume that a vacuum of 3 inches of water at the fan inlet in the case of suction draught, and a pressure of 3 inches of water at the fan outlet in the case of forced draught, will do about the same work in both cases.

About 22 lbs. of air will be required for each lb. of coal burned in both systems.

As the air is drawn from the engine-room in Mr Howden's draught, we may put the temperature at, say, 70 degrees F., and in the suction draught the temperature, taken over a number of experiments, may be put down at 370 degrees F. when burning coal at 30 lbs. on the square foot of grate.

The volume to be dealt with in the pressure fan we can take as $V=1$, and if V^1 represents the volume to be dealt with in the vacuum fan we get

$$V^1 = V\frac{t^1 + 461}{t + 461} = \frac{370 + 461}{70 + 461} = 1{\cdot}56,$$

to this must be added a small amount for the products of combustion of the fuel, but as this is only $\frac{1}{22}$ of the air supply, and as the resulting CO_2 will occupy no more volume than the combining oxygen, this is very small indeed, so we may take V to V^1 as 1 to 1·66 as more than sufficient.

The work to be done in the one case is compression, and in the other extending a given volume to the same amount, namely + or – 3 inches of water, therefore the work to be done will be $W = \int v\,dp$, but as p in this case is relatively very small as compared with the atmospheric pressure, the work to be done will, for all practical purposes, vary as the volume; or, in other words, the fan power required to burn the same rate per square foot of grate will be 1 for forced draught and 1·66 for suction draught on Ellis & Eaves' system. This will be found to agree very closely with experiments carried out at Sheffield, when it was found that the I.H.P. required for the two systems of draught was as 7 to 11.

The adjourned discussion of this paper took place on the 28th January, 1896.

Mr W. L. C. PATERSON said he thought this paper of Mr Thom's, on "The Comparative Systems of Mechanical Draught," was one that should be well discussed, for the reason that seagoing engineers and superintending engineers did not agree upon the subject. In fact, there was a wide difference of opinion as to whether there was any economy to be had out of mechanical draught. Some experts say that anything from 10 to 15 per cent. of saving could be had, and others equally experienced say there is no economy at all. He thought a meeting like this ought to do something towards settling that to some extent, and bringing opinions more into line. As he had had a comparatively free hand in trying some experiments on this matter, he would briefly tell them how he had come to the opinion which he now held. He would be guided as Mr Thom was, and speak of nothing except what came under his own personal observation. About nine years ago a steamer with compound engines required new boilers, and these boilers were made without any reference to forced draught. They were two ordinary double-ended boilers, and had one stokehole placed forward and another aft (the pressure was kept the same as in the old ones, 70 lbs.). It was thought that was a good opportunity of trying mechanical draught and short grates, the bars were made 2½ feet long and two fans were placed in the stokehole. One supplied the four after fires, and the other supplied the four forward ones. The fans drew their air from the stokehole atmosphere, and it was conveyed by pipes into each furnace, and along underneath the bars to the back ends, where there was a series of pipes at the back of the bridges for heating the air. It was then allowed to discharge itself into the ashpit at the back end. The usual air-tight doors were fitted at each furnace. They had no trouble with this arrangement at all, and they ran it for something like 3½ or 4 years. After carefully noting results, they found the coal consumption with compound engines something like 2·1 or 2·15 lbs. per hour per I.H.P. At the end of that time the pipes began to crack, and instead of renewing them they were all taken out and the bridges built in the usual way. They then had the close ashpit system with cold air. Strange to say, they found no difference in the coal consumption between the heated air and the cold air. After a while the fans began to give a little trouble and they stopped them and lengthened the fire bars to suit natural draught. Now the vessel is running with the ordinary natural draught, and they know no great difference in the coal account. They were not taking the same careful notes of the working, but it is now about 2·2 lbs. per I.H.P. Then about five years ago two steamers were built from the same specification, the same size in every respect, duplicate engines and boilers, and duplicate fan power, and it was thought that that was a good opportunity to see if they could find any difference between the Admiralty system in the one ship, and Mr Howden's system in the other. They had no unusual trouble with the boilers having the closed stokehole system, and he thought their present condition was superior to those fitted on Mr Howden's system. They had no trouble with the furnaces or tube ends with the closed stokehole system. They had the dark stokehole, but having the light from the furnaces and also from the electric lights in the corners, and the little bulls' eyes above in the air-tight deck, they soon got accustomed to it, and did not feel the stokehole dark at all. It is a dirty stokehole, but the firemen have not complained of this stokehole any more than of the other system. At any rate, they had now the same engineers and some of the same firemen as in the first voyage. They had no special complaints regarding the temperature as spoken of by Mr Thom. He spoke about 116 deg.; their temperature never rose much above 100 degrees, varying from

85 to about 100 degrees. One point was that it did not vary as much with the temperature of the atmosphere as they would expect, but kept very uniform, about 90 degrees, even in the Red Sea the men did not complain much about the heat. The other vessel fitted with Mr Howden's system was still doing very well, and he preferred the open to the closed stokehole. For this reason they had adopted it in several other ships. They had the troubles with Mr Howden's system which every person had. There was the difficulty of getting at the fires to fire them properly on account of the contracted door and the difficulty of getting the fires cleaned, and the trouble of attending to the air valves, but after they had got used to these things everything is working fairly satisfactorily. As to the comparisons of economy, the ships are in the same trade and working with the same coal, but a uniform quality of coal is a difficult thing to obtain. With economical boilers using bad coal poor results will ensue, but with boilers less economical using good coal the result might be better. Looking at the logs of these two vessels in a casual way, one would think there was no difference in economy. Scanning them over carefully he found the consumption ran about 1·5 lbs. per I.H.P. with Mr Howden's system, and 1·55 with the closed stokehole system as near as he could average it. From the foregoing experiences and similar others he had formed this opinion, that for an all round cargo steamer the ordinary large natural draught boilers and tall funnel were preferable. The last ship they supplied with new machinery was fitted with large natural draught boilers and had a tall chimney about 70 feet high from the fire bars, and 3½-inch tubes, having retarders in each tube, and that ship was doing very well. He did not think it would be fair to compare results yet, as she had only made one voyage to the East, but he thought they would be as economical as the others with the forced draught. He did not know that he could say anything further on this subject except that he considered a funnel could be made to give as strong a natural draught as it was prudent to make the ordinary marine boilers work at, and if Mr Thom called for a show of hands his hand would certainly go up for large natural

draught boilers and tall chimney. He hoped that the other gentlemen present who had marine engines and boilers under their charge would give the results of their experience.

Mr WILLIAM MORISON said that Mr Thom's paper was an interesting contribution, consisting as it did of a record of work done on the voyage. His only regret was that Mr Thom had not had more time at his disposal, which might have enabled him to give some particulars of the engine performance, and so made it possible to eliminate that factor from the general results. The examples A and B might be held to decide the question as between closed stokeholes and closed ashpits; because even if there were no relative economy, the greater convenience, cleanliness, and comfort of the latter system was quite sufficient. Referring to examples C and D, they had in those two of the later types of Howden's and Ellis & Eaves' systems. The relative economy as measured by the coal per I.H.P. was 8·5 per cent. in favour of D, which was a very considerable saving, but when they came to consider the machinery in the two vessels they found there were other factors than the system of mechanical draught employed which contributed to the economical result. Thus in C they had triple expansion engines with 180 lbs. working pressure, boilers with plain iron tubes having a ratio of heating surface to fire grate, 41·5 to 1, and a ratio of air heating to fire grate of 13·83 to 1. Adding these two ratios they got a ratio of internal and external heating surface to fire grate of 55·33. The temperature in the funnel was 495° Fahr. In D they had quadruple expansion engines with 200 lbs. working pressure, boilers with Serve tubes, and having a ratio of heating surface to fire grate of 31·78. As the air heating surface was equal to the boiler heating surface, they had a ratio of total heating surface within and without the boilers of 63·58 to 1 of the fire grate. This was 15 per cent. in excess of C. The funnel temperature in D was 396° Fahr. The factors which contributed to the economical result in D were—1st, the quadruple engine; 2nd, the Serve tubes; 3rd, the 15 per cent. excess in total heating surface per square foot of grate. As they had no information about the performance of the engines they could not with any degree of fairness estimate the relative economy of the engines, but the difference in funnel temperature afforded a means of approximately estimating the proportion of the economy due to the Serve tubes and the excess of heating surface. The method adopted was that given by Mr Macfarlane Gray in the discussion on a paper read by Mr Blychenden before the Institution of Mechanical Engineers at Liverpool on the 28th of July, 1891. In that discussion Mr Gray was speaking on the economy of forced draught as against natural draught, and pointing out that in economy of coal the only advantage that could be gained would be from some source of waste, which, considering the difference in funnel temperature, was clearly the case in this instance. Mr Gray went on to say—"Near enough" for all commercial considerations, it might be taken that the calorific effect of coal, as ascertained by laboratory evaporative tests, was equivalent to 2,500° Fahr. elevation of temperature in the products of combustion on an ordinary fire grate, whatever the quality of the coal might be. Every 25° Fahr. difference in temperature represented therefore one per cent. of the calorific value of the fuel, or the percentage lost of the calorific value of the coal by the elevation of temperature in the funnel gases was always equal to 4 per cent. of that elevation of temperature in degrees Fahr.

Funnel temperature, -	C, 495	D, 396
Air entering fan, - -	80	100
Elevation of temperature,	415	296
	4	4
100 —	16·60 = 83·4	11·84

11·84

83·4) 4·76 (5·7 per cent.

4·170

5900

5838

620

The relative economy of the boilers and appurtenances to D was 5·7 per cent. over C, as deducted from the funnel gases, leaving (8·5 — 5·70 =) 2·8 per cent. for the quadruple expansion engine. He had not attempted to determine what proportion of the 5·70 per cent. should be allocated to the Serve tubes, or the extra heating surface, but he thought there was nothing to indicate that with the fires under forced draught instead of suction draft the result for D would have been different. Of course the economy attained on D was not all profit, as the extra weight, first cost of fans and tubes, and upkeep of the additional fans, must make a pretty heavy reduction on it. As regarded example E, it would have been very interesting if they had had the temperature of the funnel gases, as they could then have made an approximate estimate of the effect of the air heating tubes, but looking to the result it did not appear that the want of them had had a very prejudicial effect. With regard to F he could not understand why the I.H.P. per ton of boilers and appurtenances worked out so nearly to that with forced draught, and would like to ask Mr Thom if the appurtenances included everything pertaining to the boiler rooms, *i.e.*, gratings, ladders, ventilators, floor plates, etc. This was necessary for comparison, because if by adopting mechanical draught they could replace, say, two double-ended boilers with two single-ended, the stokehole fittings was a saving in favour of the mechanical arrangement.

Mr HALL-BROWN said there was little use taking the coal per I.H.P. per hour in order to compare the efficiency of the various systems of mechanical draught. As an example of that he had tested engines and taken part in other tests of engines made by the same builders, one engine being a triple expansion engine, and using 19 lbs. per hour, and the other also a triple, made by the same maker, and very nearly the same size, and the consumpt of steam was only about 13·7. This gave a difference of about 50 per cent., and had the more economical engine been fitted with forced draught, and the coal consumption in the two cases been compared, it would have been a splendid advertisement for that forced draught. He had heard that night a comparative method of estimating the efficiency of a boiler by means of the funnel temperature, which was very clever, and very like Mr Macfarlane Gray, and he was very pleased that it had been brought before their notice. He knew the difficulty of getting the steam consumpt of an engine, as the means of measuring the feed water were so rarely fitted; but he thought that engineers would soon realise the importance of this. At present they were forced to content themselves with such incomplete data as Mr Thom had given. Mr Paterson had expressed opinions with which he could entirely coincide. He had had a very considerable experience of one or two systems of forced draught, and also of natural draught, and he must say that it was difficult to decide between one system and the other. Taking Howden's system, the heated air was not very much heated—Mr Howden would be able to tell them how much—but it was a very small matter compared with the temperature of the furnace itself. They might put the furnace temperature down at 2500 degrees or something over it. The same remark about the heated air applied in a lesser degree to the system of Ellis & Eaves. Mr Carlile Wallace had pointed out that they sometimes got a temperature of 370 degrees. He had been in plenty of stokeholes at 140 degrees, and from that to under 100 degrees, and the increase from 140 to 370 was not such a very big one; it would not induce him to put as much heating surface for the air as there was in the boiler itself to get it. They therefore came to the question of whether the air should be heated at all. Why did any one attempt to heat air? He thought that the original notion was that the cool air of the stokehole was fatal to the tube ends in the combustion chambers. He could not imagine that a difference of 100 degrees was going to save the tube ends, and he did not think that anyone would imagine that the slight heating of the air made any difference in that respect. Then Mr Thom gave another reason for heating the air in Ellis & Eaves' system, viz., that it was the salvation of the fans, but he did not know that that was the only way of saving the fans, and he thought that it was rather an expensive way. If it was the only way he might put up with the loss of the fans. If the intention of heating the air was to get increased economy they were setting about it in a wrong way, and any one who wished to save the heat which was escaping up the funnel could put a feed-water in the smoke-box. There was no reason why they should not do that in a similar way to what was done on land. He was convinced that it could be done with a great deal less heating surface than was required by Ellis & Eaves' system. He would like to put a feed-water heater into the smoke-box which would give as economical results at perhaps something less than a fifth or a sixth of the cost. There was no doubt whatever that with a feed-water heater they could reduce the temperature of the funnel gases with very much less surface than was required for heating air. They all knew what a difficult thing it was to heat air, and they had just been told what an enormous surface was required to get 370 degrees. Certainly a very much less surface would have sufficed to heat the feed-water of the boiler to the same temperature, and they would have had as hot feed-water as the water in the boiler. He thought that would be a more sensible way than attacking the thing from the economical side, and it would be equally good for the fans. He was astonished to find that in any system of air heating the amount of surface was anything like equal to the surface of the boiler. He dared say it amounted to something only slightly less expensive than another boiler in order to save 5 per cent. on the cost of coal. If they could save the 5 per cent. at a very much less expense he thought that was the way to set about it. Mr Thom asked them to express an opinion as to whether there was any difference between induced and forced draught, and he thought Mr Carlile Wallace had done that in a very admirable way. He did not know that he could agree with the results usually attributed to the difference between the systems, but there was no doubt that the difference was actually as he described. In the one case they had the greatest "draught" at the funnel base, diminishing to the ashpits, where it was least, and in the other case it was the greatest pressure in the ashpits diminishing towards the funnel, where it was least. The difference was very great. It was all the difference between compressing a spring and stretching it. It appeared to him that if there was any danger of the tube ends being damaged it was less with induced draught than with forced draught. He thought they could all see that for themselves, as it appealed to every one's intuitive knowledge. There was no doubt that there was a difference between the effects of forced and induced draughts, but whether one was easier on the boiler than the other must be decided by practical experience.

Mr JOHN INGLIS said Mr Thom made rather an odd suggestion. There being some doubt as to the behaviour of air with suction draught as against forced draught, he proposed to settle the question by a popular vote. Why not go a step farther and apply the principle of local option, so that the air might conduct itself differently according to the opinions prevailing in various districts? That paper led up to a table at the end giving a summary of certain results with the affectation of accuracy indicated by two places of decimals. He should like to know what these proved. If they were intended to prove anything about the relative economy of any particular system of draught, the attempt was a complete failure, like so many others of the same kind, not because so little was contained in them, but because so many things were inextricably mixed up in the results, which obscured the main question. To begin with, nothing was stated (1) about the quality of coal, its calorific value; (2) the measurements were the usual shipboard measurements—if any one thought these sufficiently precise for a philosophical inquiry his faith must be child-like indeed; (3) the quality of the stokers had some bearing on the subject; (4) the temperature of the feed-water; (5) the impurities in the feed-water; (6) the pressure in the boilers—which seemed to range from 200 lbs. to 160 lbs.; (7) the construction and arrangement of the boilers apart from the fans, fire doors, and other accessories of the mechanical draught systems; (8) the covering of the boilers and steam pipes, its quantity and quality, as a means of impeding the radiation of heat; (9) the construction of the engine; (10) its condition as regards maintenance—that was to say, whether in good or bad working order; (11) the efficiency of the lubricants used.

All these disturbing elements had to be taken out before they had any possibility of knowing anything whatever as to the advantage, if there were such, in a particular system of forced draught. But the fact was that no one had any interest in instituting a proper series of tests. Certainly no one was likely to conduct tests to establish the superiority of natural draught, and the patent-mongers seemed to be doing uncommonly well without anything of the kind. The popular vote, as recommended by Mr Thom, was what they relied on, and they were told that an invention was good because it was adopted by this or that experienced marine superindent or by the other eminent shipowner. Any nostrum or "ism" might be held as satisfactorily attested if the number of believers was to be the criterion of its excellence. He read in *Engineering* the other day that Mr Howden had applied his patent last year to machinery aggregating 278,000 horse-power. He did not know what the royalty might be, but at even half-a-crown this represented over £30,000—no inconsiderable sum. He congratulated Mr Howden, and while his (Mr Howden's) enthusiasm for science might impel him to set on foot careful experiments to demonstrate the value of his invention, his commercial sagacity would rather deter him from so doing lest he should unawares abolish so satisfactory a source of income.

Mr Howden agreed with Mr Inglis in his concluding remarks. He would not have spoken at all on this subject but for some statements in Mr Thom's paper which he could not well pass without remark. Taking the two steamers under A and B in the list, he understood these referred to the "New York" and "Paris." He had crossed the Atlantic in both of these steamers. He happened to be in the "New York" when she made her fastest western run, which was in October, 1890. The time was 5 days 21 hours 18 minutes, distance run, 2775 knots, being an average speed of 19·63 knots per hour. He considered the "New York" the finest example of the closed stokehole system that existed, and so far as he knew she was the only ocean steamship now running with the closed stokehole. He was aware that Mr Alfred Holt had some steamers running to the East some years ago with a mild air pressure in closed stokeholes, but he believed this mode of working in these steamers had been abandoned for some years. At all events he knew that Mr Holt began to use his (Mr Howden's) system about two years ago, and that now he had nine steamers with his system, some of them not yet completed. He was therefore not aware of any other ocean steamer running with closed stokeholes than the "New York." When crossing in this steamer he was very desirous to discover how it was the closed stokehole system worked in her without damage to the tubes, which happened in other steamers from this system. From his observation he came to the conclusion that the immunity from damage in this steamer arose from the following causes:—The air pressure was not high, averaging about $\frac{5}{8}$-inch water gauge; the furnaces were very large, while the furnace door was small; the coals were kept piled up in front of the furnace, so that the air had no room to get into the furnace in a large volume, it would therefore eddy about and get well heated before reaching the tube plates at a moderate velocity. The furnaces were also fitted with Henderson's moveable fire bars, which worked the coal along the furnaces, and did not require the stokers to rake the fires often. The "Paris" it was well known was fitted with his system early in 1891. If he had known the difficulties beforehand which had to be encountered in refitting the boilers of this ship he would not have undertaken the task. He had not time to explain what these were, but he had given an account of them in his paper on "Forced Combustion," read at the Engineering Congress held at Chicago in 1893. He would merely state here that one of the difficulties which had a detrimental effect was, that the pipe arrangements of the ship prevented him from carrying the air straight from the fans to the air heaters in continuous pipes, and he had to discharge the air from each fan into an aperture in the roof of a small room, and lead a pipe from the bottom with a sharp bend to the air heater. This had the effect of destroying the momentum of the current of air in its passage to the heaters. The consequence was that it took a much greater air pressure at the fan discharge to send an equal quantity of air to the furnaces in this steamer than in other steamers. It was found also that the same pressure of air in the ashpits burnt a smaller quantity of coal than in other steamers fitted with his system. He had to take a voyage to America and back in the steamer and make some experiments in Liverpool harbour before he discovered the cause of these peculiarities. The air pressure in the ashpits was increased by radiation from the bars and not by the quantity admitted, so that with the pressure as high as in other steamers the quantity passing through the bars was less owing to its high temperature and a certain condition of the furnaces. He would be pleased to leave some copies of his Chicago paper in the library, in which a fuller description of this case would be found. Early in 1892, when the passages from the air heaters to the furnaces were enlarged, allowing the heated air to descend more freely, the consequence was that in 1892 the "Paris" beat every steamer on the Atlantic, and reduced the time on the western passage to 5 days 14 hours 24 minutes, an average speed on the whole passage of 20¾ knots per hour. With this time the "Paris" held the record on the Atlantic for a good long time after the "Campania" and "Lucania" began running. He should mention that he had reduced the length of the grate bars in the boilers by exactly 20 per cent. from that used when they were worked on the closed stokehole system, and it was with this reduced grate that the greatly increased power and speed were obtained, notwithstanding the disadvantages under which this steamer ran and still runs. In 1893 she went on the Southampton route, and since then he had not seen the steamer. Whatever reason there might be for any falling off in this steamer from the high speed of 1892, he could say it was not due to any fault in his system. The other steamer, C, in the list mentioned as under his system he would not refer to further than to say that the data and figures given were quite inconsistent. For example, it was mentioned in the description of this steamer that the temperature of the escaping gases was 495 degrees, while the temperature of the air entering the fires was only 129 degrees. These relative temperatures were quite impossible with his system.

He happened to put his hand that day on the results of the trial of the "Ruahine," sent him by Messrs Denny & Co., which had much smaller air heating proportions than this steamer C, in which the temperature of the air in the reservoir was 224 degrees. These figures given by Mr Thom were quite incorrect. The vessel D in the list was a steamer of the American Line, with suction draught, and it was stated in the paper that this was a combination of Howden's and Martin's systems. He had already stated in the engineering press that the suction draught system could be called with equal justice by the name of any one in this room as by the name of Martin. This system of exhausting the funnel by a fan to accelerate the draught was the invention of the brothers R. L. and A. E. Steven, of New Jersey, who worked this system for a while in steamers in America about 1836-1840. They also originated the closed stokehole system, an account of which would be found in his Chicago paper already mentioned. He would not enter further into the figures given in this paper; he would merely say that if they were correct he did not see why any shipowner should use his system. It had been said there that night that there was no economy in forced draught. He could only say that there were numbers of steamers working on his system at 17 I.H.P. per square foot of grate, with fire-bars 5 feet in length, on a consumption, carefully ascertained, under 1·2 lbs. per I.H.P. per hour. A very strange proposal was made in this paper, that that meeting should become a court to decide on questions relating to forced draught by voting yes or no on these matters. He thought it was no disparagement to that meeting to say that there could not be many in it sufficiently conversant with that subject to deal properly with it. There was, however, one court of reference to which they must all bow, and that court was formed by the mercantile shipowners of this and other countries. As he had said elsewhere in reference to the use of water tube boilers, that, whenever they found mercantile shipowners, who had to pay for their mistakes in adopting unsuitable things, using to any extent water tube boilers in their ships, and repeating orders time after time, he should then say there was something good in the water tube boiler; so it was with forced draught. It was over three years ago since he was confronted with a powerful opposition; for a time his business was at a standstill, but after the first steamer with this competing system was tried his business returned again with a rush, and he found on looking up his books he had contracted for the application of his system to 230 steamers since March, 1893, and the number was increasing year by year, and all competition had now been left far behind. So far as this paper was concerned, and from many of the remarks made that evening, he did not well see how he should have done any business at all in forced draught. He was, however, quite satisfied with what he had done, and he could assure them that the steamship owners from whom these orders had come were not so foolish as to pay him for a thing from which they did not derive quite an equal benefit.

Professor BARR did not think it necessary to take up much of the time of the Institution, after the very able manner in which Mr Inglis had dealt with this subject. He was glad that attention had been called to the figures in the table. Mr Coleman Sellars, the great American engineer, in speaking of methods of scientific investigation, said that one thing that engineers had to learn was—"that they must never try two experiments at the same time if they want to arrive at the bottom of any matter."* Mr Inglis had pointed out that Mr Thom's data involved a large number of unknown elements, from which it was impossible to draw any conclusion whatever as regarded the relative economy of forced and natural draught, or as regards any "Comparison of Mechanical Draughts." Mr Inglis and others had also called attention to what Mr Thom, with his well-known ingenuity, had proposed—a new system for arriving at the truth on a question as to the nature of things. It was not by any show of hands that they could settle a question of scientific fact. There was a number of points in the paper which were put down as peculiar to one systen, and which he (Prof. Barr) thought were equally applicable to other systems. He might men-

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* "American Institute of Mining Engineers"—about 1876.

tion, for example, a passage on page 69:—"With suction draught it is quite possible where the fans draw from a common conduit to have much more fan power than necessary. In that case it may be found in some instances that one fan will not be doing any useful work, merely keeping the air from going back through it, but not discharging any gases, the other fan being capable of doing all the work required." As he understood that passage it was equally applicable to any such system as the closed stokehole system. Mr Inglis, in a few words, had pointed out, or at least indicated, that, in regard to the flow of gases, they were to expect no difference whatever between forced draught and suction draught. Of course there was a very slight super-atmospheric pressure all through in the one case; while in the other the pressure was all through slightly under atmospheric pressure. That was a very small matter indeed, and the flow of gases in the closed stokehole system must be almost absolutely identical—for practical purposes absolutely identical—with that upon the suction draught system, other things being the same. There was one question with regard to mechanical as against natural draught which, perhaps, did not come quite within the scope of a comparison of the different mechanical systems, but which came within the range of the discussion that had followed upon this interesting paper. He thought there was probably—he was not stating a fact—comparatively little difference in the economy of forced draught and natural draught with regard to the combustion of fuel, but there was one aspect which he thought engineers had in many cases left altogether out of account, and in perhaps an equal number of cases misunderstood. He had heard it argued by engineers—in regard to ordinary Lancashire boilers, for example—that a large flue area should be provided so that the gases would have "plenty of time to give up their heat to the boiler." He thought that was a very pernicious doctrine. If they had a certain amount of products of combustion to pass through the flues per hour the right thing to do was to get them through with the greatest velocity possible. Of course if they made the flues too small they would check the draught. That was not the question he was dealing with. Supposing they had a certain quantity of products of combustion to deal with per hour, the economy would rise, *cæteris paribus*, the more rapidly they moved the gases through the flues. He need not go into the reasons; this principle was a well-known one in connection with a number of applications. Mechanical draught gave them the power of passing the products of combustion from a certain amount of coal per hour through the flues more rapidly than they could do by natural draught. He had no doubt that if it was the case that forced draught was found to give economy, which he believed was not proved, unless they accepted as proof the very reasonable argument of Mr Howden, that people would not continue to use the more expensive system, unless there was some indications at least of superior economy; but if it were proved that mechanical draught had an advantage over natural draught in respect to economy, the consideration to which he had referred indicated the direction in which they might look for an explanation of the advantage. He felt certain that what was to be done in applying systems of mechanical draught in the future, was to contract the area of the passages, retaining a sufficient amount of heating surface, and to use the forcing or inducing apparatus to get the gases to pass through the boiler with a high velocity. He would not refer to anything else in the paper, except Mr Thom's formula for the size of the fan. If there was anything in that formula at all, it was certainly a very simple one; but he would point out that it would be simpler still to multiply the width of the periphery by the square of the diameter. Mr Thom multiplied the diameter by the circumference and divided it by 3. It would be well within the limits of applicability of the formula if he took three times the diameter for the circumference, and simplified his formula accordingly.

Mr Carlile Wallace said, with reference to Mr Hall-Brown's remarks, that there was no advantage, so far as he could see, in heating the air. Mr Hall-Brown seemed to neglect what was the case, that by heating the air they could do with smaller boilers. He thought that had been proved in Mr Howden's system, in experiments with boilers in Sheffield they evaporated 15 lbs. of water per square foot of heating surface, calculated in the ordinary way, showing that with a high rate of combustion much smaller boilers would do where Serve tubes were fitted, and then it was very much lighter to add surface in the shape of air-heating surface than it was in a boiler where they had to carry the working pressure and also the additional weight of water. What Professor Barr had said with regard to passing the heated gases as quickly as possible over the surfaces should be strongly in favour of induced draught, because, as he pointed out in speaking last evening, the tendency with induced draught was to increase the rate of the passage of the gases near the funnel, and it appeared to him that they could get a very much more rapid passage of the gases over the surface with induced draught and with the same negative pressure in the fans than they could do with the forced draught.

Professor WATKINSON said there was one thing in connection with forced draught which had been overlooked, and that was when they had heated the air prior to admission to the furnace they got more rapid combustion, and therefore a shorter and more intense flame, and they could manage with smaller tubes in the boiler. He was certainly in favour of reducing the size of the boilers and reducing the number of tubes which were subject to the full pressure of the boiler, and the failure of any one of which would put the boiler out of action until repairs were effected. He was in favour of substituting, instead of that heating surface, the air heating surface which had been adopted by Mr Howden and Messrs John Brown & Company. In that case the burning out or the failure from any cause whatever of any of the parts of the air heater would merely reduce the efficiency of the combined arrangement till it was put right. He thought that a great mistake which had been made in connection with these heaters for the air was in retaining the same tubular form that they had, either for the water tubes or for the fire tube arrangement. In the case of the fire tubes they must use cylindrical tubes of the boiler, so as to be able to clean them, but air passing through did not leave any deposit, and there was no reason why the tube should not be flattened out as in the serpollet boiler, but not to such a great extent, and the tubes also bent into a sinuous form, so that a comparatively small heating surface would give all that was necessary and far more than was obtained at present with the enormous surface such as Messrs John Brown & Company seemed to think necessary. There should be another advantage in connection with forced draught and heating the air as adopted, and that was that when they were not heating the air the lowest temperature to which they could possibly reduce their gases, unless they put a feed heater into the uptake, was the temperature of the steam, but by this other method the ultimate limit to which they could reduce the temperature was to that of the atmosphere, and so there should be a considerable gain in that way. So far no inventor of forced draught, so far as he knew, had applied that or carried the matter sufficiently far. Some years ago Mr Hoadley carried out a large number of experiments on this subject in America, using induced draught, and he found that it was possible to increase the efficiency from 10 to 30 per cent. according to the amount and heating of the air supplied to the furnaces. A most elaborate report on these careful experiments had been published by Mr Hoadley, and it would be well to have a copy of it in the library of the Institution.*

Mr NISBET SINCLAIR writes—For some years I have been familiar with three of the systems of forcing coal combustion in boiler furnaces which are referred to in Mr Thom's paper, namely, the closed stokehole, Howden's, and that of Ellis & Eaves. I have superintended the design and construction of large and small examples of the first two, and have also watched their behaviour

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* "Warm Blast Steam Boiler Furnace." Report on a series of trials of an apparatus for transferring a part of the heat of escaping flue gases to the furnace by warming the entering air. By J. C. Hoadley. Second edition. Wiley & Sons, New York.

on trial runs; and, further, on several transatlantic voyages I have observed carefully how Howden's arrangement behaved at sea. Data of trial performances of all the systems has been before me for years, and the log performances, under regular sailing conditions, of the ships A and B on the tables, and others, are quite familiar to me. Naturally, therefore, this subject presents some attraction for me; and while I have no interests one way or another, and no reason for having any bias, I wish, in the interests of fair discussion, to make some remarks on Mr Thom's paper. I had hoped to find in the paper useful data and a careful analysis of results, and I do find that the ratios quoted in Mr Thom's table seem, *for the examples selected* and *by the method adopted of deducing them from the primary facts*, to be fairly right, and, *with the same qualification*, the analyses are also, on the whole, fair. But when one undertakes to compare *systems*, even in a rough and ready way, ordinary fairness demands that the examples compared shall be the *best* or at least *good* examples. Now, I have observed in the professional papers that Mr Howden has over and over again explained, what I know to be true, that that particular case B, in Mr Thom's paper, is *not* a good example, that it is an adaptation of his system to a ship originally fitted with a closed stokehole, and Mr Howden has said that on that account everything was not arranged just as well as might have been done in a new ship. Whether for that reason or not, it is known that difficulties are experienced in this ship in ventilating the stokehole and in some other ways; these difficulties point, however, *not to troubles inherent in the system*, but to imperfect adaptation. But there are many other examples of ships with Howden's system in which, calculating at least in the same way as Mr Thom does, very much better results are obtained than those quoted; and if these are taken to show the practical possibilities of the system, we are presented with a condition of things in which Howden's system stands, I think, in the front rank of the whole of the schemes considered. In support of this view, let me quote some ratios with which I am familiar, from Atlantic ships fitted with Howden's draught, most of which figures have, I think, been already published in the "Journal of the Society of Naval Engineers," of the United States.

With Triple Engines—American Coal.

Per I.H.P. per hour, - - - lbs.,	1·35	1·56
When burning per square foot of grate, lbs.,	30·4	33.8
Length of fire-bars being - -	5 ft. ·6 ins.	5 ft. ·3 ins.

English Coal.

Per I.H.P. per hour, - - - lbs.,	1·4	1·5	1·54
When burning per square foot of grate, lbs.,	23·3	30	29
Length of fire-bars being - - -	5 ft. ·3 ins.	5 ft. ·6 ins.	5·6

If the steam generated in these boilers had been raised to 200 lbs. and used in quadruple engines, so as to be comparable with the suction draught example D, even better results than these per I.H.P. would have been shown. To be quite fair, these figures are from smaller ships than A B or D, and, having fewer furnaces and fewer stokers, a better average result can be got per man than with larger vessels. Still, the difference of results quoted is so great that there can be no question as to which system shows the best results. Since Mr Thom has, on pages 66 and 73, said that in Howden's system high rates of combustion per square foot of grate are due to the shortness of the bars, it is necessary to point out that that is not entirely the case as between Howden and Ellis & Eaves, for if the B or 5 feet 3 inches rate is reduced to a 5 feet 9 inches or D rate for the sake of closer comparison, the former becomes 25·7 for Howden against 24·2 for suction draught; and the rates given above, if also corrected for a 5 feet 9 inches bar for better comparison with the suction draught D, the results for Howden are obviously very considerably higher. But I find on examining the matter more closely that the bar in A, quoted at 6 feet long, is only 5 feet 7 inches long, and the bar in B, quoted at 5 feet 3 inches, is 5 feet 5 inches for the voyages tabulated, and that the ratios given in Mr Thom's table are actually calculated on these corrected lengths. These changes make Mr Thom's assertions that the reason for high rates of combustion in Howden's system is shortness of grate bar, entirely wrong. I wish to emphasise this point, that it seems to be a fact that with

Howden's system it is really practicable in regular running at sea to burn a greater weight of coal per square foot of grate, whether on long or short bars, than with any of the other systems presented. Now all these rates per I.H.P. quoted above are found by the rule for mean I.H.P. over the voyage given by Mr Thom. I shall show later on that this rule is *not reliable*, but assuming for the moment that it is, and following out Mr Thom's argument on that basis, I think these figures quoted above, added to those in the table, show that Howden's system on the *counts of steam generating capacity and coal economy* "leads all the rest." In contradiction of Mr Thom's statement on page 67, that "this arrangement (Howden's) is not so suitable for American coal as it is for Welsh coal," these figures also show that some stokers or engineers can manage the one coal as well as the other. I believe, all the same, that the conditions to be observed in *any* system of draught are simply to acknowledge that American coal cannot give the same power per lb. as Welsh coal, and that therefore more must be burned. In *any* system, therefore, it is necessary to design the steam generating plant to give the desired power with American coal, and if that is done the same power will be got when it is wanted from a less quantity of Welsh coal. The system of draught has nothing to do with the matter Again, the temperature of the stokehole, quoted at 116 degrees, is entirely independent of Howden's system as such, but depends simply on the arrangement of air ducts and screens, just as in any other system, for I have myself found Howden's stokehole quite comfortable when the thermometer in the outside air registered 90 to 95 degrees in the shade, and I have crossed the Atlantic with the Howden stokehole at 85 degrees Fah., our difference of experience being no doubt due to the better ventilating arrangements. Mr Wallace seems to discover special facilities in the suction draught system for drawing vitiated air from holds, but really I don't think Howden's fan has any objection to draw air from holds if anybody wishes it to do such a thing, and it can do that just as well directly as the suction draught fan can do it through a lot of heating tubes. On page 67 Mr Thom says—"This combination of Howden's and

Martin's systems (suction draught) with Serve tubes makes a comfortable arrangement." If this is to be read as a suggestion that the Serve tubes are specially useful in the suction draught system, then I must point out that there is no evidence at all to show that the Serve tube or retarders, or that the Serve tube with retarders patented by Mr Eaves, are not equally applicable and useful in the Howden as in the suction draught systems. The tube ends and furnaces seem to behave as well in one system as in the other. Smoke-boxes must be equally tight in the three closed ashpit systems, and the bunkers must be tight in the closed stokehole plan, though Mr Thom emphasises the point on page 66 in dealing with Howden's system, and forgets to mention the matter at all when he comes to speak of the other closed ashpit systems. One point more, the fans in the suction system require a peripheral velocity of about one and a half times and a capacity of about twice that required by Howden's system, and the large fans require to pass gases at 400 degrees, while the small fans work in cold air. Is it necessary to say that the small cold fan may live a long and useful life free from trouble, while the bigger or faster-running fan is likely to be more costly to make. and, with hot climate, to live a life of comparative anxiety and worry, and die of galloping consumption in what should be the prime of its life. Any difference with I.H.P. required to drive these two fans is such a small drop in the bucket of the I.H.P. developed as to be entirely lost sight of in a rough analysis such as Mr Thom's, and is not of great consequence even in a detailed analysis; such as it is, however, it is against the suction draught system. Moreover, these big fans are generally placed, in the suction system, high up in the ship on the passenger decks, thus cutting out paying cabin space, while Howden's fans can be accommodated in less valuable space lower down. I cannot see any point in which, judging from the figures before us, based on the rule explained by Mr Thom and the other information presented, as well as on my own experience, the suction system is better than Howden's, and of course neither the natural draught nor the closed stokehole nor the closed ashpit approach Howden's in the particular points of compactness of generating plant and economy of coal, and therefore also of bunker space on board of ship. So that, since no better results of the suction draught system at sea have been presented in discussion than those in the table, we are led by Mr Thom's mode of investigation to find that *so far as* the suction draught system has been *matured* it is not capable of producing as good results as Howden's. Further, the explanations as to fan troubles and how to overcome them make one think that the suction system is simply Howden's plan standing on its head, and to keep it in equilibrium in that shaky attitude big, expensive, and uncomfortably hot fans have been introduced to bolster it up at the further expense of the absorbed cabins. Looking now at the rule which Mr Thom brings from American Navy practice and recommends to superintending engineers as "the more accurate method" of finding the mean I.H.P. over a voyage. This rule assumes that if one set of indicator cards is taken during a seven days' voyage, the mean I.H.P. over the voyage may be found thus:

$$\text{I.H.P.} = \frac{\text{I.H.P.}_c \times R_m{}^3}{R_c{}^3}$$

in which I.H.P._m = mean I.H.P. over the voyage,

I.H.P._c = I.H.P. by cards,

R_m = mean revolutions during voyage by counter,

R_c = revolutions when cards were taken.

I think any one familiar with the Atlantic knows that the variations of weather from day to day are so great, and that the draft and trim of a ship undergo such variations during a voyage, that any simple rule applied to revolutions and I.H.P., and to all ships indiscriminately, is not likely to be a very trustworthy guide to the end desired. Still, I have had occasion to reduce this thing to the concrete form, and the results are something like these. I caused eighty sets of indicator cards from successive voyages across the Atlantic of sister ships to be placed in pairs, each pair representing the power and revolutions at the same mean displacement of the ship, and the exponents of the powers of the revolutions corresponding to the I.H.P. to be found. Sixty-three results showed exponents to range thus:—

$$\text{from I.H.P.}_m = \frac{\text{I.H.P.}_c \times R_m^{\cdot 006}}{R_c^{\cdot 006}}$$

$$\text{to I.H.P.}_m = \frac{\text{I.H.P.}_c \times R_m^{13\cdot 263}}{R_c^{13\cdot 263}}$$

and, out of these sixty-three examples, in 3 cases only did the exponent of R approximate 3 as in the rule given by Mr Thom, and in 18 cases only did it range from 2·5 to 3·5. These results are so far from the cube of the revolutions that it is not necessary to point out that all the ratios involving mean I.H.P. given by Mr Thom, and the ratios involving the same unknown quantity quoted by myself for comparison's sake, and all the analyses and inferences and deductions from them, even as approximations having relative truth, fall to the ground, and *all we learn from the table is that so much coal was burned per square foot of fire grate.* Since, then, the argument of the paper is thus without reliable premises, it becomes, to a casual reader, or to any one without intimate knowledge of the matter, a source of misconception and error. Is it a reasonable thing to present in name of an instance of one system of draught against another, a comparison of the ships' speeds on a run between "Mira" and "Hermione," without giving such particulars of dimensions and powers as are required to enable any one to judge even roughly, whether it was ships' form or dimensions, or engines, or boilers, or coal, or men, or what it was that beat in the race? And almost equally loose and unsatisfactory is the comparison of the same kind instituted between ships A and B on page 72. Such suggestions need not lead a professional man astray, but they might seriously prejudice the lay reader. I do not forget, in what I have said, that Mr Thom has safeguarded himself, to some extent, by saying that better examples of any or all of the systems may be found than those quoted; but his saying so does not prevent misapprehension from being conveyed. Are we still a long way from convincing shipowners that it would be to their interest to place a research committee, with a sufficiently large staff, possessing physical as well as scientific aptness, on board ships carrying typical examples of machinery and boilers, so that trustworthy investigations might be made, the whole marine engineering position simplified, and real progress encouraged?

Mr THOM in reply writes—Where several speakers have mentioned similar points in the paper, I think a general reply will be all that is necessary. The fan formula that has been spoken about by several, as far as I can learn from my friends who have compared it with actual results and found it satisfactory, certainly, as pointed out, it does not give the fan a high efficiency, which is not desired in a formula where you want to be sure of attaining the desired result. Professor Barr's remarks on fans perhaps being larger than necessary in suction draught would also hold good for the forced draught fans, but he lost sight of the fact that you neither see the suction nor discharge orifices in induced fan arrangements, and you might have a fan working for weeks, without effect; in forced draught fans discharging into the stokehole it would be noticed at once. In reference to Mr Inglis' remarks, my paper states it is only intended to start a discussion on mechanical draught, and from the number of proof sheets on discussion submitted to me, I think it has attained its object. In reference to the summary of results, these vessels are not run on the ordinary familiar lines where you depend on a meagre log. Most of the vessels have an office on board and a man specially told off to insure accuracy from experience of the work, and most of the vessels are made by the same builder, and obtain same stores and coal, and then the crucial test is the difference of speed, for instance, between A and B. This eliminates entirely all the points raised by Mr Inglis. I am pleased to hear from Mr Nisbet Sinclair that most of the log performances of the various voyages have been before him, and that the ratios deducted from them in summary are correct. Mr Hall-Brown's proposal to heat the feed water by the escaping gases has already had many supporters, and one of our Presidents (the late Mr Kemp) found that in working it up to perfection it required nearly as much surface as the boiler, but you can never reach perfection in this direction. As pointed out by Professor Watkinson, you cannot reduce the temperature of the escaping gases below the feed temperature. In reference to Mr Hall-Brown's question, Why heat the air? I was amused to find when reading the life of Richard Trevithick in reference to a boiler he had designed to work with heated air in 1830, he said, "As it is possible to blow so much cold air into a fire as to put it out, by first heating the air it would burn all the stronger." In reference to Mr Morison's remarks, the funnel temperature is certainly the place to look for efficiency in the boiler, and, as pointed out by Mr Macfarlane Gray, with ordinary draught about 25 per cent. of the heat goes up the chimney; with the best example here of mechanical draught only 12½ per cent. goes up the chimney. With the ordinary run of mechanical draught examples 16½ per cent. goes up the chimney, so the saving is about 8½ per cent. when you allow surface enough to absorb the heat. Mr Howden refers us to his paper read before the Engineering Congress in Chicago in 1893, where he explains the reasons for vessel B not doing better, and states that, if properly arranged, 26,500 I.H.P. could be easily obtained instead of 20,000. Since that Mr Howden has had another chance with two sister vessels with about the same boiler power, but there is not much difference in the results so far. The extra 6500 I.H.P. has still to be obtained, so that B cannot be reckoned as a very bad example of his system. If time had permitted, I should have liked to go further into the question, and to have dealt especially with Professor Barr's remarks on the disputed point as to the size of flues.

The late Sir Edward Harland.

At the meeting held on 24th December, 1895,

Mr **Hector MacColl** said—Mr President, I am quite sure that this meeting would not like to separate without expressing its sense of the immense loss the engineering profession has sustained in the death of Sir Edward Harland. I read this afternoon with great regret and surprise the announcement of his sudden death. He was a man, as you all know, who, by his conspicuous ability and boundless energy, converted what was one of the most insignificant of shipbuilding yards into one of the grandest establishments which exists over the whole world. I am sure we must feel, in losing Sir Edward Harland, that we have lost one who has been an ornament to every branch of the profession.

The **President** said—Gentlemen, you have all seen the sad intimation of Sir Edward Harland's death. I do not think any man in the engineering profession has stood higher than Sir Edward Harland, and we are all extremely sorry to learn of his sudden death, which has occurred to-day. The family of Sir Edward Harland have our sincere sympathy in their bereavement.

On "Cast-Iron Segments for Railway and other Tunnels."

By Mr EVELYN G. CAREY.

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

Received 10th, and held as Read 24th December, 1895.

THE subject of the manufacture of cast-iron segments for railway and other tunnels has not hitherto, so far as the author is aware, been brought before this Institution, and it is with a view of inviting discussion on this important topic that the following notes have been assembled bearing on work carried out in our midst during the past few years.

The construction of the Glasgow Harbour Tunnel, the Glasgow District Subway, the Mound Tunnels in Edinburgh, and several important sewers in connection with the Glasgow Central Railway, in all of which segments of cast-iron have played an important part, renders some brief accounts of their manufacture not out of place before such a Society as this; whilst the operations of a large establishment on the banks of the Clyde, the British Hydraulic Foundry Company, Limited, of Whiteinch, who have laid themselves out for such work as a specialité, and where the whole of the segments for the Blackwall Tunnel, under the river Thames, have been turned out, appear to the author to fall naturally to be laid before an audience so closely identified in local surroundings with all these important undertakings.

The author has been desirous, moreover, of collecting and recording various items of interest in regard to these works which otherwise, being in many different hands, would inevitably be lost and scattered by the action of time.

The important place in tunnel construction now occupied by cast-iron segments needs no comment before an audience who, for many years, have daily witnessed their application. The advantages of employing segments may be briefly stated to be, that they are much quicker and more convenient to build than brick or masonry work, and that the lining at once attains its full strength on being bolted up, in marked contrast to the time occupied by brick or stone joints in setting.

The importance of this point where soft ground is encountered and a heavy pressure to be resisted will be at once obvious.

Moreover, cast-iron tunnels can be made perfectly water-tight whatever pressure surrounds them, whilst, unlike brick or masonry tunnels, greater strength can be secured without undue enlargement of the outside dimensions; and, with cast-iron segments, a smaller area requires to be excavated than with brick or masonry lining, and the method lends itself especially to construction by shields.

These considerations, and the cheap rates now ruling for the raw material, in addition to improved and rapid methods of segment manufacture, have operated largely in favour of iron lined tunnels.

The original use of cast-iron segments appears to have been in connection with colliery shafts, and Mr R. Nelson Boyd, in his paper, "Collieries and Colliery Engineering" (Transactions of the Society of Engineers, 1893), states that "cast-iron tubbing in circles" was used for the first time in 1795 at the Walker Colliery, in the North of England, and that in 1796 cast-iron segments were used as tubbing at the Percy Main Colliery.

Since these dates it has been the universal practice in the North of England to line the shaft near the surface with cast-iron tubbing in order to dam out the water, the rest of the pit being lined either with stone or brick.

In this connection it may be noted that the shafts would range from about 6 to some 30 feet diameter, and that unmachined segments with timber packing were employed.

Turning, however, to horizontal shafts,

As far back as 1818 Brunel, in taking out a patent for tunnel construction by means of a shield, refers to the lining in the following terms:—

"The body or shell of the tunnel may be made of brick or masonry, but I prefer to make it of cast-iron, which I propose to line afterwards with brickwork or masonry."

The old Thames Tunnel between Wapping and Rotherhithe was constructed by Brunel between 1825 and 1842, cast-iron lining not being, however, employed.

Coming to more recent dates, Mr Peter Barlow proposed, in 1867, a system of iron subways for the relief of London traffic, and the Tower Subway, London, built in 1869 by Mr Peter Barlow and Mr J. H. Greathead, is to be noted as the first horizontal tunnel constructed with cast-iron lining, the external diameter being 7 feet 1¾-inch.

In 1886 the City and Southwark Subway (now known as the City and South London Railway), running from the Monument in London to Stockwell, a distance of some three miles, and passing beneath the Thames, was commenced by Mr J. H. Greathead.

The undertaking is formed of two separate tunnels, each 11 feet 3 inches external diameter, lined with cast-iron segments.

In America, the St. Clair Tunnel was formed with cast-iron segments, and had a diameter of 21 feet; while the Hudson, commenced in 1871, and suspended when nearly completed in 1891 owing to financial difficulties, was similarly lined with iron.

Turning, however, to the undertakings which form the more immediate object of this paper and the segments employed in them:

THE GLASGOW HARBOUR TUNNEL.

This undertaking, commenced in 1891 and completed in 1895, consists of three parallel tunnels, each 16 feet (internal diameter of iron) and about 800 feet long. The centre tunnel is reserved for foot passengers. All the tunnels are formed with cast-iron segments, filled with concrete and lined with glazed tiles.

The shafts at each end, 80 feet diameter and 80 to 90 feet deep, are similarly iron-lined.

The strata encountered were boulder-clay, sand, and gravel. The engineers were Messrs Simpson & Wilson, of Glasgow, and the contractors Messrs Hugh Kennedy & Sons, of Partick.

The segments in both shafts and tunnels are similar to those subsequently described for the Glasgow District Subway, viz., they have joints formed by a chipping edge and soft wood packing, no machining being performed.

In the shafts the segments were 4 feet long by 2 feet deep, the flange being 3 inches deep, and the thickness of iron ½-inch over all. The segments were bolted together by ½-inch bolts, spaced about 12 inches apart.

A space of about ⅛-inch was left between the flanges for wedging with soft wood.

The tunnel segments were 4 feet by 18 inches wide, with a flange 6 in. deep, measured from the outside of the body of the plate. The back of the segment was 1 inch thick, with flanges 1½-in. thick. Like the shaft segments, those in the tunnel were strongly stiffened with brackets on every flange.

The shaft segments were secured together with ¾-inch bolts, spaced about 9 inches apart, leaving a space of about ⅛-inch between the flanges for wedging with soft wood.

Scotch grey iron was employed for these segments, with a tensile strength of 6½ tons per square inch before fracture, and 2½ tons per square inch without loss of elasticity. The transverse test was 7 cwts. in a bar 1 inch square on bearings 3 feet apart.

About 4000 and 550 tons of segments were used in tunnels and shafts respectively.

The segments were hand-moulded by Messrs Goodwins, Jardine & Co., of Ardrossan.

THE GLASGOW DISTRICT SUBWAY.

This undertaking, now rapidly approaching completion, has a length of 6½ miles, and will connect the more important quarters of

Glasgow by a circular route, which passes twice beneath the river Clyde. The engineers are Messrs Simpson & Wilson, of Glasgow.

Two lines of tunnel, each 12 feet external diameter, and spaced from 3 to 6 feet apart, are each formed of 9 segments and 1 key-piece.

Three thicknesses of segments were employed—¾-inch, 1-inch, and 1⅛-inch—the first being the ordinary section throughout the undertaking, the second being employed in passing beneath the river Clyde and beneath the Glasgow Central Railway, whilst the third section, which, unlike the two preceding ones, was machined at the edge strips, was employed in the passage beneath the Caledonian and Glasgow and South-Western Railways at Pollokshields.

Figs. 8 and 9 (see Plate IV.) give the remaining particulars of these segments, which were 4 feet 1¼ inch by 1 foot 6 inches, the flanges being 6 inches deep, and strengthened by feathers or brackets 1 inch thick in the case of the ¾-inch and 1-inch segments, and 1½-inch thick in the case of the 1⅛-inch segments, four brackets and one bracket being cast in the long and short sides respectively.

Holes for 1 inch diameter bolts were cast midway between the brackets, viz., 9 inches apart from centre to centre.

The special feature of interest is the joint, which is formed by a strip ¾-inch wide by $\frac{3}{16}$-inch deep unmachined (except in the case of the 1⅛-in. segments), metal to metal, the remainder of the joint being made up with a soft wood packing piece filling the rest of the space.

Though four machines were put down to execute this contract, only two were employed (for they worked in pairs) during the greater part of the time, the producing power of the plant being considerably in excess of the demand at site for the segments.

The whole of the segments for the undertaking were manufactured by the British Hydraulic Foundry Co., Limited, being moulded in the patent hydraulic machines, which forms one of the specialties of the Company.

Reference to Fig. No. 1 (see Plate III.) will show this patent hydraulic moulding machine to consist essentially of a 4 inch hydraulic ram, working from below and operating vertically the pattern and moulding-box.

The swing head is held in position by a pair of side levers, 7 inches by 1½ inch, attached at their base to stout plummer blocks and actuated by a second hydraulic ram (2 inches diameter, with a downward stroke of 11 inches) working a heavy cast-iron lever secured to each side lever.

A massive cast-iron base-plate carries the 4 guides, each 4½ inches diameter, which regulate the action of the main ram and its attachments, and forms the support of the moulding-box, when, after the final squeeze, the pattern and ram descend again.

Both pattern and outline plate (carrying the moulding-box) are counter-balanced, and the ends of the segment pattern, being inclined inwards and therefore unable to be "drawn," are actuated by hand-worked screws and brought below the outline plate previous to the mould being taken off the machine.

The sand is fed into the moulding-box from a hopper above the machine (holding the exact quantity required) by means of a wooden shoot working by a hand lever, and swinging out of the way when not in use.

The process of working the machine will be noted to be as follows:—

An empty moulding-box having been brought beneath the machine on a bogie on a line of rails, the outline plate of the machine is thrown over, and picking up the empty box, at once transfers it to the machine; the ram then brings up the pattern (which is attached to its head) into position inside the moulding box, and sand is forthwith fed in from the hopper above, filling the moulding-box; the swing head of the machine is then brought over the moulding-box by means of the side levers already described, and the ram being again raised carries the moulding-box off its supports (the heads of the four guides) and presses it smartly against the swing head of the machine, which is furnished on its under side with a block of hard wood of size sufficient to fit the moulding-box. This action gives a firm ramming-home to the mould and completes the formation.

Nothing then remains but to lower the ram, withdrawing the pattern attached to it. Screw down the ends of the pattern and throw back the swing head. The outline plate is then thrown over on to the bogie in waiting below, and the moulding box and its contents, being released and resting on the bogie, are moved along the tramway by an endless chain and brought beneath the cupola and filled.

The next bogie is then brought beneath the moulding machine and the process repeated.

The outline plate, it should be added, is operated also by hydraulic power, so that four levers under the control of one boy govern the action of the machine, viz., two levers for the main ram (a quick and slow motion), one lever for controlling the swing head, and one lever for controlling the outline plate. The pressure is about 1500 lbs. per square inch, all waste water being returned to the supply tank

The tops of the moulds are made by hand, and are added with the cores as the bogie proceeds to the cupola, a lad subsequently tightening up the boxes and adding the pouring heads.

The pattern is kept warm by means of a gas jet placed beneath it to prevent "clagging" or adhesion of sand to pattern on the withdrawal of the latter from the moulding-box.

Each machine was capable of turning out 1½ rings or 13½ segments per hour, being at the rate of 1 segment per 4½ minutes, this speed being maintained from 6 a.m. to 5-30 p.m., or, allowing for meals, for 9½ hours.

It is unnecessary to deal further with the Glasgow Subway segments, as the process follows on the lines of those adapted with the Blackwall Tunnel segments, fully detailed later.

The Glasgow District Subway required 120,000 segments, weighing about 20,000 tons.

The quality of iron used in these segments was required to stand a tensile strain of 6½ tons per square inch, and of 2½ tons per square inch without loss of elasticity, whilst bars 1 inch square in section were required to stand a load of 7 cwts. applied at the centre of a 3 feet span.

THE MOUND TUNNELS IN EDINBURGH.

These tunnels have been carried out by the North British Railway

Company in connection with the widening of their Waverley Station, Edinburgh, and its approaches.

The work, which commenced in August, 1893, was executed for the Company by Mr George Talbot, and consisted in the construction of two tunnels, one on either side of the old main line tunnel.

Cast-iron segments were used throughout, the external diameter of each tunnel as measured from back to back of segments being 18 feet 6 inches.

The segments (13 to each ring) were 18 inches in width, with flanges 7 inches deep, brackets of stout build connecting the flanges and back—the long side containing 5 brackets 1⅝-inch thick; the short side 2 brackets 1½-inch thick, washers ⅛-inch thick being cast on the inside of each flange for the bolts. The grouting hole was 1¼-inch diameter. (See Figs. 14 and 15, Plate V.)

The keys were 9 inches wide and similar in type to the segments.

The holes in the side flanges were drilled to $1\frac{7}{16}$-inch diameter, those in the end ones being cored 1½-inch diameter. The number of holes in the sides and ends was 6 and 3 respectively.

Two thicknesses of segment were used in the undertaking, viz., segments with backs 1¾-inch thick in the middle of the tunnel under the Art Galleries, and 1¼-inch thick at each end of the tunnel. Except in regard to the thickness of the back, both classes of segment were of similar dimensions throughout.

The segments for one tunnel were executed by the Carron Co., those for the other by the British Hydraulic Foundry Co., Limited.

The segments were machined on all four faces in a milling machine smaller in size but similar in type to that employed for the Blackwall Tunnel segments, and subsequently described in detail, rendering further particulars of this machine unnecessary.

The number of rings in each tunnel was 215, and each segment, weighing about 8 cwt., was lifted into position in the tunnel by hand.

The material used and the processes employed, differing in no way from those subsequently described for the Blackwall Tunnel segments, need not be here detailed.

The tests required by the North British Railway Company were a tensile strength of 6½ tons per square inch, with an elastic limit of 2½ tons, the transverse tests being 28 cwts., with a 2-inch by 1-inch section and 3 feet bearings.

The segments were grouted externally with Arden lime, injected by the Greathead patent grouting-pan, the lower portion of them being finally filled up flush to the flanges with concrete.

GLASGOW CENTRAL RAILWAY.

Cast-iron segments have been employed on and in connection with this undertaking for sewer formation—

1st, a sewer in Argyle Street - -	700 yards long.
2nd, a sewer also in Argyle Street -	330 ,,
3rd, a sewer in Maxwell Street ·	300 ,,

All three sewers were identical, so far as the segments were concerned, and had an external diameter of 4 feet 7½ inches.

The segments were of ¾-inch metal, 5 to the ring, 1 foot 6 inches wide, and with 3-inch flanges. Brackets were arranged, as shown on the drawing, square bolt holes being cast in midway between the brackets.

The holes were $1\frac{3}{16}$-inch square, whilst both flanges, back of segment, and brackets were all ¾-inch thick. The grouting holes had a diameter of 1¼-inch.

A sewer of similar type (see Fig. 7, Plate IV.), recently built in Glasgow in Kent Street, has an external diameter of 5 feet 3½ inches, and is in all other particulars identical with those just described.

The Possil Burn sewer, also constructed recently in Glasgow (see Fig. 11, Plate V.), consisted only, so far as the cast-iron segments were concerned, of some 10 rings, but is of interest in differing from those already described in being formed of two segments only.

The external diameter is 5 feet 11 inches. Each segment has 4-inch flanges, 1-inch thick, and is of 1-inch metal throughout. No brackets are used, and the bolt holes, 1⅛-inch diameter and 14 in number, are spaced equally around the circumference.

The width of each casting is 3 feet, the horizontal joints being formed by 3 bolts (see Fig. 11, Plate V.) spaced at 14-inch centres.

A feature of the above segments is that no machining was performed on the edges, and that the joints were made with strips of tarred felt.

With the exception of some segments cast by Messrs Alley & MacLellan, of Polmadie, prior to commencement of operations at the British Hydraulic Foundry, the whole of the above work was executed by hand-moulding by the latter company.

It may be noted in passing that the three first-named sewers were executed with compressed air, no shields being employed.

THE BLACKWALL TUNNEL, LONDON.

The Metropolitan Board of Works in 1887 obtained Parliamentary powers for the construction of this undertaking, but it was not until 1892 that operations were commenced by Mr Binnie, the Chief Engineer of the London County Council.

The Blackwall Tunnel consists of a single tube 27 feet in diameter, and designed both for vehicular and foot traffic, the total length from entrance to entrance being 6200 feet.

Sir Benjamin Baker, who in 1890 had, under instructions from the London County Council, inspected both the Hudson and St. Clair Tunnels in America, and reported that no serious difficulties need be apprehended with that proposed at Blackwall, was consulted with Mr J. H. Greathead, by Mr A. R. Binnie, Engineer-in-Chief to the Council, and tenders were invited in 1891, that of Messrs Pearson & Son being accepted.

Mr D. Hay and Mr Maurice Fitzmaurice were appointed by the Council as Resident Engineers on the work under Mr A. R. Binnie, and Mr E. W. Moir took charge on behalf of the contractors.

The whole of the segments for this important undertaking (the largest tunnel yet constructed by the shield and segment system), amounting to upwards of 20,000 tons, were manufactured at the works of the British Hydraulic Foundry Co., Limited, Whiteinch, Glasgow.

Fig. 6 (see Plate IV.) fully details the segments, of which two thicknesses were employed, viz., the 2-inch section under the river and the 1½-inch section under the Middlesex approach.

On all four faces the segments were machined, the 2-inch recess at the inner edge being subsequently caulked with rust cement.

It will be noted that no feathers or brackets are employed.

Each ring consisted of 14 segments and a key, the width being 2 feet 6 inches and the weight for the 2-inch material about 14 tons.

The accompanying plan of the works of the manufacturers will enable the processes of casting and machining to be readily followed. (See Fig. 10, Plate V.)

Arrived at the works, the raw material was fed into the cupolas shown, each being a 6-feet cupola with a capacity of 50 cwts. of molten iron—the cupolas being used on alternate days.

Each ton of iron required about 1½ cwt. of coke for its reduction, the blast being about 1 lb. per square inch.

The average output was about 100 tons per day of 9½ hours.

THE PATENT MOULDING MACHINE..

The application of the term "hydraulic" to the moulding machine of the Blackwall Tunnel segments would be a misnomer. The segments are too large for the application of the principle of that hydraulic moulding machine already described and figured in connection with the Glasgow District Subway, which forms the specialité of the British Hydraulic Foundry Co., Limited. The Blackwall segments are machine-moulded in a patent machine of special design. (See Figs. 2, 3, 4, and 5, Plate III.)

This machine rests on 3 main cast-iron girders 9 inches deep by 9 inches wide in the flange supporting the main cast-iron framing, on whose top is carried the pattern.

The main cast-iron framing is 8 feet 3 inches by 4 feet 4 inches by 2 feet deep, and forms the recess into which the sides of the pattern are retired previous to drawing the body of the pattern.

The moulding-box surrounding the pattern is 7 feet by 3 feet 4 inches by 20 inches deep.

The essential feature of the machine is that the main framing is hinged, and revolves on large bearing surfaces turning completely over and carrying bodily with it both pattern and mould.

Four hand-wheels (see Figs. 2, 3, 5, Plate III.), 24 inches diameter, actuate worms and raise or lower the flange of the pattern to enable the mould to leave the same, the travel being the height of the flange.

The moulding-box is held down by 2 screw clamps, one at either end.

The girders rest on blocks of brickwork, the H beams being bolted together by two cast-iron distance pieces.

The pattern, which is made of mahogany, is brass-bound at the edges.

Operations are conducted as follows:—

The mould box being in place, with the flanges in position, the box is filled with sand and the pattern rammed up, a cast-iron plate, forming a lid, is then clamped on to the top of the moulding-box, and the whole main frame, with moulding-box and pattern, is turned over by means of a hydraulic crane.

The flanges are then withdrawn by means of the four handles already described, and the clamps holding the moulding-box having been released, the main frame is turned back again by the hydraulic crane into its original position, leaving the mould ready for coring, finishing, and receiving the top part, which has been in the meantime moulded by hand.

The cores are made by hand in the usual way, and call for no special remark.

The facing sand employed consists of:—

2 parts of white rock sand.
1 part of Belfast red sand.
1 part of coal dust.

Mixed with an equal bulk of old black sand. All burnt sand being carefully avoided.

On finishing, the mould is dusted with blacking and plumbago passing through a cloth bag, and is then finally "sleeked" with the tool.

On the final dusting of blacking and plumbago much of the smoothness of skin attained depends.

That this process of machine moulding produces very accurate castings cannot now be disputed. All the bolt holes are cored so truly that, although there were about 18,000 separate plates, each having 20 holes, no difficulty has been experienced in bolting plates selected at random together, although the contract is now nearly completed.

The segments were immersed cold, and remained in the solution from half-an-hour to one hour, viz., until the solution boiled.

The tanks (two in number) were 6 feet by 12 feet by 4 feet, were heated by coils from a boiler (steam pressure about 60 lbs.), and were provided with lids.

A crane locomotive performed the dipping and handling of the segments.

The keys are moulded by hand, and cast with two runners, one at each end and a flow in the centre, the head given being 6 inches above the top of the lug.

Each runner and the flow are 1¼ inches diameter. After fetling and dipping, the keys were machined in two shaping machines of ordinary type, and calling for no special remark.

The mixture of iron employed in the Blackwall, the Glasgow District, and the Edinburgh segments was as follows:—

No. 3 pig-iron (English or Scotch), -	10 cwt.
Hematite, - - - - - -	2 „
Scrap (machinery, railway chairs, etc., etc.),	6 „
„ (heads and gates), - - -	2 „
	20 cwts.

The brands of No. 3 pig necessarily varied, but a mixture of 5 cwt. of "Clarence" and 5 cwt. of "Govan," No. 3 may be taken as typical of the class used.

The quality of iron supplied for the Blackwall contract was under constant supervision, test bars being run twice a day.

The tensile samples were required to stand a strain of 8 tons per square inch, whilst the transverse samples, 3 feet 6 inches long by 2 inches by 1 inch, were required to stand 28 cwts. on bearings 3 feet apart.

The customary deflection of the transverse bars at 28 cwts. was

$\frac{9}{32}$ inches to $\frac{10}{32}$ inches, and at fracture (usually a cwt. or so higher) from $\frac{10}{32}$ inches to $\frac{11}{32}$ inches.

MILLING PLANT.

The milling machine, for machining the sides of the segments, consists of a substantial bed-plate 14 feet by 2 feet 3 inches by 20 inches deep, carrying a travelling table 8 feet long by 2 feet 9 inches wide, to which the work is attached, the arrangements being capable of planing any widths from 18 inches to 36 inches on both sides simultaneously. The table is actuated by a steel screw 2½ inches diameter, worked by a three-speed transverse cone, worm, and worm wheel, placed as shown in Fig. 12 (see Plate V).

The remainder of the bed-plate consists of portions at right angles on either side about 5 feet long, 2 feet 4 inches long, and 18 inches deep, which carry the headstocks, one on each side of the table and adjustable to it in position by means of a screw with worm wheel and worm for exact adjustment to $\frac{1}{100}$-inch.

The dimensions of the headstocks are 3 feet 9 inches long by 3 feet wide, and 24-inch centres. Each is fitted with spindles of cast-iron, having a diameter of 8 inches, and running in bushes of the same material, fitted into square holes. A strong thrust arrangement is provided, whilst two hard grooved gun-metal washers take up the wear to permit lubrication.

A strong steel worm in an oil bath drives each spindle through a worm wheel, a three-speed cone, 5 inches wide, the largest being 27 inches diameter, communicating the motion.

When the cut is performed the table makes the return stroke rapidly by means of a pair of pulleys and bevel wheels, which drive the screw at the end of the bed-plate remote to the feed gear already described, the worm wheel being disconnected.

A traversing cone, with four speeds (see Fig. 12, Plate V.), gives a variable feed to the table, ranging from $\frac{3}{8}$-inch to $1\frac{3}{4}$ inches for each revolution of the cutter.

The milling machine for dealing with the ends of the segments is essentially of a type of construction similar to that already described for milling the segment sides, the main difference being that in the machine for the ends, the milling heads are caused to travel, whilst in that for the sides, the milling heads are fixed.

The milling machine for the ends consists of two milling heads travelling on vertical guides, and furnished with cutters about 3 inches apart, the diameter of the milling head being from 2 to 3 feet.

This design enables the tool to cut at any angle required, as in the case of the ends of the K segments as distinguished from those of the ordinary segments.

Each milling head is carried on a stout vertical cast-iron standard, inside which the gearing actuating the head is carried.

To facilitate the raising of the milling head (the cut is made by travelling downwards), counter-weights are arranged.

Simultaneously with the milling of the ends of the segments, the drilling of the grouting hole (1½ inches diameter) is performed in this machine by a small horizontal drill, resting on the table on which the segment itself is carried, the feed is automatic and the arrangement calls for no special comment.

The foregoing machines were designed by Mr Stephen Alley for dealing with the Blackwall Tunnel segment contract.

The milling machines have been designed, as far as possible, to dispense with hand labour and produce accurate work. That this end has been attained is proved, the plates being exact duplicates of one another, so much so that none of them were marked; yet when taken at random and placed in the tunnel all came in truly, and fitted so closely together that they formed a metal-to-metal joint without any packing on jointing; and when it is remembered that in this undertaking there are over 50 miles of planed metal-to-metal joints, the result may be considered at least satisfactory, and to reflect credit on the makers.

THE JOINTS OF CAST-IRON SEGMENTS.

The most judicious manner of jointing the segments may, in view of the diversity of practice still obtaining, be regarded as still moot points, bearing in mind that the question of cost necessarily forms a not unimportant factor in the problem.

For the City and South London Railway, the longitudinal joints were made with unmachined flat faces, ¼-inch pine packing being inserted, ¾-inch at the face joint being left open for subsequent painting with Roman cement.

The vertical joints had a chipping edge, similar to that of the Glasgow District Subway.

The engineer of this undertaking was Mr James H. Greathead, with Sir John Fowler and Sir Benjamin Baker as consulting engineers.

For the Hudson River tunnel, of which Sir John Fowler and Sir Benjamin Baker and Mr Greathead were consulting engineers, the joints were planed.

For the St. Clair tunnel (of the Grand Trunk Railway at Saguinay), packings of hard wood were introduced between tooled faces of iron, the wood joint running through and through, in some parts lead caulking being resorted to.

In the Waterloo and City Railway, now under construction, the longitudinal joints are planed and iron to iron, whilst the transverse ones are formed by wooden strips.

Both the Glasgow Harbour Tunnel and the Glasgow District Subway (engineers, Messrs Simpson & Wilson) have joints with a chipping edge and soft wood packing.

The Blackwall Tunnel segments, and the Edinburgh Mound Tunnel segments, have planed joints, and are metal to metal throughout; the former have a recess on the inner edge (see Fig. 6, Plate IV.), and the latter being iron to iron for the whole width.

The importance of the flanges in work of this class must not be overlooked, for to them is due the rigidity of the tube; and without them, as Sir Benjamin Baker, President of the Institution of Civil Engineers, recently pointed out, a tube ¾-inch thick would be as flexible as a child's hoop.

The necessity of transverse strength is obvious, and it is imperative that the tubes be properly grouted externally—viz., backed up at the sides and furnished with abutments.

The critical time, as the same authority pointed out, for testing the strength of the joints is when the pressure of the soil first comes upon them—or, in other words, before the soil has thoroughly consolidated around.

To again quote Sir Benjamin Baker's opinion, the great variety of joints can be made equally efficient, local considerations alone determining their respective values. In a good sound clay, Sir Benjamin Baker has no objection to a wooden joint carried right through, but in bad ground he considers a chipping strip at the back advantageous, because

1. The joint cannot close up at the back.
2. Wedges or cement can readily be inserted in front.

Turning, however, in conclusion to the question of planed joints, and again turning to the views of Sir Benjamin Baker, it is of no small interest to quote the words he uses in connection with this form of joint:—

"Having reference to the small cost of planing, I should, if a contractor, prefer to have planed joints, even if I had to pay the expense myself, because the job as a whole would probably cost less; but I am of opinion that an equally sound and strong job can be made on either system."

The author ventures to commend this expression of opinion to the members of this Institution as containing the gist of a matter which has exercised engineering circles in and around Glasgow for some time.

The author has only, in conclusion, to acknowledge his numerous obligations for much valuable assistance in preparing this paper.

To Mr Maurice Fitzmaurice, M.Inst.C.E., Resident Engineer at Blackwall, for the use of his paper on the Blackwall Tunnel, before the British Association in 1894.

To the directors and staff of the British Hydraulic Foundry Co., Limited, to all of whom the author is indebted for great aid in preparing the foregoing remarks.

On "Tunnelling in Soft Material," with special reference to the Glasgow District Subway.

By Mr ROBERT SIMPSON, B.Sc., C.E.

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

Received and held as Read, 28th January, 1896.

IN a former paper submitted to this Institution, the method was described of forming part of the Glasgow City and District Railway through running sand. Since that date a very large amount of tunnelling has been done in Glasgow through almost every variety of material, from soft liquid mud to hard rock. The object of the present paper is to describe shortly and comment upon the methods adopted in forming the Glasgow Subway through the different varieties of the softer material, as very little of this kind of tunnelling has been done in Scotland, and, as far as the author is aware, one or two of the methods adopted were employed for the first time.

This subject has no doubt been well discussed during the last few years in papers before other institutions, but there are some aspects of the question which the author has not yet seen described, and which the construction of the Subway has given opportunities for observing, and this must be taken as his excuse for adding one more to the number of papers. In endeavouring to make the thing as complete as possible, he is afraid he will, to a certain extent, be going over ground already traversed in other papers, but in a subject of this kind it is difficult to avoid this. In particular, he will have to repeat some of the facts mentioned by Mr Carey in his valuable contribution to the subject, as this will be necessary for the purposes of illustration.

It might be advisable, before proceeding further, to indicate the main features of the Subway. The author is aware, of course, that the whole undertaking has been pretty fully described in the newspapers and engineering journals, so that he will take it very shortly.

The line is a circular one, not in the same sense, however, as the Cathcart Railway, as, in the case of the Subway, the trains will continue to go round without coming to a terminus. It is laid out with comparatively easy curves and gradients so as to be suitable either for cable haulage or haulage by electrical engines. The sharpest curves are 10 chains radius, and the steepest gradients 1 in 20 to 1 in 23, which occur at each river crossing.

The intention is to connect the western suburbs of Glasgow—Hillhead, Partick, Govan, and Kinning Park—with the centre of the city by a line, the service on which will be as frequent as the tramways on the streets, and the trains having a speed equal to those on metropolitan railways, viz., about 12 miles an hour, including stops. The line is wholly in tunnel, there being two cylindrical tubes side by side, each 11 feet internal diameter and varying from 2 feet 6 inches to 6 feet apart. Total length of double tunnel 11,527 yards, or, roughly, 6½ miles. The Clyde is crossed twice, on the east at the Custom House Quay, and on the west between Govan Cross and Partick. There are 15 stations, the average distance apart being about 770 yards. These are all 28 feet wide and about 150 feet long, with island platforms 10 feet wide, both lines of rails being here, of course, under one arch. The height of this arch varies from 11 feet to 16 feet above the platform level at the different stations. (See Fig 3, Plate VII.)

For convenience of reference while reading over the descriptions, the following table, giving in a short form the depths and strata passed through, may be useful (see Figs. 1 and 2, Plate VI.):—

1. Govan to Partick West. Distance, 2800 feet. Under river. Greatest depth to top of tunnels from high water, 56

feet. On Govan side sand, on Partick side mud, under river rock and boulder clay.

2. Partick West to Partick East. Distance, 2155 feet. Under Dumbarton Road. Depth about 20 feet. Beginning in clay and passing into hard rock, then shale with old coal waste.
3. Partick East to Hillhead. Distance, 1994 feet. Under Byars Road. Depth from 20 to 38 feet. In shale and standstone.
4. Hillhead to Kelvinbridge. Distance, 2948 feet. Under Glasgow Street and River Kelvin. Depth from 22 to 115 feet. Shale and sandstone, and passing through old filled up quarry at the east end of Glasgow Street.
5. Kelvinbride to St. George's Cross. Distance, 2588 feet. Under Great Western Road. Depth from 25 to 42 feet. Through shale and sandstone.
6. St. George's Cross to Cowcaddens. Distance, 2314 feet. Under New City Road. Depth about 25 feet. Shale and sandstone, with soft clay opposite the Normal School.
7. Cowcaddens to Buchanan Street. Distance, 2610 feet. Under Cowcaddens Street and Buchanan Street. Depth, 25 feet to 72 feet. Sandstone and shale.
8. Govan to Copland Road. Distance, 3007 feet. Passes diagonally through Govan. Depth, 8 feet. Sand, muddy sand, and clay.
9. Copland Road to Cessnock. Distance, 2182 feet. Passes diagonally through Govan. Depth, 13 feet. Muddy sand and clay.
10. Cessnock to Kinning Park. Distance, 1614 feet. Passes diagonally through Govan. Depth, 7 feet. Muddy sand.
11. Kinning Park to Shields Road. Distance, 2671 feet. Under West Scotland Street. Depth, 9 feet. Sand and muddy sand.
12. Shields Road to West Street. Distance, 1964 feet. Under Scotland Street. Depth, 13 feet. Brick clay.

13. West Street to Bridge Street. Distance, 1710 feet. Under Cook Street Depôt and Caledonian Railway. Depth, 27 feet. Brick clay.
14. Bridge Street to St. Enoch. Distance, 2204 feet. Under Coburg Street, River Clyde, and Dixon Street. Depth under high water, 41 feet. Sand.
15. St. Enoch to Buchanan Street. Distance, 1819 feet, Under Buchanan Street. Depth, 21 feet. Sand, with sandstone near St. George's Church.

The depths given are, in all cases, to the top of the arch of the tunnel. The shallowest station is Kinning Park, 14 feet to platform level, and the deepest Buchanan Street, 40 feet to platform level. The average depth is 23 feet, but taking out the two deepest stations, Buchanan Street and St. George's Cross, the average depth for the remaining 13 is only 20 feet. Under Hillhead and Great Western Road the strata passed through contain the same seams of coal as are met with in the Possil district, and the two seams passed through are supposed to be the upper and main coals of that district.

It was decided some time ago to adopt cable haulage, and the erection of the machinery at Scotland Street is almost completed. The vertical curves at the depressions at the two river crossings have been calculated so that the strain on the rope will not raise it off the sheaves. The sharpest radius is 2500 feet. A short length of a 1 in 20 gradient leads up to most of the stations, and the same leads down from them on the other side. This is to facilitate the starting and stopping of the trains.

As will be seen from the above table, the depth to formation level varies from 17 feet 6 inches in Govan to 127 feet in Hillhead, and the author has divided the conditions met with and the methods employed in constructing the tunnels into the following cases:—

Case I.—Depth to formation not over 30 feet, surface unoccupied, and material dry or capable of being easily drained.

This is ordinary cut and cover (see Fig. 4, Plate VII.), and the parts of the Subway falling under this head are in Scotland Street, from Shields Road to West Street, where the material is brick clay, and through Govan, from Broomloan Road to Cornwall Street, where the material is sand, interspersed with occasional patches of clay. The depth to formation in these two cases varies from 17 feet 6 inches to 28 feet.

In the case of the City and District Railway in Kent Road, the concrete arch forming the roof of the tunnel was thrown on the sand, and the rest of the work done from below. In the case we are considering, the contractors adopted the plan of opening the trench right to the bottom after piling the sides, then putting in the invert, building the walls and throwing the arches on centres. The section was designed, however, for the Kent Road method, and it was expected that this would be followed out, especially in the street, where the concrete arch thrown on the sand acts as a strut between the piles, and very much diminishes the chances of injury to the buildings at the sides while the work of excavating below and underbuilding is going on. Indeed, if this method be carefully and properly carried out, the author does not think that any damage whatever should happen to the buildings, provided, of course, that no sand be allowed to come through the piles when the operations below the arch are going on. However, in the case of the Subway, no obligations having been imposed on the contractors as to the way of carrying out the work, as they were held responsible for all damage due to subsidence, they elected to go down at once and build from the bottom.

As the circumstances turned out, this was fairly successful. In Scotland Street the material was good stiff clay, and in Govan the work was mostly through open fields, where the same precautions were not necessary as if there had been buildings along the route. At one or two points in Govan very soft muddy material was reached on the bottom, but, by taking short lengths at a time and sheeting off each length, the invert in all cases was successfully got in.

No doubt the contractors had to pay for damages to property in some cases, but it is not too much to say that a good many proprietors got their properties put in thorough repair, painted and papered, without any cost to themselves. So much underground work going on in Glasgow during recent years has made people very keenly alert as to the raising of claims on every possible opportunity.

When the work was done in the street the piles were driven from the surface, but in the open a trench was cut 6 feet deep and the piles driven from that depth, thus saving 6 feet in their length. The piles were held apart by 12 inches by 6 inches walings and two (or three) tiers of rances 12 inches square. In the street the top tier was usually left in as a guard against draw at the sides.

Very good speed could be made with this kind of work. In the open the excavation of the trench, the piling, the second excavation, the inverting, the building of the walls, and the throwing of the arch were done by different squads of men, each squad following up the one in front. The average speed was 140 feet per month of finished work, and the greatest in one month was 280 feet, working day shift only.

This, of course, necessitated the opening up of a great stretch of ground at once, but in the street this was impossible, as the Subway Act prohibited the opening up of more than 100 lineal feet at a time, and the openings could not be nearer than 150 yards. The speed got here was therefore considerably less than in the open, being about 90 lineal feet per month, and the greatest length done in any one month was 127 feet. The lengths taken at a time were about 15 feet.

One of the most difficult parts of the whole job was the construction of Cowcaddens Station by the Kent Road method (see Fig. 5, Plate VII.). This was done by Messrs M'Alpine. The depth to the rock here varies from 18 feet on the east to 23 feet on the west, the material above consisting of clay, and the depth to the top of the concrete arch is about 13 feet. The difficulties lay in the tramway lines, which could only be closed for a short time during the night, and a 3 feet 6 inches water main and 3 feet sewer, which had to be supported while the work of putting in the concrete arch was going on under the timber bridge supporting the street. The method of timbering can easily be understood from Fig. 5 (see Plate VII.)

without any explanatory remarks. When the arch was thrown the timber was removed and the street restored. Then the "dumpling" was excavated and the side walls built.

Case II.—Depth to formation not over 30 feet, surface unoccupied, but material capable of being drained only with great difficulty, or not at all.

Underpinning under air pressure (same cross section as in previous case). This occurred at two places on the Subway in West Scotland Street, from Cornwall Street to the terminus railway, and under the Joint Lines Station ground, Govan. The natural way to carry out this work is by iron tunnelling under air; but as the tunnels here were to be at no great depth—21 feet 6 inches to formation—it was decided to try the cheaper method of throwing the concrete arch on the sand and completing the covered way under air. The work was successfully completed in this way, and when the costs were compared it worked out to about £15 a yard of double tunnel cheaper than the cost of iron tunnels. In the underpinning the cost of the air machinery installation (about £4000 for West Scotland Street) and the cost of shifting the locks are included.

After the arch had been thrown, a short length of covered way (about 20 feet) was constructed at the end. This had to be done in the ordinary way, and here the locks were built. The air, of course, escaped with great rapidity through the sand at the face and through the concrete arch, but a pressure of from 2 to 3 lbs. was got, and this dried the bottom sufficiently to enable the concrete invert to be put in.

As the work progressed, however, and a greater area of concrete arch was exposed, it became more and more difficult to maintain the requisite air pressure, and when it became altogether impossible to do so the locks were shifted forward. The distance in West Scotland Street through which the air could be got to dry the bottom averaged 465 feet, and the greatest distance done from one position of the locks was 614 feet. The locks were shifted four times in the whole distance (1915 feet), and the speed at which the underpinning was carried on averaged about 130 feet per month, taken in 9 feet lengths. This includes the time lost in shifting the locks, which was about a fortnight each shift. The greatest length done in a month was 232 feet of double tunnel. The cover on the arches varies from 6 feet to 13 feet, and consists of fine sand. The bottom is very fine sand, or sand and mud.

In this manner the station at Govan was constructed, which would have been a long and arduous, and perhaps impossible, job otherwise. The necessary pressure to dry the bottom was maintained under the large arch (28 feet span and 150 feet long) at a depth of only from 4 to 7 feet from the surface.

Great care had to be taken with the concrete in the invert, as, after the air was taken off, considerable pressure was brought to bear on it from below, and any defects would speedily have been made evident by sand being forced through. Several of these blows actually did occur, but were stopped by calking the lower part of the holes with oakum and filling up with Roman cement. It is impossible to exaggerate the serious effect this escape of sand may have on the work if not promptly checked. The work below required but little timbering, as the double arch being caught on the piles, and only 9 feet taken at a time, it was quite strong enough to stand. Also, for greater security, the one tunnel was kept two lengths, or 18 feet, ahead of the other, so that in reality the centre part of the two concrete arches was never left unsupported.

The installation for West Scotland Street consisted of two duplex compressors by the Anderston Foundry Co. 30-inch air cylinders, 24-inch steam cylinders, and 24-inch stroke, and three Lancashire boilers 28 feet by 7 feet, 80 lbs. steam pressure. The installation at Govan consisted of one duplex compressor by Slee of Earlestown, 26-inch air cylinder, 24-inch steam cylinder, and 36-inch stroke, and two Lancashire boilers 28 feet by 7 feet, 80 lbs. steam. This installation was afterwards increased by two double and one single Anderston Foundry engines and three 28 feet by 7 feet boilers for the higher pressure required for tunnelling under the river.

Case III.—Material impervious to water, surface occupied, and avoidance of all subsidence a desideratum.

Iron tunnelling without air (see Figs. 6 and 7, Plate VII.). The only part of the Subway where this could be done was from Coburg Street, under Eglinton Street and the Caledonian Railway and Joint Lines, which at this place are supported on arches. The material, as already stated, is good brick clay, and this was the only part of the Subway where the much-lauded shield was of any real service, although even here it would have been quite possible to construct the tunnels without it.

In all, 16 shields were in use on the Subway, made for the most part by Markham, of Chesterfield, and each 12 feet 1½-inch inside diameter. They were 6 feet 6 inches in length over all, and the shell consisted of two skins of steel each ¼-inch thick (see Fig. 8, Plate VII.). The cutting edge projected 1 ft. beyond the diaphragm or bulkhead in which the door was placed. There were six rams capable of working up to a pressure of 2200 lbs. per square inch, although the actual pressure required for forcing the shield forward seldom exceeded 800 lbs. The weight of the whole shield was about 6 tons.

It has hitherto been thought that the shield is inseparable from iron tunnelling, with the result that the first thing the contractors for the iron parts of the Subway did was to provide themselves with shields. One contractor had as many as ten. When the author comes to deal with the tunnelling under air it will be seen that the shield was really of little use, and in some cases the shields were broken up and taken out as being actually a hindrance to the work.

In the case we are considering the use of the shield saved perhaps a little timbering. It also pared off the roughnesses of the excavation as it was forced forward, and on this account the excavation could be taken out slightly smaller than would be possible without a shield. The procedure was as follows:—A length for two rings of iron (3 feet) was excavated in front of the cutting edge, the shield pumped forward before the clay could get on the move, the iron built in at once, and the annular space behind the iron grouted. This was done with considerable celerity, and from 4 to 6 rings per day of 24 hours were usually got in. The average speed was about 150 feet a month, and the greatest length done in one month was 195 feet.

Some slight subsidences did take place, but this was due wholly to the fact of stopping the work over Sunday. On Saturday afternoon a length would perhaps be half out, and thus it would stand till Sunday at midnight, giving the clay time to get in motion. Work of this kind should never be allowed to rest.

Case IV.—Material impervious to water, surface occupied, but possible to repair the damage at moderate cost should subsidence occur.

Ordinary brick tunnelling (see Fig. 9, Plate VIII.). This was the method adopted under Cook Street Depôt, where the sidings could be made up at little cost. The material is brick clay, and even with these brick tunnels there is no reason why the work should not be done with very little subsidence indeed, if short lengths are taken and the brickwork proceeded with at once. With iron, of course, the risk of subsidence is reduced to a minimum, because it takes very much less time to build in the iron than it takes to build the brick. Also, with iron the length can be taken out almost exactly to the outside diameter of the tunnel, while with brick, bars and poling are required. Under Cook Street Depôt the tunnels advanced at the rate of about 73 feet per month, lengths of 9 feet being taken at a time. The greatest length done in one month was 93 feet.

Case V.—Tunnelling through water-bearing strata at considerable depths.

Iron tunnelling under air pressure (same cross section as for Case III.) This system of tunnelling was carried on at six different places on the Subway. (1) At St. Enoch, for Buchanan Street and the river crossing; (2) at Coburg Street, to join the St. Enoch tunnels; (3) at Govan, for the river crossing; (4) at Partick, to join the Govan tunnels and for the tunnels from Hozier Street to Dumbarton Road; (5) at Copland Road, for the tunnels from there to Whitefield Road, Govan; and (6) at Shields Road, for the tunnels under the terminus railway. All kinds of soft material were met with, but for convenience the author has divided them into the two categories of sand and mud.

The tunnels through sand, in the ordinary meaning of the word, are those in Buchanan Street, under the river at the Custom House Quay, and in Govan, and the author thinks he can best deal with the subject by describing in detail the operations from St. Enoch.

The first thing to do was to get a base from which to start away the tunnels, and this was got from the station, which was constructed on the Kent Road principle. The work of getting down to the bottom for the invert (31 feet deep) was long and tedious. Water was met with at a depth of 15 feet, and great difficulty was experienced in getting the sand drained below that, owing to its very fine nature at this place. The trench, which was driven up the centre of the covered way, could only be lowered a few inches in a week.

Towards the north of the shaft, which was put down rather to the south of the station, the sand was more open, and the excavation was lowered about 6 feet a month; but on the south side the sand was much finer, and it took six months to lower the excavation 12 feet. The total time occupied with the excavation below the arch and putting in the concrete invert was seven months.

When the station was completed four shields were erected below, two for working up Buchanan Street and two for working towards the river. About 12 feet of tunnel had then to be constructed in each case without air, to admit of the locks being built in position. These short lengths were difficult to construct, as the shields showed a strong tendency to sink, the bottom being very soft and wet. Of course in air there is no danger of this.

While this work was proceeding below, the installation for air pressure was being got ready on the surface. At first one double Slee engine, same as before described, supplied with steam by two

Lancashire boilers 26 feet by 7 feet, was put down, but this was found to be only sufficient for two tunnels, and an Anderston Foundry engine, also same as before described, and a third boiler were added. The whole installation, therefore, for supplying the four tunnels with air consisted as follows—although, as a matter of fact, the whole four were going at once only till the south-going tunnels had reached 370 feet from the station, and only one tunnel was carried across the river at a time, the second being stopped at the quay wall, and by the time it was started the Buchanan Street tunnels were finished:—

PLANT.—Two duplex compressors, one by Slee, 26-inch air cylinder, 24-inch steam cylinder, and 36-inch stroke, working up to 60 revolutions per minute; and one by Anderston Foundry Co., 30-inch air cylinder, 24-inch steam cylinder, and 24-inch stroke, working up to 75 revolutions per minute, and capable of compressing the air up to 25 lbs.

Three Lancashire mild steel boilers 26 feet by 7 feet, by Penman, 80 lbs. pressure, provided with M'Vicar's mechanical stokers.

Two egg-end air receivers about 24 feet by 5 feet, connected with the engines by 9-inch steel galvanised piping. The receivers were absolutely necessary for steadying the air going into the tunnels, and for the purpose of cooling it water was allowed to run over the receivers. Even with that the air was sometimes almost unbearably hot just inside the locks. From the receivers 9-inch piping conveyed the air to the tunnels. There were thus four separate systems of piping, and the amount of air passing into each tunnel was regulated by a reducing valve. These reducing valves, of course, could not regulate the pressure, but after being set they maintained the tunnels at the pressure they were under when the valves were set.

Two grouting engines, by Anderston Foundry Co, 6-inch steam and air cylinders and 6-inch stroke, the air being carried to the grouting pans by 1½-inch malleable piping. From these pans the grout is forced into the space behind the iron lining by a pressure of about 40 lbs. per square inch.

The boilers were fed by two Worthington feed pumps, and the exhaust steam was carried through a 7 feet by 7 feet by 6 feet feed-water tank into the stalk. The stokers were operated by a small 4-inch engine.

The tunnelling up Buchanan Street (494 yards of double tunnel) was done from one position of the locks, but when the south-going tunnels had advanced 370 feet additional locks were built in at the faces, and from this position the tunnels across the river and on the south side (573 yards) were completed.

The air locks were 13 feet 9 inches long by 5 feet 9 inches diameter of ⅜-inch steel. They were built into the tunnels by brick in cement walls 6 feet thick, which were found amply sufficient to withstand the highest pressure—30 lbs. (See Fig. 10, Plate VIII.)

This drawing shows the number of pipes which have to be carried through the brick bulkhead for the various purposes inside the tunnel, viz, the air supply pipe, usually 9 inches in diameter; the grouting air pipe, 1½-inch diameter (in duplicate); the water supply pipe for the grout, also 1½-inch in diameter (in duplicate); the water outlet pipe, 4 inches in diameter, through which the water that collects in the finished tunnel is blown; the pipe for passing in the rails, 6 inches in diameter; and the air gauge pipe, ½-inch diameter. Besides the pipes, there are electric wires for signalling through the bulkhead.

The whole installation in connection with the air pressure, and including the pit-head frame, winding engine, pumps for water, hutches, trolleys, tools, etc., cost well on for £7500. This figure includes the supplying and building in of four air locks, building the boilers, erecting engine-house and chimney, and all kindred work.

It is almost impossible to estimate beforehand the amount of power required in an air installation. As already stated, there was first of all put down at St. Enoch one double Slee engine. This was found only to be able for the two Buchanan Street tunnels, which were started in April, 1892, and went on continuously. One of the south-going tunnels was tried, but was only able to advance 186 feet. The Anderston Foundry engine was then ordered, and this was started in January, 1893, when the whole four tunnels were set agoing. The air supply began to show signs of running short in April, 1893, when the two south tunnels had advanced 370 feet. New locks were built in at the face of these tunnels, and the whole four went ahead once more in August, 1893, till the south tunnels reach the quay wall, and then the west tunnel pushed on alone with results which will be afterwards described.

The tunnelling, where not under the river, was done by taking out a length for 6 rings, that is 9 feet, a heading always being carried 9 feet ahead. This length in front of the shield was close poled from the top to near the bottom, and sometimes right round, with 3-inch poling, which was all carefully grouted to prevent the escape of air. The face also of each length was close poled and grouted. This formed an almost air-tight barrel 12 feet 3 inches in diameter, through which the shield was propelled and the iron built in. When the 6 rings had been installed, the annular space of about 1½-inch which had been left all round was then grouted. The method of timbering is shown in Fig. 11 (Plate VIII.), which, the author thinks, explains itself.

It may be asked of what benefit was the shield here? The answer is—very little. It no doubt enables the iron rings to be built in their places with facility, and the end of the poling is supported on the outside of the cutting edge, but this could quite as well be supported on the last ring of iron. Beyond these certainly very minor details the author has failed to see any benefit in the shield in this method of tunnelling. It was not even a safeguard, because the miners had always a couple of rakers through the door supporting the face of the excavation, so that the door couldn't have been shut in an emergency.

Two of the contractors at other parts of the work, after starting away with shields, took them out as being in the way, and finished their tunnels without them. A third contractor finished 300 yards of iron tunnel under air without introducing a shield at all. When working in sand you have to introduce poling, and when that is done the use for the shield vanishes. Also, when the air stiffens the material so that it will stand without support, the tunnelling can quite well be done without the shield.

The only difficulties that were experienced at St. Enoch was when the first or westmost tunnel reached the riverside, on September 20, 1893, and then they certainly became serious enough, for before the tunnel had advanced 80 feet into the river the bed had blown up no less than ten times. The worst burst occurred on February 24, 1894, when the whole timbering was blown up into the river and floated away, and a hole about 24 feet square and 16 feet deep formed. It was after this that the original contractor retired from the job, which was then taken in hand by Mr George Talbot and successfully completed. The first 80 feet of the westmost tunnel took 5 months to construct, and a part had to be done over again, while the eastmost tunnel was carried right across the river (410 feet) in 3½ months, and the author thinks it might be interesting to mention the circumstances which enabled this to be done.

In the first place the air pressure must be regulated by the state of the tide in the river, and the roof of the excavation must be made so as to stand the additional pressure required for drying the bottom. Theoretically, the pressure of air required to expel the water is given by the formula—

$$\text{Pressure in atmospheres} = \frac{\text{depth in feet}}{31{\cdot}4}.$$

This, of course, is above the ordinary atmospheric pressure. The depth under high water at the place we are considering varies from 47 feet to 55 feet to formation, therefore by the formula the greatest pressure required should be 26¼ lbs. on the square inch. As a matter of fact, the highest pressure required was 23 lbs., so that the intervening sand, which at this place was about 25 feet, caused very little diminution from the theoretical pressure. At the Harbour Tunnel, at a depth of 63 feet below high water and with only 15 feet of sand intervening, the highest pressure required to dry the bottom was only 18 lbs. per square inch. In many of the lengths it was a good deal less than this, sometimes as low as 8 lbs. This would seem to show that a slight variation in the material has considerable effect on the pressure required to dry it. It has been asserted that, in the case of the Harbour Tunnel, the pumping going on in the two shafts at the side of the river had something to do with the low pressure required, but the author hardly sees how this could be, as this pumping did not affect the head of water above the tunnels in the river.

The importance of having the roof thoroughly secured when taking out the bottom can easily be understood. In the case we are considering the height of the excavation was 12 feet 3 inches inside the poling. Theoretically, this means a difference of 5·8 lbs. per square inch between the top and bottom, or, in other words, there is an upward pressure of 835 lbs. per square foot in excess of the downward pressure of the water. The additional weight required to hold down the top must be made up by material on the top, or if the material be insufficient, the roof of the tunnel must be held down by appliances used in the tunnel itself.

The weight of a cubic foot of sand in water may be taken at 40 lbs., so that to balance the upward pressure there would be required about 21 feet of material. This, of course, is the theoretical view of the question. The actual pressure required to dry the bottom being less than the theoretical, and it being found that the difference between the pressures required for the top and bottom did not exceed 5 lbs., of course the actual amount of cover required to hold down the top will be considerably less than stated. It will be something greater than 14 feet and less than 21 feet. Even then, of course, the pressure requires to be regulated with the tide. In the harbour of Glasgow there is a tide of 11 feet. This means a difference of pressure equal to 5¼ lbs. between high and low water, so that if the high pressure were kept up with a falling tide you would blow up the river bed even with 21 feet of cover.

When the Harbour Tunnel was constructing the state of matters there did not at all bear out the theoretical view of the question. The height of the excavation was 17 feet 3 inches, equal to a difference of pressure between the top and bottom of about 7¾ lbs. per sq.

inch or 1108 lbs. per square foot. This would require a height of 30 feet of sand to balance it, while, as a matter of fact, there were only 15 feet, and never any sign of a blow up. The fact of the material here being much more open than at St. Enoch may have had some bearing on the question.

At the Custom House Quay the cover is 14 feet, gradually increasing towards the south side of the river to 29 feet. No additional cover could be put on, as the Clyde Trustees insisted on a depth of 10 feet at low water, but all the holes were filled with clay. It was necessary therefore to secure the roof very carefully, and this was attempted at first by fastening all the poling boards together by timber dogs and grouting well behind them. Several lengths were got in in this way, but when Mr Talbot took over the contract he inserted a ½-inch iron plate under the poling of the arch. This was bent round to the curve of the arch over a rib resting on a 10-inch sill put across the centre of the face and securely fastened to this sill. This is the method which enabled the work to be done so successfully at the Harbour Tunnel, where, however, the roof was kept down without the use of the iron plate, the poling being well held together and grouted.

Another necessity in tunnelling under the aforesaid conditions is to take the shortest possible length at a time. For a while under the river where there was the least cover, lengths for only one ring, or 18 inches, were taken, and the face in each case was as securely timbered and grouted as for a 6 ring length. The heading was also abolished. One ring in 24 hours was easily done, and then when the cover began to increase two ring lengths were taken, and these lengths could also be finished in 24 hours.

Another condition quite as important, and which has considerable effect on the success of the work, is to keep it going constantly. At first the work was carried on with two shifts in the 24 hours. The tunnels were deserted at meal hours, and no work was done from Saturday at two till Sunday at midnight, a period of 32 hours. The second contractor at once altered this to the three shift system of eight hours each, with no stopping on Saturdays or Sundays, and this was an immense improvement. Not only was more work got out of the men, but the tunnels were never deserted, and any defects in the timbering had no time to develop.

The average rate at which this kind of tunnel, with extensive poling, could be constructed was 100 feet per month. The greatest length done in any one month was, the author thinks, 124 feet in Buchanan Street.

The conditions at Govan were practically the same as from St. Enoch to the Custom House Quay, but at Partick liquid mud had to be dealt with, and so many curious ideas are held regarding the conditions necessary for successful tunnelling through this material that the author hopes he may be excused for going into the subject rather in detail.

The material here consists of extremely fine particles of matter forming a silt almost impervious to water, but which, when thoroughly dried, presents the appearance of flour. There is no loam or clay in it, as it does not crack in drying, but to dry it requires a considerably higher pressure than in the case of ordinary sand, owing to the tenacity with which it holds on to the water. The greatest depth of this material on the top of the tunnels is 57 feet, and the pressure required at this place was 30 lbs., which is just about as high as men can work in with safety. In fact, even at this pressure there were a great many cases of illness, and it was sometimes curious and sad to see the men, when they should have been at home in their beds, coming back to the tunnels to get under the air in order to get relief from their pain.

A great many aspersions have been cast on the design adopted for these tunnels, and more than anything else, on the fillet which projects $\frac{3}{16}$-inch all round the back of the segments (see Fig. 7, Plate VII.), the joints being filled with wood. The author may say that there is a diversity of opinion among engineers as to what is the best form of joint, some maintaining that the horizontal joint should be iron to iron, others that a thin layer of wood should be interposed, and so on. The following examples will bear out this. In the City and South London Tunnels, internal diameter 10 feet 2 inches, the horizontal joints have flat, unplaned faces with ¼-inch pine packing between them, leaving ¾-inch at the inside for filling with Roman cement. The vertical joints have fillets at the back. The Hudson River Tunnel, 18 feet 2 inches internal diameter, has joints with flat faces and wooden packing. In the St. Clair Tunnel, 19 feet 10 inches internal diameter, the segments are 2 inches thick with flanges 7 inches deep. These are planed at the joints and have hard wood packing between. The Mound Tunnels, Edinburgh, have their horizontal and vertical joints planed and made iron to iron, but here we must note that there is no water in the strata. The segments of the Blackwall Tunnel, which is 25 feet internal diameter, are 2 inches thick, with a depth of flange of 12 inches, and the joints are planed and iron to iron, except 2 inches in front, which is filled with rust. The Waterloo and City Tunnels, London, 12 feet internal diameter, have their longitudinal joints iron to iron. The Harbour Tunnel joint is similar to that of the Subway.

Including the Subway, these are eight examples of joints, and considering only the horizontal joints, we find that three have the flanges iron to iron, three have flat faces with wood packing between, and two have flat faces with a fillet at the back and wood packing between. Various engineers have objected to this fillet at the springing joint, as forming a pivot or hinge for the plates to turn on, and that it must therefore be an element of weakness in the tunnel. The fallacy of this view will be at once seen when it is remembered that before any turning on this so-called pivot can take place the tunnel must begin to widen, or go out at the sides and come down at the top. This, the author need hardly say, cannot possibly happen if the annular space round the iron be timeously grouted or filled up. This must hold good in any kind of material, and we are therefore brought face to face with the proposition that the stability of an iron tunnel does not in the least depend on the form of joint. No tunnel, however strong the iron and whatever be the form of joint, will stand unless there be practical equality of pressure all round, and it is to secure this condition that the space behind the iron must be filled up before the surrounding material has time to move. If the material be very soft, a sufficiently strong air pressure must be kept up to hold it back from closing in on the iron before grouting is done. So impressed are the most experienced contractors, who have executed work of this kind, with the importance of this that they close poll the excavation from top to bottom to make perfectly sure that the material will not close on the iron.

This is well exemplified in the case of the Grand Trunk Tunnel at Saguinay, which was constructed through yellow, soapy clay. It was impervious to water, and they started driving the tunnel without air. What was the result? The inevitable space left by the shield was at once filled up by the clay closing in, and therefore little or no grout could be got in. This led to deformation of the tunnel and cracking of plates, and then air was put on, not for the purpose of expelling the water, for there was none, but solely for the purpose of holding back the soapy clay till the annular space could be grouted.

An eminent London engineer has expressed the opinion that in soft mud there is more pressure upward on the bottom of the tunnel than there is downward on the top, or in other words, that the tunnel is lighter than its own displacement of water. The argument from this is that the tunnel, since it does not move upwards, has a tendency to flatten, and that this is only kept from taking place by very strong horizontal joints. This view may be theoretically correct, but even in semi-liquid material the pressure must be practically equal all round or nothing could keep the tunnel from moving.

In the Hudson Tunnel sufficient air pressure could not be used to dry the mud, as the miners could not keep their health in the high pressure required. The result was that the stuff closed up on the iron the moment the shield was moved forward, and no grout could be got in. The author is not aware whether timbering was used or not. At any rate, inequality of pressure was brought to bear on the iron, which at places became distorted even although there was no fillet at the back of the horizontal joints to act as a hinge. Another evil here was a very heavy shield, which was quite out of place in material that could not be perfectly dried. The author understands that great difficulty was experienced in keeping it from sinking, and that at one time it was actually descending on a gradient of 1 in 10.

The distortion of parts of this tunnel seems to bear out the view that the form of joint is of infinitely less importance than the grouting as regards the stability of the tunnel.

Sir Benjamin Baker has given, in the author's opinion, the clearest enunciation of this, and he cannot do better than repeat his words:—"If the iron work (referring to the Subway) had been cast in complete rings and unsupported at the sides it would only bear an unequally distributed pressure of 2 tons per square foot, but with segments bolted together, even were the joints iron to iron, this would be reduced to a quarter of that, or 10 cwt. This is altogether insufficient for the work it has to do, and it is therefore absolutely necessary that it should be supported as an arch by an abutment. Every brick tunnel is in the same condition, which, every one knows, should be built up solidly against the earth. A brick tunnel has no girder strength, and depends entirely on the firm bearing against the earth, and it is equally essential that an iron tunnel, even although it has girder strength to a certain extent, should be supported by the ground at the side so as to resist the thrust of the earth. The critical time for testing the strength and the joints is when the pressure of the soil first comes upon the tunnel."

As giving some idea of the effect of unequal pressure, the author may mention that in Partick, when the air pressure was not sufficient to dry the material so as to have the grouting properly done, the pressure coming down on the top when the sides were not held was sufficient to tear out the horizontal flanges 1 inch thick which were held across the tunnel by union screws. This distortion has been attributed to the fillet at the back of the plates, but this cannot be the case, as the same thing happened at the Hudson Tunnel where there is no fillet; and, in point of fact, when the distorted parts of the Partick tunnels were renewed by the second contractor, none of the fillets were found to be touching.

With the outside diameter of the tunnel 12 feet, the inside diameter of the shield is 12 feet 1½-inch, so as to allow of the plates being built in with facility. The skin of the shield is ½-inch thick, so that an annular space of 1¼-inch is left round the iron when the shield is shoved forward. If the air pressure is not kept up till this space is grouted the material will close down on the top and force out the sides, so that to start with the tunnel would be 2½-inches wide. The grout used in all the Glasgow tunnels was Arden lime.

We now come to one of the most important points to be considered in designing a joint for a tunnel through water-bearing strata, viz., how to make it water tight. A joint simply with wood packing is not a finished joint. It can be made water tight in either of two ways, by wedging up with hard-wood wedges, or calking the front with iron rust, cement, or other material.

In the Harbour Tunnel it was originally intended that the joints should be wedged with hard wood, but at the time a good deal was being said about the rust joint, and eventually the wood packing was cut out for a space of 1½-inch in depth, which was filled with a paste consisting of iron turnings and sal-ammoniac. (See Fig. 12, Plate VIII.) This was not quite successful in keeping out the water, and in the Subway recourse was had to the older method of wedging up the joints. Provision was made for this from the very first by carrying out the packing flush with the inside of the flanges. This was put in ½-inch thick, and was split with oak wedges 3⅛-inches long by 1⅞-inch wide by ⅜-inch thick (See Fig. 13, Plate VIII.) The flanges are protected by brackets for the purpose of enabling them to withstand the pressure due to the driving in of the wedges. Of course this wedging cannot be done till the tunnelling is completed, but it is an operation that should be finished before the air pressure is taken off. The necessity for this was well seen at Partick, where the original contractor took the air off part of the tunnels before wedging, the result being that at places where insufficient grout had been got in the mud squeezed through the joints, and at once the tunnels began to show signs of giving way. A considerable length of the tunnels here had to be taken down and rebuilt by an experienced contractor under a higher air pressure than the original contractor thought necessary.

The oak wedging makes a beautifully tight joint, much superior to the rusted joint, the advantage being that you can at once close up any leakage by driving in additional wedges. The author does not think there is a single drip of water in either tunnel from St. Enoch on the north side of the river to Coburg Street on the south. Of course all the bolts have to be grumetted, and this is an operation which is also usually done when the tunnelling has been finished. The wedging cost about 1s 5d per yard of joint or £2 6s per yard of tunnel in air, or out of air 1s and £1 10s respectively, against 2s 2d for the rusting per yard of joint. This latter price is in air of course, as the rusting cannot be done without it.

The fillet at the back of the segment is a necessary part of the oaked-wedged joint. Without this the driving of the wedges would be apt to force back the wood packing. This form of joint is a very old one, having been extensively adopted in the tubbing of colliery shafts, the great merit being of course that the joints can be made perfectly water tight with little trouble.

The only other point which remains to be spoken about in this method of tunnelling is the quantity of iron required in the segments. To get at this, each segment is considered as held at both ends and treated as a girder, and it will therefore be seen that the strength of the tunnel depends more on the depth of the flanges than on the thickness of iron in the body of the plate. In the Subway segments a very large margin of safety is given. The load that the segments will stand, treated as girders, is 7 tons per square foot, equal to a column of earth 160 feet high, while the greatest depth of material on any of the tunnels is only some 60 feet. Considerable attention has been drawn to this subject lately, and several engineers did not hesitate to hazard the opinion that certain plates were too light, without having made any calculations whatever to verify their statements, basing their opinion merely on the fact that some of these plates were broken under certain circumstances, but plates from the same mould were installed at the same place by a different contractor, and not a single one broke. The author will be delighted to give any member facilities for seeing the tunnel as now finished where this was done.

In many cases where it is possible to do the tunnelling without air it might be cheaper to employ it, as, if the material be anyway wet or moist, it enables the work to go on with greater facility, and experience has shown that it may also be speedier. For instance, the iron tunnels from Copland Road to Whitefield Road in Govan are through material (soft clay and sand) in which it would have been possible to tunnel without air, being at no great depth. But it would have been a wet piece of work, necessitating extensive timbering. With about 6 or 7 lbs. of air, however, the whole aspect was changed, and the contractor was enabled to go ahead at the rate of 150 to 200 feet per month, having actually done in one month 258 feet; while the greatest speed in good brick clay without air, from Coburg Street, was 195 feet in one month. In the Copland Road case the small pressure dried the material sufficiently to enable the contractor to dispense almost entirely with timber. It may be asked why, in all cases of sand or mud dried by air pressure, the contractor could not work without timber by taking short lengths, say for one or two rings of iron ? The answer, of course, is that all kinds of material will not stand even when dried, and that the face and roof would require to be timbered no matter how short the length. When this has to be done it is found better to take longer lengths, and then, for the purpose of keeping the sides secure and also for keeping in the air, it becomes necessary to timber right round or nearly so. Under the river the timbering was continuous round the bottom, and here also, as we have already stated, there was no heading.

In conclusion, the author may mention one or two points in connection with the air pressure that have been noticed as the work went on. At St. Enoch, in clean sand, the highest pressure required was 23 lbs. per square inch. At Partick, in mud, with a less head of water than at St. Enoch, the highest pressure was about 32 lbs., or slightly over two atmospheres. The men worked 8-hour shifts, and were about 3½ hours in the air at a time. The author does not think they could have worked for nearly that length of time in a higher pressure. As it was, towards the end of the work there were signs of serious trouble. Two men died, one of them the foreman miner at Partick, who had been on the work from the first; he succumbed almost immediately after leaving the tunnel. Cases of partial paralysis were numerous, and sometimes many of the men were off in the hospital. The engineers' inspector suffered severely, being in great pain and unable to walk for many weeks.

The author has added to the drawings a sketch (see Fig. 15, Plate VIII.) showing the route of the Subway, which may be interesting as showing the curves to be traversed by the cable, and he has also added a cross section (see Fig. 14, Plate VIII.) showing the lining of the rock tunnels. Only at very few points was the rock hard enough to stand being shorn, and the shale or "blaes," of which a large amount was met with, is friable and does not weather well. On this account almost all the rock tunnels have been lined, and this has been done with concrete—a method initiated by Mr Robert M'Alpine, and which, when well done, makes an admirable lining.

The discussion on this and the previous paper (on "Cast-Iron Segments for Railway and other Tunnels," by Mr Evelyn G. Carey) was taken conjointly on 25th February, 1896.

Mr CHARLES P. HOGG said that these two papers taken together brought very fully before them the most recent development of the application of cast-iron to the lining of tunnels. In Mr Carey's paper there was some difference in the tests to which the cast-iron was to be subjected, due, of course, to the specifications of different engineers. There was considerable similarity in all cases with regard to the transverse strength, but on p. 123 he noticed that in the case of the Blackwall segments the cast-iron was required to be of a tensile strength of 8 tons per square inch, while for a bar 2 inches deep and 1 inch thick the transverse strength was 28 cwts. on bearings 3 feet apart. He should like to ask Mr Carey whether he had had any difficulty in getting cast-iron of that tensile strength? It seemed to him on the whole rather high, and particularly so having regard to the very moderate transverse strength required. Mr Carey dealt with the much-vexed question as to the best form of joint, and he gave particulars of all the well-known examples in iron tunnels, but as Mr Simpson also dealt with the joint question, he preferred to postpone making any remarks on that part of the paper till he discussed Mr Simpson's paper. Mr Simpson's paper was an exceedingly interesting one, and brought before the Institution very valuable information, which could only be obtained from an engineer of his great experience in tunnelling. In the general description of the Subway he noticed that Mr Simpson said nothing about the gauge of the Subway. He understood that when the Subway was first authorised it was to be of the standard gauge of 4 feet 8½ inches, but since then they obtained an Act reducing the dimensions of the gauge. He was not sure whether it was 3 feet 6 inches, but to make the paper complete Mr Simpson might mention what the gauge was. As regards the speed, he had no doubt that they would be able to maintain an average speed of 12 miles per hour, and that would add greatly to the convenience of rapid transit throughout the city. Some five years ago, after the opening of the City and South London Railway (a subway worked by electric locomotives) he made a trial trip during the day with Mr Simpson's father, and they found that they were able to go at the rate of about 13 miles per hour, but that was not at the busiest time of the day. The distance from Stockwell to the Monument was about 3 miles, and that distance was covered in something under 14 minutes. There were four intermediate stations, and the average time for stoppage at each of the stations was from 13 to 14 seconds only. That was very good work. In the busy time of the day he supposed that the speed would scarcely be so great and the stoppages would be rather longer. He noticed that on p. 132 of Mr Simpson's paper there was a very good idea as regards the gradients at the stations; that was introducing a gradient of 1 in 20 up to assist the train in coming to rest, and a gradient of 1 in 20 down to assist the train in departing. He thought that was a good idea, and it might be more largely adopted on suburban railways. Then, on page 136, Mr Simpson referred to the necessary pressure to dry the bottom of the excavation at the Govan station; he would like to know how much it was in pounds. He gathered from Mr Simpson's remarks throughout the paper, especially his remarks on pp. 137 and 142, that he had very little faith in the use of the shield. He had had, through the courtesy of Messrs Simpson and Wilson, an opportunity of visiting the Harbour Tunnel when it was in course of construction, and he must say that at the time of his visit there was really very little use for the shield. They were working 15 feet under the bed of the river in very good sand, taking a 9 feet length and close poling right round. The timbering was very well done, almost as close as the staves of a barrel, and the shield was really only useful for getting in the cast-iron segments, and they might have been placed very well without it. At the same time, he thought that Mr Simpson rather unduly undervalued the advantage of a shield, and that probably if he had to execute larger tunnels, such as the Blackwall Tunnel, he would not venture to execute them without the use of a shield. There was one thing he should like to emphasise, and that was the remark as to the importance of continuous working. In all excavations, especially in tunnelling work, it was of the greatest importance to secure an open face as soon as possible to prevent material getting on the move. Once it got on the move it was exceedingly difficult to prevent a crush. On page 138 Mr Simpson referred to the ordinary brick tunnel that was carried under the Cook Street Depôt, and he said there that even with these brick tunnels there was no reason why the work should not be done with very little subsidence indeed if short lengths were taken and the brick work proceeded with at once. He did not know how the work was done, but he remembered seeing the surface of Cook Street Depôt, and he was bound to say that there was subsidence exceeding a foot, probably if he put it at 18 inches he would not be very much over the mark. Mr Simpson had noted in several places throughout the paper what he himself had observed in the course of his practice in sinking bridge foundations under air pressure, and that was that the pressure necessary to expel, or rather to keep back, the water was not always so great as the theoretical or hydrostatic pressure. The reason of this he took to be the friction of the water in passing through the sand, which in these cases was assisting the pressure and so reducing it. In some cases he had noted that the pressure was only about 70 per cent. of the theoretical or hydrostatic pressure, due to the head of water in the river, and he found some figures quite corroborative of that in Mr Simpson's paper. But whatever might be the reason, he quite agreed with him that in the case of the Harbour Tunnel it could not have been due to the pumping that was going on in the shafts on either side of the river. At the time of his visit to the Harbour Tunnel they had 15 feet of cover measuring to the river bed; he forgot how many feet of water, but probably from the bottom of the tunnel to high-water level would be upwards of 60 feet, and with an air pressure of 9 or 10 lbs. per square inch the material was perfectly dry—in fact, the men were working as if they were in a sand pit. The formula given for air pressure might be more conveniently expressed in lbs. per square inch. Mr Simpson had given a very full description of the difficulties which had to be overcome at the Custom House Quay, under the Clyde, and all engineers were very much indebted to him for putting this on record. On p. 146 Mr Simpson dealt with the conditions necessary for successful tunnelling in mud, and he hoped to be excused for going into the subject rather in detail, but he thought that Mr Simpson had scarcely gone enough into detail in the matter, at least he might have given them a good deal more, and they would have gladly excused him. Besides, he had rather mixed up the subject with the form of joint. He ventured to think it would have been better if he had dealt with the mud by itself, and with the joint later on. On page 149 Mr Simpson referred to the case at Partick where, on taking out the broken segments, the fillets were found not to be touching. He believed that at the sides they would not be touching, but he would be surprised if the fillets were not touching at the crown of the tunnel. He was very much inclined to agree with the eminent engineer whom Mr Simpson quoted. In a recent discussion on a paper which was read in that room before the Glasgow Association of Students of the Institution of Civil Engineers, Mr Harrison had shown very clearly that the form of equilibrium for iron tunnels in liquid mud was not a true circle, but rather flattened at the top, and he thought that was what one would expect to be the shape that it would naturally take. As he had already said, Mr Simpson had dealt very fully with the joint question, and he thought he had made out a very good defence for the Subway joint as he might call it. There was a great deal to recommend it. As regards the joint of the Mound Tunnel, where it was iron to iron and planed throughout, that might be taken out of the category altogether, because the Mound Tunnel was through forced material. It was quite true that it was made under a very valuable building, but the work no way compared with that which had to be done in the Harbour Tunnel or in the Subway. Besides, it was a perfectly straight tunnel, and so there was no reason why the joint should not be planed throughout. The form of joint adopted at the Harbour Tunnel and in the Subway Tunnels with the fillets at the back, and the soft wood packing when combined with the wedging was, he thought, as complete a form of joint as there needed to be, and, besides, there was a great facility in changing the direction either horizontally or vertically. Mr Simpson had given the cost of the air installation and also the cost of the wedging, and the comparison of cost in two different forms of tunnelling, but if he would be at the trouble to add a few costs for representative sections and different classes of work it would add very greatly to the value of his paper, which he (Mr Hogg) considered to be a very important contribution to the literature on the subject.

Mr GEORGE C. THOMSON said that there were one or two points that he had been struck with in reading Mr Carey's paper. With regard to the District Subway, there was the patent moulding machine, Fig. 1, Plate III. On page 117, after the description of the working, he said that each machine was capable of turning out 1½ rings or 13½ segments per hour, being at the rate of one segment per 4½ minutes, this speed being maintained from 6 a.m. to 5-30 p.m., or allowing for meals, for 9½ hours. That ran out to something like 120 per day. On p. 115 it was stated that the whole of the segments were moulded in the patent hydraulic machines, while in another part of the paper it was stated that the tops of the moulds were made by hand. It would require a very large number of people to keep up with that speed on the machine. He thought that there must be something wrong there when they did it so quickly, because on page 116 Mr Carey stated that the ends of the segments were inclined inwards, and therefore they could not draw them, and they had to take them back to work with the hand, and of course the whole thing would be required to be made up afterwards. That speed seemed very high. Then, on pages 122 and 123 there was another machine shown on Plate III., Fig. 2. In that case it was also stated that all the work in these segments was done by the machine, whereas only the bottom half of the mould was so made, and the other half was wrought by hand. He would like to know how many of these No. 2 machines there were. Further, on p. 122 there were some statements as to the accuracy of the work, and he spoke of some thousands of segments selected at random that they could put together without experiencing any difficulty with the bolting together of these segments. It seemed to him rather strange when they took so much hand work in connection with machinery that there should be no cases of a bolt not coming in fair. That would lead him to suppose that the holes must be very big or the bolts small. Then, with regard to the milling machine, he would like to have a little more information as to the time that it would take to do the edges of one of the rings.

Mr A. S. Biggart said he had read the two papers with great interest. There was a good deal of novelty about Mr Simpson's paper, and it had that charm about it which was due to the successful overcoming of many difficulties. On page 135 Mr Simpson said, "After the arch had been thrown, a short length of covered way (about 20 feet) was constructed at the end. This had to be done in the ordinary way, and here the locks were built. The air, of course, escaped with great rapidity through the sand at the face and through the concrete arch, but a pressure of from 2 to 3 lbs. was got, and this dried the bottom sufficiently to enable the concrete invert to be put in. As the work progressed, however, and a greater area of concrete arch was exposed, it became more and more difficult to maintain the requisite air pressure." He would like to ask Mr Simpson if any means were taken to prevent the air escaping through the concrete, such as washing or rendering it with cement or any of those well known methods whereby porosity might be overcome to a great extent. He remembered a case recently where his firm had a cylinder that was sunk with a brick lining and without any idea of putting it under air pressure at a later date. Air pressure had, however, to be adopted, and after the air was put in they rendered the surface with cement wash several times, with the result that the composite brick material was made air-tight so that it took hours to reduce the pressure from 35 pounds to a pound or two less even without the engine at work. In this case if there had been something of that kind adopted it might have saved a good deal of shifting and expense. Then on page 146 Mr Simpson said, "The greatest depth of this material on the top of the tunnels is 57 feet, and the pressure required at this place was 30 lbs., which is just about as high as men can work in with safety." He supposed that Mr Simpson spoke in a comparative sense; they were all aware that men had worked for a long time on end in much higher pressures than 32 pounds. In America perhaps the highest pressure had been 42 lbs. per square inch, and this pressure was used in connection with the St. Louis Bridge. In connection with his own firm they had had up to 38 lbs. per square inch. After all it meant that when working over 30 lbs. per square inch they must take very special precautions for the safety of the men. For instance, after 25 to 30 lbs. had been reached it was desirable that they should reduce the working hours as they increased the pressure. It was also desirable that they should largely extend the time during which the men were passing from the higher to the lower pressure. As to the causes of serious accident in connection with working under high air pressures, he thought that was the one that was responsible for the largest amount of trouble, viz., that of passing from a high pressure to a low pressure too quickly. If care was taken and plenty of time allowed after the men had come out into the open air for rest, and something hot, such as coffee, was freely given, and if after this the men would leisurely go away, they would find that there would be very few accidents at 35 lbs., or a good deal higher, per square inch. In speaking of high pressure they were probably not aware that within almost earshot of where they were the highest pressure that had been wrought, he believed, in the sinking of cylinders was being applied to the sinking of the caissons of the Broomielaw Bridge at the present time. The pressure there had been as high as 45 lbs. per square inch. The cylinders had been carried much deeper than anticipated, and the strata was such that it was of a water-bearing nature, and it thus required the full pressure due to the head of water. He thought that they had stepped over the limit at 45 lbs., and certainly it was desirable to avoid such high pressures. This could be done, although not in every strata, and possibly this was one of the cases where it could not be done. They (his firm) were sinking some time ago a cylinder to the depth of 130 feet under the surface. They knew that this depth, if the pressure was that due to the head of water, would be far beyond anything that Mr Simpson had experienced, but they took means to avoid such a high pressure by simply throwing out the water from the bottom as it collected. The strata were such that it could not collect so rapidly as they were able to throw it out, and while the pressure ought to have been 45 to 50 lbs. per square inch, they were able to get it down to 25 or 30 lbs. They were able to throw water to a height of 100 feet with an air pressure of something like 15 lbs. to the square inch. He mentioned this in passing, as it might be of interest to some of them, and as showing how in some cases the problem of carrying cylinders to a greater depth with air pressure than under ordinary circumstances was possible.

Mr Robert Simpson said Mr Carey had given several very conclusive reasons why an iron tunnel was preferable to a brick one, and no doubt these reasons would appeal to most of them as sound; but, at the same time, he would like to say that he did not think an iron tunnel would ever be adopted in place of a brick tunnel where the material was such that it was possible to build a brick tunnel. The chief reason for this, of course, was the high cost of iron in comparison with brick. Mr Carey had mentioned the Subway, which consists of tunnels 11 feet in diameter. The amount of excavation saved by using iron instead of brick in a tunnel of that diameter would only be about 5 cubic yards per lineal yard, so that the saving of the excavation would be a very small inducement to use iron instead of brick. He had had numerous opportunities of comparing the relative cost of brick and iron tunnels, both on the Subway and in the Harbour Tunnel, and with 11 feet diameter the cost of an iron tunnel would be about £10 a yard more than the cost of a brick tunnel. Mr Carey also gave a very accurate description of the segments both on the Subway and the Harbour Tunnel, and described these as having a chipping edge on the outside of the plate. With all due deference to Mr Carey he would like to offer a mild objection to the term "chipping edge." In the case of those plates he had mentioned, the little fillet at the back of the plate was not really a chipping edge, which was a projection round the outside of a plate for the purpose of being chipped or planed, and there was no such intention in the case of the Subway plates. The fillet there was for the purpose of keeping the wood packing from being driven back by the wedging. Chipping edges were mostly used in tanks where the iron came together. No doubt some of the Subway plates were planed, but that was in the horizontal joints, and these were only used under the Caledonian Railway. That was a condition imposed upon them by the engineers of the Caledonian Railway Company by Act of Parliament; otherwise it would not have been done. At the end of Mr Carey's paper he quoted Sir Benjamin Baker, on page 127, as follows:—"Having reference to the small cost of planing, I should, if a contractor, prefer to have planed joints, even if I had to pay the expense myself, because the job as a whole would probably cost less; but I am of opinion that an equally sound and strong job can be made on either system." He thought Mr Carey seemed to endorse that opinion. As regards planing of joints, he did not think it was of much use in those segments. Where the planing might be of advantage was in iron to iron joints, but he did not think that was a proper joint in water-bearing strata. The only case he was acquainted with of a finished tunnel with this joint was the Mound tunnel in Edinbuurgh, where there was no water in the strata, but seeing that Mr Carey seemed to support Sir Benjamin Baker that the work would cost less, he would like if Mr Carey could give a reason for that opinion, as in his own opinion the planing added to the cost of the plates, and therefore the cost would be more. In the case of the Subway it would have been almost impossible to have had planed joints, there were so many curves and gradients. Between Govan and Partick the Subway was on a horizontal and vertical curve at the same time, and they would have required 10,000 or 15,000 special castings had the edges been planed. Besides that they would have lost the advantage of having the plates interchangeable. With regard to Mr Carey's description of the moulding and milling machines he would merely like to make one remark. He had had an opportunity of seeing these machines at work, and he was struck with the systematic manner in which the segments could be turned out. He was interested at that time in the cost of cast-iron segments, and it struck him that the cost of turning them out in this way must be very much less than doing it by hand. He thought it would be useful if Mr Carey would supplement his remarks by giving them an idea of how much less the segments could be manufactured for when the moulding was done by this method than when it was done by hand.

Mr CAREY said Mr Simpson's paper was one of particular value in every way, and one which certainly ought to be brought before such an Institution as that. It gave them very clearly and concisely, and with exceeding accuracy, details of a great work which had been carried out in Glasgow, and he thought it was of the greatest value to this Institution and to the members of it that a paper of that sort should be laid before the Institution. He need scarcely say that he read the paper with great interest, and that, as far as criticising went, it was hardly a paper that lent itself to criticism. It was a plain statement of work that had been carried out with great accuracy and great care. There were one or two points, however, which he would like to say a word upon. The whole question of air pressure was rather a wide subject in itself, and one on which a good deal might be said. The Forth Bridge was perhaps a matter of ancient history now, but they had the same experience there as Mr Simpson seemed to have had, viz., that the pressure of air required was not as high as that which their calculations led them to expect. As Mr Biggart had told them, the pressure ranged from 36 to 38 lbs. per square inch where they would have expected it to have gone up to 45 or 50. The only question he would like to ask Mr Simpson was whether he had any trouble in putting these segments together, and whether the holes came quite accurately, or whether there was any twisting or warping? The question of two classes of segments, those with planed edges and those with fillets, appeared to him to hang a great deal on the question of cost. Referring to his own paper, he was somewhat interested in Mr Hogg's question, as Mr Hogg laid his finger on what was unquestionably a point in testing the iron for the Blackwall Tunnel, in which it was required to have a tensile strength of 8 tons per square inch, and he might say at once that this was a cause of a certain amount of anxiety and trouble. He might say that in order to get this high test of 8 tons the specimens had to have what he might call absolutely fair play; they had to be absolutely sound and good castings, and unless they were put into the testing machine absolutely straight—that was to say, without any side twist or strain on the samples—there was great trouble in getting the 8 tons per sq. inch. Mr Thomson had asked several questions of interest to which, however, he was afraid he could hardly answer. He had the information, but in the exigencies of trade he did not feel at liberty to deal with these questions. The only other question was the question raised by Mr Simpson himself with regard to the facts on page 112. He had not made the calculations that Mr Simpson spoke of as to the relative cheapness, but he had no doubt that what he (Mr Simpson) said was accurate. The question was raised about the term "chipping edge," an expression he had found in several documents on the subject, and therefore copied it, but perhaps, on a whole, the word "fillet" was more satisfactory. His own view was that if they planed edges—that was to say, if the castings had to be planed—they must use the highest class of iron. If they used an inferior class of iron there was great liability of the segments being warped and twisted, and he could not but think that one of the reasons Sir Benjamin Baker had for wishing to use planed edges was that *ipso facto* he was assured thereby of getting the highest class of iron. Certainly in the Blackwall segments a very high class of iron had been employed, and he thought the fact that so large a number of holes had been fitted throughout the work, and had given no trouble, was a proof that a high class of iron had been used. He admitted that as regards those holes there was a certain amount of clearance. If they referred to the drawing (see Plate IV.), they would find that, whereas the bolt was 1½-inch, the hole was 1⅞—that was to say, there was a clearance of ⅜-inch. He thought, notwithstanding that clearance, that it was extremely satisfactory that there had not been the slightest difficulty with regard to the fitting together of that enormous number of segments. He thanked the members for the interest evinced in the subject he had endeavoured to bring forward as a suitable one for the Institution.

Mr ROBERT SIMPSON, in reply, said with regard to Mr Hogg's question about the gauge of the railway, it had been settled at four feet. The original intention was to have had it 4 feet 8½ inches—the same as the railway gauge—but this was because the intention at first was to make the tunnels 12 feet in diameter. As stated in the paper, these had been made 11 feet, and the gauge was reduced in proportion. They hoped eventually to have a speed of 18 miles an hour. He did not think that was too great, because on the streets of some towns in America—Chicago, for instance—the cable had a speed of 14 miles an hour, and surely in a tunnel where there was no obstruction a speed of 18 miles might be arrived at. At Govan station, under the arch, the air pressure was from 2 to 3 lbs. Mr Hogg made some remarks about the use of the shield, and he thought, on the whole, he (Mr Hogg) rather agreed with the sentiments expressed in the paper, that the shield was of no great necessity. The use of it at Blackwall was an exception, however, and he agreed with Mr Hogg on that point, because the Blackwall Tunnel was 27 feet in diameter, which meant a very great difference of pressure between the top and the bottom when the tunnel was being constructed under air. The shield was divided into compartments, and he thought that the chief purpose it served was to regulate the air pressure, the divisions enabling the pressure at the upper part of the face to be kept lower than that required for the bottom. He had no doubt that the subsidence at Cook Street Depôt had been what he stated, but he would mention that the lengths taken out were 9 feet, and that there was always about 14 feet of a heading in front. No doubt the form in which the formula for air pressure was given might be improved, thus:

$$\text{Pressure in atmospheres} = \frac{\text{depth in feet}}{31{\cdot}4}.$$

That, of course, multiplied by 15 would give the pressure in pounds per sq. inch. Mr Hogg mentioned that he could have put up with more details about the tunnelling in mud in Partick, and thought that the question of the joint might have been kept separate, but that was impossible, because it was only at that place and in that very material that the joint came to be disputed. Several engineers were under the impression that the joint might do well in one kind of material and not in another. He had tried to show in the paper that as long as the joint was finished, that is, wedged, it was bound to succeed in every kind of material. He thought that in most cases fillets were found to be separate at the top. He did not see them himself, but the workmen who saw them stated that none of the fillets were touching. Mr Hogg also referred to the Mound Tunnel in Edinburgh, and stated that it might have been kept out of consideration in this question, as there was no water in the strata and it could not bear any comparison. That was quite true, and the reason he introduced the Mound Tunnel was to show that there being no water in the strata was the reason why the planed joints might be used. Had there been water in the strata he had no doubt another form of joint would have been adopted. He was afraid it would be impossible to give the costs of the different sections. He could not see any harm in doing so, but in the meantime he had other people to consult, and he would hardly like to do so just now. Mr Biggart referred to the remark on page 135 as to working with air pressure under the concrete arch, and mentioned what he thought would be the means adopted to prevent escape. He was quite right in his surmises. The under side of the arch was cemented at the places where the air was found to be escaping badly, but the bulk of the air went through the sand at the face, and it was quite impossible to prevent the escape there. This was not altogether an evil, as it was the means of maintaining a very pure atmosphere in the tunnels. He also referred to the pressure of 30 lbs., and that men have been known to work in very much higher pressures. That might be so, but it was, nevertheless, a fact that the men were suffering seriously in a pressure of 30 lbs. Some one had suggested that that might have been due to the impure atmosphere. In the mud in Partick, there being almost no escape of air, the burning of the candles and the breath of the men made the air rather impure, and he thought that that, combined with the high pressure, might have had something to do with the illness of the workmen. He had great pleasure in stating, in answer to Mr Carey, that in putting the segments together there was no trouble whatever with the holes. The plates fitted with great perfection, and he had never heard of any of the workmen having the least trouble with the bolts.

On "Rates of Speed and Rates of Freight."

By Mr JOHN INGLIS,
Past President and Honorary Councillor.

(SEE PLATES IX. AND X.)

Received 30th January; Read 25th February, 1896.

THE commercial efficiency of steamships has been the subject of several papers read to this and kindred societies. An excellent one, by Mr James Hamilton, may be found in our twenty-fifth volume, and the same writer contributed a paper on another aspect of the question to the Institution of Naval Architects in 1883. Mr Jas. R. Napier and Mr Millar, our Secretary, have dealt with the subject, and recently a paper, entitled "The Commercial Speed of Steamships," was read to the Marine Engineers' Institute by Mr J. Denholm Young. This latter was noticed by a well-known London weekly remarkable no less for its outspokenness than for its robust common sense; but Mr Young was not so fortunate as to carry with him the journalist, who rather resented the attempt to apply scientific methods to commercial affairs, on the ground that those responsible for the management of the great steamship lines were of unquestionable competency, and that what they had not learned regarding the working of steamers could not be considered knowledge.

I wish to disarm any criticism of this kind by pleading that I am entirely of the critic's opinion, and the contribution I am about to offer to the discussion of the important subject—the profitableness of steamship owning—is not intended for those who have an exhaustive acquaintance with the subject already, and who have long ago solved all the problems that can present themselves in the carrying on of that complex and hazardous business.

If the method I have chosen be not absolutely novel in some respects, it has not hitherto been made use of publicly, so far as I know. Before proceeding to consider it, I must ask you to permit me some assumptions which consist with a state of things, desirable perhaps, but not such as we are accustomed to.

I shall ask you to conceive a ship of about 10,000 tons gross differing from all other ships in possessing the remarkable property of a variable displacement on a given draught: that is to say, she alters her form and becomes finer and finer as the power of her engines and the desired rate of speed are increased; or otherwise, let there be an infinite number of such steamships differing from each other in form by very minute gradations.

Then we are to suppose that the shipowner can choose any rate of speed he likes without thereby affecting the volume of his business, his hand not being forced in any way by competitors; also, that he can always fill his ship with cargo to her utmost capacity, and that the number of passengers is the same on the average whatever time the ship takes over her voyage.

Let us first take the case of a voyage out and home between two ports exactly 3000 miles apart, performed at average speeds varying from 15 knots to 21 knots. Our steamer is assumed to have a displacement of 18,000 tons when adapted to the 15-knot rate, and for every knot added to the mean speed at sea 600 tons is taken off the displacement.

This is indicated on diagram No. 1 (Plate IX.) by the line A, a straight one, the ordinates being set up from the base line, which is divided to represent knots.

The number of hours required to steam 3000 miles at the different rates is shown by the curved line B. Our shipowning friends have no doubt realised in their practice that this line is a rectangular hyperbola, and are quite alive to the significance of the obstinate slowness with which it approaches its asymptotes. This is more easily appreciated by reference to the small diagram No. 2 (Plate IX.), whereon speeds from 5 to 40 knots are taken account of. It may be observed that an increase of speed from 10 to 20 knots effects a saving of time of 6¼ days on the voyage, but to go from 20 to 30 knots only results in a saving of 2 days 2 hours, and from 30 to 40 knots of no more than 25 hours.

The indicated horse power is computed from data in my possession which I think reliable, and may be taken as that which would, when at the disposal of a qualified naval architect, be sufficient to ensure the corresponding speed in fair weather. It is shown by the curved line C.

But in calculating the weight of machinery and the consumption of fuel on the voyage, an allowance is made for a certain proportion of unfavourable weather such as experience has shown to be inseparable from ocean navigation, and an allowance for engine-room stores is supposed to be included in the cost of coal.

The hull proper would not vary much in weight throughout the changes of form of under water body—a trifling allowance is made for additional engine seating, bunkers, etc., as the power of machinery increases.

An allowance of 20 per cent. on coal consumed on the voyage is carried in the bunkers as a reserve; a uniform weight of 500 tons is taken for passengers, their baggage, stores, and fresh water. The remainder, after subtracting all these from the displacement, is what is available for deadweight cargo.

This varies from 7373 tons in the 15-knot ship to only 18 tons—practically zero—in the ship of 21 knots, and therefore 21 knots is the limit of speed on a 3000 miles' run for the imaginary vessel.

The time the vessel remains in port is, in the case of those with lower speeds, determined by the rate at which cargo can be discharged and loaded; and I am assured that 750 tons per day is as much as can be dealt with on the average, taking into account the inevitable delays in distributing and collecting general cargoes. The curve D, which is derived directly from the curve K by multiplying the ordinates by a constant, exhibits the delay at either end of the voyage involved in the discharge and loading of the whole cargo, exclusive of bunkers, the work at them being supposed not to interfere with the work at the holds.

But there must be a minimum time in port even when there is little or no cargo, and I am advised that seven days is the minimum for such a ship according to the custom of some ports.

A horizontal line to represent seven days cuts the line D at the ordinate corresponding to 19¼ knots' speed. The ship, therefore, which is adapted to that speed, according to our hypothesis, will carry just as much cargo as can be discharged and loaded in seven days, and all the faster ships of that family will have a certain amount of lost time unless the delay in port be necessary for other reasons. The extreme importance of this will become apparent later on.

The next diagram, No. 3 (Plate IX.), displays the various items of which the total expenditure is made up, viz., the port charges (L), office expenses (M), wages of officers and crew (N), provisions for the ship's company (O), and passengers (P), insurance (Q), maintenance and repairs, shore gang and docking (R), coal and engine-room stores (S), and depreciation (T).

It is assumed that 40 days in the year, besides the intervals between voyages, are reserved for overhauling and repairing, leaving 325 working days per annum. The average number of passengers is supposed not to be affected by the speed. This is not likely to be the case until after wars and fightings have ceased among rival steamship lines, but it is convenient for the purposes of this paper to make the assumption.

Two such undoubted authorities as Mr Boumphrey, of the Cunard Line, and Mr A. C. Henderson, of the Anchor Line, agree almost to a passenger on the number that may be taken as a reasonable average on the North Atlantic; the mean of their estimates is 185 first-class, 110 second, and 400 third each way, and for these numbers I have allowed on both sides of the account, as, although the ships and route are entirely imaginary, it is better to get as near to practical conditions as possible.

The port and dock charges, pilotage, and office expenses are taken in proportion to the number of voyages. The wages of officers and crew are partly annual and partly dependent on the number of days at sea. Provisions, of course, cost according to the number of meals. Insurance is an annual charge. Maintenance and repairs are charged at 2½ per cent. on the hull cost and 7½ per cent. on the machinery. The coal and engine-room stores are in terms of the power and duration of the voyage, and depreciation is taken at 7½ per cent. on the first cost. This amount may appear excessive when compared with the allowance which income-tax surveyors are disposed to make, but it must be remembered that in many trades, especially where passengers are carried in large numbers, the fashions change rapidly, and a vessel which has not appreciably deteriorated as a structure may be found out of date and greatly reduced in value after a not very extended period of usefulness.

I find in a recent address by Sir Thomas Sutherland a statement of the sale of 60,000 tons of shipping at 8 per cent. of its original cost, the depreciation in that case being at the rate of 7½ per cent. for more than twelve years; but the amount of this allowance is not of very great importance in this investigation, as I propose to show comparative and not absolute results, and modifications can be easily applied by any one in possession of better information than I have at my disposal.

It will be observed that these curves are discontinuous at the point indicating when the time in port is a fixed minimum and begins to be longer than is absolutely necessary for the handling of the cargo. The expenses mount up less rapidly, but unfortunately the receipts have a downward tendency from this point, unless this be corrected by the raising of rates.

The curves of receipts are drawn from the following data:—The price of a first-class passage is taken at £6 per 1000 miles, a second-class at £3, and a third-class at £1 10s. Deadweight freights are taken at 3s per ton per 1000 miles, and from these rates the numbers of passengers given above and the deadweight carried in each type of vessel the ordinates of the curves U V and W are set up.

The curve U shows the annual receipts from cargo only, V the receipts from passengers, and W the total receipts from passengers and cargo.

Diagram No. 3 (Plate IX.) shows the margin of profit widening slightly but continuously as the speed rises, until a speed of 19¼ knots is reached, when the time in port is fixed at the minimum of seven days; above that speed profit rapidly decreases, becomes zero at 19·675 knots (less than half a knot above the speed of maximum profit), and is transformed into a loss of £34,589 annually, equal to 9⅓ per cent. on the cost of the vessel, when the speed is 21 knots.

In the next diagram, No. 4 (Plate IX.), is shown the effect of reducing the minimum time in port to four days. The best paying speed is no longer 19¼ knots, but is now 20 knots, and the vessel adapted to that speed makes a profit of £13,898 instead of a loss of £7555. The speed at which profit vanishes becomes 20·425 knots, instead of 19·675 knots, and the loss on the 21-knot steamer is reduced from £34,589 to £18,893.

The paramount importance of despatch is thus shown in a very striking manner. Evidently it is by no means advantageous to encumber the working of costly passenger steamers by the carrying of heavy cargoes, which cannot be discharged from and loaded into such vessels with the rapidity which is quite possible in the case of vessels expressly built for cargo carrying.

It might even be shown that it would be more profitable to run the 15-knot steamer with half cargoes, so long as she could obtain her average complement of passengers on more frequent sailings, rather than keep her in port for the additional time necessary to handle the full cargo, but in that case she would be unnecessarily full in form for the purpose.

Let us rather take the most finely formed ship of the series and modify the power and weight of machinery as required for the various speeds ranging from 15 to 21 knots. A new set of curves may be derived from the altered data, and these are shown on diagram No. 5 (Plate X.). A summary of the results is also given in a tabular form, but instead of showing the varying profits derivable from fixed rates, I have shown the variation in the first class fare that would have to be paid to ensure a modest 5 per cent. dividend. The other rates are easily derived from this, as, by hypothesis, a first-class passenger pays as much as two second-class, four third-class, or 40 tons of deadweight cargo.

Table I.—Ports 3000 miles apart. Displacement varying with the speed.

No. of round voyages p. annum.	Speed.	D.W. cargo.	Days at sea, single voyage.	Days in port at each end.	Cost of each round voyage.	First-class fare to pay 5 per cent. dividend.			D.W. cargo carried per annum.
	Knots.	Tons.			£	£	s.	d.	Tons.
6	15·3	7100	8·16	18·88	17,650	19	6	0	85,200
8	17·425	4950	7·17	13·16	15,840	19	2	0	79,200
10	18·55	3600	6·74	9·57	14,650	18	18	10	72,000
12	19·237	2680	6·50	7·13	13,800	18	14	7	64,320
14	19·70	2000	6·35	5·32	13,200	18	9	7	56,000
15	19·875	1760	6·23	4·66	12,930	18	6	7	52,800
16	20·325	1050	6·15	4·00	13,000	19	5	3	33,600
16·31	21·	18	5·95	4·00	13,414	21	8	1	587
12·26	20·	1600	6·25	7·00	14,268	20	12	8	39,232
12·54	21·	18	5·95	7·00	15,030	24	5	8	451

Table II.—Ports 3000 miles apart. Constant displacement, 14,400 tons.

No. of voyages per annum.	Speed.	D.W. cargo.	Days at sea, single voyage.	Days in port at each end.	Cost of each round voyage.	First-class fare to pay 5 per cent. dividend..			D.W. cargo carried per annum.
	Knots.				£	£	s.	d	
8	15·4	4600	8·13	12·23	14,130	17	16	1	73,600
10	17·325	3400	7·22	9·04	13,540	17	12	6	68,000
12	18·45	2550	6·78	6·78	13,120	17	6	10	61,200
14	19·19	1900	6·52	5·05	12,730	17	18	6	53,200
15	19·46	1650	6·42	4·38	12,560	17	18	7	49,500
16	20·325	800	6·15	4·00	12,900	17	8	11	25,600

In Table I. the fares yielding 5 per cent. profit decrease as the speed increases up to a certain point, whereas those shown in Table

II. increase from the lower limit of speed. The finer type of ship carries passengers more economically than the fuller up to a speed of about 19·85 knots, when the paying passenger rate becomes £18 7s 3d for both, and above that speed—for example, in the ships making 16 round voyages in the year—the fuller ship can afford to reduce the rates a trifle, the extra 250 tons cargo carried per trip making up for the decreased receipts from passengers.

If these remarks should reach any shareholders in steam shipping property of a type resembling that under consideration they will probably recognise what may be called the *precariousness* of the results, and how much the gains depend on a sagacious choice of form and proportions, the narrow limits within which the managing owner's judgment must be exercised, and the slightness of the change which suffices to convert substantial profit into serious loss.

The demand for rapid transport is continually extending, even when the length of voyage would appear likely to increase the difficulty of the shipowner. Let us examine the effect of doubling the distance between the terminal ports, the conditions otherwise being the same.

To simplify the question, let there be no stops on the way, and let the ships carry coal for the whole voyage.

The limit of speed will be reduced from 21 knots to 19 knots, as at higher speeds the coal supply could not be carried, the fixed weight for mails, passengers' baggage, stores, and fresh water being 700 tons, instead of 500 tons as in the 3000-mile voyage. Seven days will probably be considered a short enough delay at each end after a voyage of such length.

By plotting the results in the same way as before (Diagram No. 6, Plate X.), it is shown that the margin of profit is much broader at all the speeds than it was with the shorter voyage, and does not become zero within the scope of our observation.

The vessel making 8 round voyages of 12,000 miles has the same annual mileage as that making 16 voyages of 6000 miles, but her speed is 19 knots as against 20·325; her delay of 14 days in port per round voyage amounts to 112 days in the year, whereas the 8 days per round voyage of the vessel on the shorter trips make a total of 128 days annually, and, largely on that account, the cost of the longer voyage is only about 46 per cent. over that of the voyage half the length.

Table III. will show that the cost of conveying passengers is proportionally much less over the long voyage.

Table III.—Ports 6000 miles apart, displacement varying with speed.

No. of round voyages p. annum.	Speed.	D.W. cargo.	Days at sea, single voyage.	Days in port at each end.	Cost of each round voyage.	First-class fare to pay 5 per cent. dividend.			D.W. cargo carried per annum.
					£	£	s.	d.	
6	15·875	4290	15·74	11·44	20,340	25	7	7	51,480
7	16·9	3200	14·80	8·53	19,120	25	5	5	44,800
8	19·0	165	13·16	7·00	19,019	30	12	2	2,640

Under the chosen conditions, a first-class passenger can be carried over a 6000-mile voyage at the speed of about 17 knots for almost exactly a penny a mile, but if he must travel at 19 knots he ought to pay a shilling for ten miles, whereas the passenger on the 3000-mile voyage would have to pay about fourteenpence for the same service in the same ship.

I should have liked to consider the effect of delays *en route* for mails, coaling, etc., the effect of alterations in size of vessel, and many other variations in the conditions under which a vessel may be worked, but this paper will probably be deemed sufficiently long already.

I have appended another diagram (No. 7, Plate X.), to which only the briefest reference is necessary. It is made up from the actual working of an oil-carrying steamer, which is one of the simplest kinds of cargo steamer, looked at from the commercial point of view, because she is always full the one way, always in ballast the other, and her loading and discharging are effected with extreme rapidity. Her carrying capacity is affected by speed when the bunker coal begins to trench upon the deadweight capacity allowed for cargo. What the diagram is intended to show is the most profitable speed for any given rate of freight, and the speeds at which the earnings just balance the expenses. These can be seen at a glance, and it is also evident from the diagram that the lowest speed is not always the most profitable.

The foregoing may not be altogether beneath the notice of even the experienced shipowner, and, on the other hand, the constructors of ships would, I believe, greatly appreciate the information which shipowners must possess, and which would make such estimates as I have attempted more reliable and complete.

In the after discussion,

Mr **James Hamilton** said there could only be one feeling in the meeting, that this paper was a most valuable contribution to the transactions of the Society. It was impossible to criticise it on the spot without a considerable amount of consideration, because the writer of the paper had given them, condensed into those curves, an enormous amount of work; it was full of speculation, and one did not know where to begin to criticise it. He himself had tried, in a paper read before the Institution, to work somewhat on the same lines as Mr Inglis had adopted, and therefore ought to be able to assimilate this a little more readily than anybody else, but he confessed that it would require some time to understand it thoroughly. One thing that struck him was that a shipowner, looking upon this paper as an attempt to apply scientific methods to the problem of the profitableness of steamships, might, if he were inclined to be hypercritical, refer to those gradual curves marked *w*, which represented the freight corresponding to all those different speeds, and he could imagine him saying that instead of earnings going by gradual gradations like that, they would go by steps and stairs on account, perhaps, of not being able to utilise the small increase of speed between, say, 17 knots and 18 knots on account of the difficulties of working the service. For instance, Mr Inglis took, as he understood him, 7 days in port at either end, and with a 15-knot ship he thought it would work out at 7 days for the voyage each way, and that would be a month to represent the round voyage. Supposing an owner wanted to have a weekly service, he would require four ships going at that speed to make the round voyage. If he could only save a day each way, he would require to have a great number of ships before he could utilise the day, supposing even that the Sunday did not intervene, which would be rather a difficulty in the matter; but at the same time he could quite understand him making great use of these curves, and he was quite sure that, if made use of by an intelligent shipowner, they could be made of great value to him. Supposing he wanted to extend that ideal service with 7 days in port and 7 days on the run, which enabled the owner to keep, for instance, his Monday or Tuesday sailings, and supposing he were to conceive that he might be able to halve the time, that would be 7 days in port at each end and 3½ days on the voyage, that would be 3 weeks for the round voyage, so that in that way he might expect or conceive the idea of doing the voyage at the rate of 3 weeks instead of a month, and the result would be to do the weekly sailings with three ships instead of four. If he wanted to know what it would cost him if he applied those figures that Mr Inglis had given he would find that, whereas at 7 days' running each way, about 15 knots odds, his passenger rate would need to be something like £19 to pay the modest figure of 5 per cent., and if he ran out these curves he would find that possibly to make the round voyage in three weeks instead of a month it would take over £70 for every first-class passenger to make it pay. That was the *reductio ad absurdum*. The thing would not be possible. He would see that his hopes were in vain and give them up. That was one great use that shipowners could put this method of investigation to, and he thought they were greatly indebted to Mr Inglis for bringing the paper before them, and he hoped that they would have a further opportunity of criticising it more severely.

Prof. BILES said he was afraid he had very little to say at this stage of the discussion. The paper represented an enormous amount of work condensed in that masterly way that Mr Inglis was so famous for, so that it was almost impossible to fully appreciate the whole of it at once. The general question that Mr Hamilton had raised of the introduction of other conditions into the problem did not in any way detract from the merit of the problem investigated on the assumed conditions. It introduced the principle of discontinuity, which was not in the curves. They knew that there were steamers running 3000 miles at about a 20-knot speed, and that they remained only three or four days in port, and that they did their work successfully. The introduction into this series of diagrams of the conditions which made it necessary to run steamers in that way would bring about discontinuity in the curves. It did not, however, detract in the slightest degree from the accuracy of the curves as stated, but it pointed to the fact that these curves necessarily had their practical limitations, or that they were limited in their application. The question was a very interesting one, one that had been worked upon by others in various forms, but never, he thought, in the full way for the highest speed that they now saw before them. The subject had been investigated in another form with fixed speed and varying block co-efficients of fineness of form. He thought the Institution was very fortunate in having such a very valuable paper placed before it. The figures that were given were extremely valuable. He could not, of course, pretend to say that they were beyond criticism at that stage of the discussion, but they were valuable, and what was most valuable of all was the clear exposition of the method. The assumptions were clearly stated, and if the assumptions were not accurate they could be modified, but the method was still applicable as far as a continuous study of the question made it. They were opening up here an exceedingly interesting study, and he hoped that another opportunity might be afforded them of discussing the subject in a more careful manner, and in the meantime they owed Mr Inglis a great debt of gratitude in presenting this paper in such a full, clear, and concise manner before them.

The discussion on this paper was resumed on 24th March, 1896.

Mr Robert Caird said that, as he moved the adjournment of the discussion, he supposed, according to the usual rules of debate, he should be the first to speak. They all knew of the answer of the student who thought Gamaliel was a mountain in Sicily, but in these days of technical education and science teaching they would be more likely to say that Gamaliel was a shipbuilder of Pointhouse, and he confessed that he would feel much more comfortable sitting at his feet than attempting to criticise his paper, more especially seeing that the paper was such an excellent one in so many ways. For lucidity of presentation of data, he did not think that even Mr Inglis himself could criticise it severely if it had been written by some one else. The curves on Fig. 1 that lent themselves to analysis from a shipbuilder's point of view were, he thought, A, C, E, and H. Taking C, the curve of indicated horse-power, he found that the horse-power curve, if they examined it from the point of view of the Admiralty co-efficient, appeared to be rather too low, because the co-efficient started at about 280 at 15 knots, and then went up to about 312 at 18 knots, and came down to about 293 at 21 knots, which certainly was very high. If the displacement were reduced by half the coal consumed during the trip, so as to get the mean displacement, the values of the $D^{\frac{2}{3}}$ constants came out about ten lower than those just given, and even then appeared too high. The curve of $D^{\frac{2}{3}}$ constants sweeped pretty much as in progressive trials, whereas, seeing that the displacement was made to vary to suit the different speeds, the $D^{\frac{2}{3}}$ value should probably be constant, or nearly so. He would be inclined to think that the horse-power might be raised by about 12 per cent. at the 15-knot, and about 20 per cent. at the 21-knot speed. When he fell upon that, he thought that he had caught Mr Inglis, but he found that the allowances made on the figures which were deduced from the I.H.P. curve were such that they might raise that curve even as much as now suggested without altering the others. Of the other curves, the first was weight of machinery. He found that Mr Inglis had taken about 4 to 4½ horse-power per ton weight of machinery, and he thought they might safely go to 5½ or even to 6, taking the usual practice on the Atlantic, so that his curve for weight of machinery might stand. The same was true of the curve of coal consumed. He had taken it at something like 2·2 to 2·5 pounds per indicated horse-power per hour, so that, if they brought it down to 2 pounds (a sufficiently safe figure), his value would still stand. But it seemed to him that there was another curve which was not so correct. It was that of the weight of hull, the ordinates between A and E. He found on analysis that a vessel, to fulfil the conditions set down, would have approximately the following dimensions:—558 by 62 by 40, and that that vessel on a 25-feet draught would have a block co-efficient of about 0·73 at 15 knots, and 9·58 at 21 knots. He did not think they could possibly take the weight of hull of that vessel, being a first-class passenger ship for Atlantic service, at less than 7612 tons, whereas Mr Inglis took it at 6120. There was a difference of about 1500 tons, which, applied on the cargo curve, would considerably affect it. He was sorry that Mr Inglis was not present himself to explain it. He had no doubt that there was some reason why he had taken his hull so light, but, in comparing it with three well-known vessels, the "Campania," "Paris," and "Teutonic," as near as he had been able to get at the figures of weight of hull of these steamers, he found this error of about 1500 tons in Mr Inglis' calculation confirmed. He did not want to make any more of this than it would justly bear, and, if it did alter the curves, it did not vitiate the method, and the curves were still very instructive. He would like to call attention to the critical point which was introduced by the time in port. He thought that it was a very beautiful, graphic device. The cordial thanks of the Institution were certainly due to Mr Inglis for bringing before them this most ingenious and suggestive application of graphic methods to so complex a subject.

Professor **Biles** was afraid that he had very little to add to what he said at the last meeting. This paper might be said to be an academic paper. If they attempted to criticise it from the point that Mr Caird had criticised it as to the absolute accuracy of the figures they were open to Mr Inglis's crushing reply that he did not pretend that any of his figures were correct, and that he was only putting forward a method of arriving at the result when they had the right figures to operate upon. The figures were so complicated, and there were so many involved in this beautiful investigation which were partly at the disposal of the shipowners, and partly at the disposal of the shipbuilders, that he thought it was impossible to arrive at any practical conclusion from those figures as they stood. Each one who wished to arrive at a practical conclusion must take the figures which he could be sure were correct figures, and then apply this method to obtain the correct results. He did not suppose that Mr Inglis had put these forward as in any way absolutely accurate figures, but they were put forward as exemplifying the method whereby with the use of accurate figures, accurate results could be arrived at. There were one or two of the assumptions that he might make a remark upon. There was the assumption that a margin of 20 per cent. of coal consumed on the voyage should be carried in the bunkers as a reserve. That was a very considerable margin, and one which, if changed, would tend in the same direction in which Mr Caird had pointed out that the change of the weight of hull calculation would go. Twenty per cent. was not the margin that the shipowner referred to in the early part of the paper, as one who knew all about his business, was likely to carry in his ships. There was one little remark of Mr Inglis's there that he thought was not quite accurate. On the third page of his paper he said, speaking with reference to the time a vessel must be in port in order to take in and discharge cargo—"I am assured that 750 tons per day is as much as can be dealt with on the average, taking into account the inevitable delays in distributing and collecting general cargoes." He did not quite see what the delays in collecting and distributing general cargoes had to do with putting the cargo on board the ship or in discharging. There was another point that he did not think Mr Inglis had taken account of, and which should be taken account of, and that was that when they got the comparatively small amount of cargo which these higher speed vessels would inevitably take, the question of time required to take in coal would take the place of the time required for handling cargo, and as they increased the amount of coal for the speed, and reduced the amount of cargo, the critical thing would be the time required to put the coal into the steamer, and not the time required to put the cargo in. There was another remark on the sixth page of the paper—"The paramount importance of dispatch is thus shown in a very striking manner. Evidently it is by no means advantageous to encumber the working of costly passenger steamers by the carrying of heavy cargoes, which cannot be discharged from and loaded into such vessel with the rapidity which is quite possible in the case of vessels expressly built for cargo carrying." He thought that the practice in the passenger vessels, even those that carried a small amount of cargo, was quite as good in the matter of dispatch of cargo as in the vessels that he referred to there expressly built for cargo carrying, and therefore he did not see that it applied at all. In fact, it seemed to him that, with the extra sub-division that was insisted on in cargo steamers, they were compelled to have an extra number of hatches, and thereby they were almost inevitably thrown into having greater facilities for handling cargo than the average facility in a cargo steamer. Just as an instance of how the delay in port could be reduced, he would mention one fact that he came across not many days ago. The amount of time required to fill the bunkers of an Atlantic Liner carrying about 2500 tons had been reduced, so that it could be done in 24 hours. The rate at which coal could be put in was dependent upon the length of side of the shop occupied by bunkers. If very considerable increases of speed were attempted, considerable increase of dimensions would undoubtedly have to be involved, and the extra length that would be involved would certainly add to the facility for putting coal in in proportion to the amount of coal that would be carried, so that they might look to very considerable increases of speed without much doubt as to the ability to put coal in. He thought that if they got as high as 30 knots speed they would be able to do the necessary coaling in 24 hours in a 30 knots steamer.

If they reduced the amount of cargo below the amount which could be put on board in the time that the coal could be put on board, then they were in this position that the 30 knots steamer would do the 3000 knots that was taken as the standard in 4½ days. So that if she could recoal in one day, he thought that they would have a sufficient margin of time to enable them to say that a vessel would leave England on one day in the week, say on Saturday, and leave New York on the following Saturday. The best that could be done just now was to leave in about 10 days; that was to say, they left this side on Saturday and the other side on the Wednesday. That was only done in the case of one Line. In the most of the Lines the time was one week at sea and one week in port. If they reduced the time that a ship increased the number of voyages in the proportion of doubling, then the amount of earning of that ship must be enormously increased. He merely mentioned that point because it seemed to him that Mr Inglis had not quite emphasised or realised the improvements that could be made in the reduction of time in port in a properly-arranged Line. All that he had said latterly, he was afraid, was deviating from what he started with, that no criticism of this paper was worth anything, because the paper was in itself complete. It showed clearly what he started out to show, and it was an admirable method of arriving at an accurate result when they had accurate data to go upon. He thought that the whole of the members of this Institution who were interested in this subject would wish to take it up in a systematic way, and they were under a great obligation to Mr Inglis for putting the subject before them in such an admirable manner.

Mr J. DENHOLM YOUNG writes:—I feel sure, and unquestionable authorities have already given us their assurance, that there are many interested in shipping who will welcome this last outcome of the large experience and knowledge of our Past President. Mr James Hamilton, who has been a pioneer in this branch of analysis, has pointed out that some of the curves shown might in practice be stepped or discontinuous. Catching or missing a tide does in many actual cases, especially with coasting steamers, produce such discontinuity as stated in the paper read in November, 1894, before the Institute of Marine Engineers. Especially valuable, I think, are the results of the oil-carrying steamer given in the plates. Of course a good deal depends upon the rate at which the "coal curve" rises. The vessel illustrated appears to have a wide range of speed, and the form of the curve indicates a greatly decreased efficiency of the boilers at the lower speeds, which might not have been the case had the boat been specially intended for these lower speeds. Probably another cause which brings about a comparatively larger coal consumption per indicated horse power at lower speeds is the comparative disadvantage which low-powered boats have in facing stress of weather.

The CHAIRMAN said that, if no one else wished to speak on the subject, they would close the discussion with a vote of thanks to Mr Inglis. He knew personally that Mr Inglis had devoted a great deal of time and trouble to the preparation of that paper, and he thought the thanks of the Institution were due to him for it.

The vote of thanks was heartily accorded.

Mr JOHN INGLIS, in reply, writes:—I am much obliged to those gentlemen who have criticised my paper, and only wish we had been favoured with some observations from the shipowners' point of view in addition to what we have had from the naval architects' side. Mr Caird's remarks are perfectly fair, and, before the diagrams could be put to practical use, some such examination as he has given to them would be absolutely necessary. Professor Biles, however, has anticipated the reply which it is open to me to make, namely, that I offered a method only, and not a table of minimum rates for use in the booking-office. But it would be barely courteous so to evade criticism, and I propose to answer as briefly as possible the objections raised. So far as the curve of indicated horse power is concerned, I feel on safe ground, as it was derived from actual trial results of ships closely resembling in form, though not in dimensions, some of the imaginary ships of the investigation. As I have said in the body of the paper, these are minimum powers to ensure the speed in the most favourable circumstances, and the margin necessary at sea is given both in the weight of machinery and in the consumption of coal. I am glad to find that I have regained Mr Caird's confidence by the time we arrive at the curves E and H. I am not aware of any reason why the Admiralty "constant," as it is called, should be really constant, even in this case, for, although the displacement is reduced while the speed is increased, there has been no attempt to establish such a relation between the two as would keep the expression $\frac{V^3D^{\frac{2}{3}}}{P}$ equal to a constant. It may be noted also that if a factor like Rankine's augmented surface be introduced, the propulsion co-efficients do not rise and fall as do the values which Mr Caird has found for the Admiralty "constant." With regard to the weight of hull, I thought I had protected myself against the discussion of such details by carefully avoiding any statement regarding the dimensions of hulls, the materials or mode of construction. I admit that I deliberately assumed a weight rather less than ordinary practice would indicate, and the descent of the cargo curve to zero at 21 knots speed is not purely accidental. But there is less difference between Mr Caird and myself than he supposes. The dimensions of hull upon which I figured were 540 × 60 × 27 feet draught of water. Mr Caird's weight for these dimensions would be 7128 tons if reduced in proportion; my weight is 6300 tons; the difference is therefore not 1500 tons, but 828 tons, a much more manageable quantity. I trust I shall not be understood as in the very least disparaging the magnificent vessels which Mr Caird has cited, if I venture to suggest that the last word in the design and construction of steamers has not yet been said. Already the builders of torpedo-catchers are using a material unknown to the Registry Societies, and I doubt not Professor Biles is thinking of some of the alloys of steel for the hulls of the 30 knot vessels he has in his mind. But even without the metals of the future, the difference of 828 tons can be disposed of. Professor Biles is willing to give up the greater part of the 20 per cent. coal margin, say 400 tons in the fastest steamer, and, out of the weight of machinery, fuel consumed, etc., Mr Caird is evidently ready to concede something. On the whole, I daresay we may agree that a steamer can be produced ready to start on a 3000 mile voyage, at 21 knots speed, with bunkers full, on a displacement of 14,400 tons. With all deference to Professor Biles, I think the collection and distribution of cargoes have something to do with the rate of loading and discharging, because, if the cargo is not brought to the ship's side, it cannot be put on board, and if not taken away from the ship's side, discharging cannot go on. Where sailings are frequent it may happen that the port will not furnish cargo with sufficient rapidity to utilise the cargo handling appliances—and it was partly this consideration that fixed the amount of cargo assumed to be dealt with at 750 tons per day. Within the limits of my investigation, the time required for coaling does not affect the delay in port, if four days be taken as an irreducible minimum, seeing the greatest weight to be put on board is 2660 tons. When we come to 30 knot steamers, with 24 hours in port, it will be different. Professor Biles has said that I have not sufficiently emphasised or realised the improvements that could be made in the reduction of time in port. My object was rather to show the great importance of reducing the time in port; the means by which reductions of time may be effected might very well form the subject of another paper, say, by Professor Biles himself. Mr Denholm Young calls attention to the varying efficiency of the boilers at different rates of speed, and no doubt the efficiency of the engines would also be affected. This opens up what is in itself a large subject which might be separately treated, with observations on the use and abuse of trial trips. I would only add that I greatly appreciate the compliment implied in the minute examination to which Mr Caird and Professor Biles have evidently submitted my paper, and, for the additional light they have thrown on the subject, we owe them our thanks.

On "The Recovery of Tar and Ammonia from Blast Furnace Gases."

By Mr ANDREW GILLESPIE.

Received 12th; Read 25th February, 1896.

THOUGH coal tar as a distillate from coal was known for over a century before 1798, having made its appearance in connection with various attempts to make coke for smelting purposes, it was not till about that time, when William Murdoch made his discovery of illuminating gas from the destructive distillation of coal, that tar as a product was made in such quantities as to demand separate attention. At first, it was got rid of as a "nuisance," and ultimately it was found to have such distinct values of its own as to remove the reproach of *by*-product and bring it into line with original processes.

As to the "nuisance," it may be said that within living memory it seemed practically impossible to get rid of the tar, and as to value, coal tar now counts over fifty constituents of separate commercial importance.

As this fact came to be realised, together with the growing necessity for economising fuel, attention was directed to the waste of coal gases seen burning at the top of blast furnaces. Until comparatively recent years it was considered that the coal put into a blast furnace had done its whole work when the ore was smelted and run into pigs, the air of the hot blast being heated by additional coal in a separate stove. The first step in the utilisation of the waste gases was in closing the furnace tops, and passing the gases so confined by a system of piping to the boilers for supplying steam to the blowing engines and to the air stoves for heating the blast. This was a clear saving of all the coal used outside the furnaces, and the next step was taken when it became evident that the tar which revealed itself in the green gas coming from the closed furnace top, causing trouble and discomfort in the combustion of the gases, might not only be removed, but turned to advantage, as had been done in the production of illuminating gas.

The initial difficulty in the treatment of such gases lies in their enormous volume. The quantity of gas obtained from a ton of coal distilled in ordinary retorts for illuminating purposes is about 10,000 cubic feet, while from the presence of the air blast mixing with the coal gas distilled in the process of smelting the volume is increased to about 130,000 cubic feet, or thirteen times the quantity of illuminating gas; the valuable by-products which come from the coal alone are thus diffused through the entire volume, and to recover them it is necessary to deal with the whole. To give some concrete comparison of such a large volume, it may be stated that the largest output of gas from the whole of the Corporation Works in the Glasgow district is under 30 million cubic feet per 24 hours, while the volume coming from four blast furnaces is over 40 millions, requiring a collecting main of 8 feet diameter.

The next difficulty lies in the high heat of the gases which pass by the collecting main to the recovery plant at a temperature of about 300 degrees F., and this must be reduced to under 70 degrees before ammonia can be properly recovered, the tar being meantime obtained in the process between these limits of temperature.

It thus becomes apparent that the apparatus must be on a very large scale, while the difficulty and expense is increased by the fact that the combined gases form an approximately explosive mixture, rendering it necessary to make ample provision against possible danger.

The first attempt to recover the tar and ammonia from blast furnace gases was carried out about 16 years by Messrs M'Cosh & Alexander, of the Gartsherrie Iron Works, and known as the Gartsherrie process. Other methods followed, all more or less based on the ordinary process of removing the tar and ammonia from illuminating gas, differing chiefly in dimensions, till now nearly all the active blast furnaces in Scotland have been furnished with a recovery plant of one form or another.

As yet scarcely any of the furnaces in England are so equipped, the smelting in them being chiefly effected by coke instead of raw coal. In a few cases the products have been extracted from the ovens in preparation of the coke, but as a rule the product-bearing gases are neglected, and lost by combustion in the coke oven.

It might be supposed that while the recovery of the ammonia from the blast furnace gas does not reduce the calorific value, the extraction of the tar compounds would have such a result; but practically this has not been found to be the case, for the clean gas after the recovery process is in better condition for burning under the steam boilers and in the hot air stoves than when it was laden with tar and dust, and it is clearly proved that from the same coal put into the furnace, or, more accurately, from the surplus gases generated from the coal in combustion, is derived the heat energy sufficient to drive the blowing engines and heat the air of the blast to 1700 degrees F., plus the oil, pitch, and sulphate of ammonia obtained in the recovery plant. To put this again into concrete form, it may be stated that the results obtained from a plant recently erected in connection with four furnaces show that, in addition to the usual output of pig iron, the clean gas raises steam in 17 large high-pressure boilers, heats the air in 3 regenerative stoves, distils the tar into oil and pitch, and evaporates the waste liquor; while the recovered tar yields 7 gallons oil and 86 lbs. of pitch, and the ammonia liquor 25½ lbs. sulphate of ammonia per ton of coal put into the furnaces. The total recovery for 1895 from 92,940 tons of coal carbonised in the four furnaces amounted to 677,000 gallons oil, 3550 tons pitch, and 1057 tons sulphate of ammonia.

As we are not concerned with the gases in combustion in the boshes or hottest part of the blast furnace, where the ore is being reduced, but with those that form between the burden of raw coal and iron ore and the closed top, and which we may term the surplus or green gases, these prevented from access to the air and consequent ignition pass by the open valve of the downcomer tube from each furnace to the collecting main. The green gas is drawn through the main by exhausters placed further on in the plant, and the high temperature conserved as far as possible by a firebrick lining inside the main. The gas then enters the first vessel in the process, the "tar washer," which is a large oblong-shaped tank having the bottom ridged and sloping to each end. Internally there are two compartments formed by longitudinal partitions to give a double wash; the partitions are fitted with serpentine diaphragms having serrated edges. When in operation the compartments are charged with tar till it rises above or seals the edges of diaphragms, rendering it impossible for the gas to pass except by washing through the tar, the gas is drawn through the seal by the power of the vacuum formed by the exhausters, and the entire area continuously agitated, with the double result—first, that the hot gases partially distil the water out of the tar; and, second, the contact with the tar in the washer entangles the tar particles in the gas and precipitates them on the sloping bottom, whence the heavier tars are run off at intervals to the stock tank.

Along with the heavier tars, the gas has lost in this washer about 130 degrees of its heat, and is ready for the final cooling in the "condenser."

The condenser is divided into eight sections, each having a separate chest fitted with 18 pairs of 20-inch diameter pipes 54 feet high; an arrangement is made in the chest so that the gas passes up one pair and down the next continuously, till by the time it reaches the final pair the exposure to the atmosphere reduces the temperature to 70 degrees and under. In warm weather it is necessary to supplement this cooling by a spray of water on the top of each pipe which runs down the outer surface, both reducing and equalising the temperature.

The lighter tars and weak ammonia liquor separated from the gas in condensing are collected from each section, and pass into a "separator," where, by the difference in their specific gravities, the tar and liquor are automatically separated.

The gas now passes by double branches into the first "liquor washer," a vessel 60 feet long by 12½ feet wide and 7 feet high, fitted internally with a longitudinal partition and serpentine diaphragms similar to the tar washer, but with a wider single action, the diaphragms are sealed in weak liquor, and the gas, now at a temperature of about 60 degrees, is again drawn through the seal by the exhausters, the diaphragms divide the gas into thin streams, and in the continuous agitation caused by the displacement the light tars are washed out and the ammonia taken up by the liquor. The products pass by a regulating valve into another separator, the liquor at an ammonia strength of 1½ degree Twaddel is run into a stock tank for treatment in the sulphate stills, and the light tar to feed the tar washer.

The exhausters, which come next in the process, are of various forms. There are three of the ordinary Roots blower type, each capable of passing 900,000 cubic feet of gas per hour. As the effective washing of the gas depends on the depth of seal in the washer, the vacuum necessary to draw the gas forward is regulated for each vessel by tubes connected from them to gauges placed in the exhauster house, so that the attendant may control the speed as required.

The second and final liquor washer is placed beyond the exhausters and is the same in all respects as the first, except that the gas is forced through the seal, and the vessel is fed with clean cold water. In this washer the last traces of tar and ammonia are recovered and the gas cleaned, ready for use at the boilers and air stoves, to which it returns in a pipe 5 feet diameter. The products, consisting of weak ammonia liquor of about ½ degree Twaddel strength and light frothy tar, are again separated, the liquor returned to feed the first liquor washer, and the tar as before to the tar washer.

In the further treatment of the recovered products the heavy tars run periodically from the bottom of tar washer into the underground stock tank, are run as required into blowers, and delivered by compressed air into an elevated charging tank near the tar stills, into which the tar gravitates for distillation. The tar stills are waggon-shaped boilers formed with double flue recesses on the bottom, and fired by the clean gas. Each still is supplied with a worm condenser placed in a cold-water tank.

When a still is charged, and the gas turned on and ignited, the first portion of the distillate is water. The tar as at first recovered from the furnaces carries about 80 per cent. of water, but this has been reduced, as we have seen, by exposure to the hot gases in the tar washer; when the water has been driven off a light oil begins to appear, getting heavier as the distillate approaches the pitch stage. The distillate running from the worm passes into a separator, the water, with traces of ammonia in it, is cooled and sent back to feed the first liquor washer, and the oil passes into blowers, whence it is delivered by compressed air into the oil stock tank, or into barrels for immediate sale. When the still is ready for pitching, the worm is shut off and the liquid pitch run first into a cylindrical cooler, and afterwards into open ponds, where it hardens solid, and is then broken up, packed, and despatched.

The ammonia liquor stored in the liquor division of the stock tank is run into blowers and delivered into an elevated tank as described for the tar, whence it gravitates continuously into the sulphate stills. In the sulphate house there are two vertical cylindrical stills each fitted internally with 11 horizontal trays having open nozzles projecting upwards, placed as close together as possible, and each nozzle covered by a loose cup with serrated edges. The ammonia liquor is run in upon the top tray, filling all the space round the nozzles and sealing the cups, the liquor is compelled by a baffle plate to circulate round the nozzles, and at a certain level runs off by a pipe to the next lower tray, where the process is repeated from tray to tray till the bottom is reached; at this point steam is introduced under the bottom tray, and passing up by the open nozzles, bubbles out through the serration of the cups; the steam ascending through the nozzles from tray to tray meets the descending liquor, and, by the inducement of greater affinity, robs the liquor of its ammonia, carrying it off at the top in the form of ammonia vapours. These are conveyed by a system of piping into the "saturator," a lead-lined vessel charged with sulphuric acid, the vapours are taken right to the bottom through a lead cracker pipe perforated with small holes through which the vapours pass, and combine with the acid, forming ammonia sulphate, which contains 24 per cent. of pure ammonia.

After boiling for some time, crystals of this salt are precipitated on the bottom of the saturator, fished out by hand ladles or mechanical dischargers, placed in skips over a draining table, and, when dry, conveyed by an overhead rail to the sulphate store for packing and despatch.

So far, we have been recovering saleable products from what was formerly "waste and nuisance," but it cannot be said we have entirely removed the waste or the nuisance. The waste or surplus gas not required for any heating purpose is automatically passed into the atmosphere when the quantity exceeds the pressure required, the escaping gas being burned as it passes into the air.

The waste vapours coming from the saturator may be condensed and purified before passing into the air or destroyed in the still flues and chimney, but the waste or effluent liquor coming from the sulphate still is not so easily got rid of, and the efforts to dispose of it remind one of the tar nuisance of former days. Even after filtration it is not safe to run it into a stream ; it seems to be fatal to fish, at least they don't thrive on it.

At the works referred to in this paper the form of still adopted removes nearly all the solid matter from the liquor. The stills, which are fitted with appliances for ease and rapidity in cleaning, are opened at intervals, and the cups and nozzles cleaned of the pitch deposit, the liquor as it leaves the bottom of still passes into a large settling tank, through which the current travels slowly against baffle plates, throwing down any solid matter. The clean liquor is then run off hot from the top of tank to feed the steam boilers, where the larger proportion is evaporated in raising steam, and the remainder drawn off from the boilers into a special evaporating pan or furnace, where any remaining solid material is burned down to ash, yielding on further treatment a small proportion of potash.

It is not in the province of this paper to follow the various products recovered in the process and their ultimate uses and effects in the industrial arts, but these are not without interest. The pitch oil is extensively used as "light" in factories and large areas by the medium of "Lucigen," "Wells," and other lamps and torches, and in enriching poor coal gas. It is also used as fuel in steamers, and in other steam boilers and furnaces.

The "pitch" is utilised in many forms. In a thoroughly equipped colliery the coals are washed and screened to various sizes, till the ultimate dust is carried off in the washing as mud. The mud or coal dust is then dried, steamed, and mixed with a proportion of the pitch, and moulded by machines into briquettes. The pitch is also used in all the appliances of asphalte for paving, roofing, and felting.

The commercial sulphate of ammonia, besides its numerous chemical applications, is now extensively used as a manure, and holds a first place as a fertilising agent. It combines readily with the soil, imparting to it the nitrogen necessary for absorption and assimilation by the roots of plants. It is most widely used in the production of "beet," and as a top and second dressing on grass lands, and generally for the stimulation of all forms of plant life.

It has been said that the world owes much to the man who can make two blades of grass grow where but one grew before, and though hard things have been said about the desolating action of the "coal and iron seeker" in the havoc he has wrought on the earth's surface, still we have seen how even he has done something to bring back a smile to that fair face of nature he has done so much to scar and defile.

He may have done all this for selfish ends as something to compensate him for the low price of pig iron, but he has paid a debt to nature in practising economy instead of waste of her forces, and fulfilled a duty to society which might be imitated by other coal users on land and sea, for he has taken full use of his coal gases, and his chimneys are now restricted to their primary use, that of creating a draught, and not for creating an intolerable nuisance.

At the meeting held on 24th March, 1896, Mr HENRY A. MAVOR, Vice-President, in the Chair,

The CHAIRMAN said that before the members proceeded to the business of the evening he had the very pleasant duty to perform of introducing Mr A. J. Durston, C.B., who was an honorary member of the Institution. It was needless to say anything in introducing Mr Durston, but he only wished to give to him a hearty welcome to the Society.

Mr A. J. DURSTON, C.B., who was cordially received, said that he was very sensible of the great honour they had conferred upon him, and sorry that circumstances over which he had no control prevented his joining them on the recent James Watt Anniversary. He took it as a special honour at the present moment, when, as most of them knew, he was engaged on special work embracing two of the greatest practical problems that had been attempted in this kingdom in connection with water tube boilers, and particularly so that these works were being carried out on the Clyde. He did not assume in any way that they approved of the special work he was doing, yet he took it as a great compliment to himself that they approved of his endeavours to do what he thought best in the circumstances. He was very much obliged to them.

On "The Manufacture of Welded Iron and Steel Pipes."

By Mr J. G. STEWART, B.Sc.

SEE PLATE XI.

Received 4th and Read 24th March, 1896.

It has been considered that a few remarks upon iron and steel pipes might be of interest to this Institution, as during the last few years welded pipes of iron and steel have been extensively introduced for purposes for which pipes of other material were formerly exclusively used.

Engineers, while generally admitting the theoretical advantage of this innovation, have not been devoid of suspicion of the new material and it has been subjected to the most rigorous examination and tests.

The results obtained by these special tests of welded steel and iron pipes have (so far as I have been able to learn) been uniformly most satisfactory.

While it would not be within the limits of this paper to enumerate every individual test to which iron and steel pipes has been subjected, the method of testing may be said to have been directed to ascertaining the strength of the welded tube against internal pressure, and the changes in elasticity and durability which the process of welding had caused in the steel or iron by breaking strips at the testing machine, and noting the elongation and the elastic strength and ultimate tensile strength of the weld.

A very large number of pipes, both of iron and steel, were experimented upon by cutting them into circumferential strips.

Each such strip would yield three test pieces 14 inches long, two being out of the unwelded part and one containing the weld across it. Pieces were also cut out of the pipes longitudinally, one containing the weld and several out of the solid plate, but no particular information was derived from this latter test.

Attempts were also made to ascertain the strength of various tubes by pressing them by water to destruction, one or two tubes out of a quantity being selected for this purpose by the consumer. This method of testing has, owing to the cost and the time involved (as in some cases the pressures reached in attempting to burst the pipes has been as high as 5000 lbs. per square inch), been superseded by the breaking test on strips which, in addition to costing very much less, gives more positive results and tells us more of the quality of the material in the pipe.

It is generally admitted that the results obtained by these tests compare very favourably with those of the material which it has been proposed to supplant, and those who have been fully conversant with them are, I believe, unanimously of opinion that the change has been justified.

The endeavours which have been made to introduce iron and steel for marine steam pipes have not been encouraged by the Board of Trade, which has placed a most hampering restriction on the use of steel steam pipes by making it a condition of the manufacture that a butt strap be riveted from end to end of the pipe over the weld, thereby weakening the pipe circumferentially by the rivet holes, and introducing a source of trouble in the rivets of the strap both from erosion of the rivet heads and possible leakage at the rivets.

The cost of riveting a strap upon a pipe is considerably more than the cost of welding it. Unless the welding be excessively badly done and the steel wasted, the butt strap is of no use, but a positive evil; and if there is any likelihood of the steel being spoilt in this way and the butt strap be a necessity, the pipe would be better not to have been welded at all.

The weld of a pipe may be so very thoroughly tested as to leave no reasonable doubt of its reliability. Strips may be cut from each end of every pipe and tested by breaking across the weld, and each pipe may be subjected to an hydraulic pressure 4 to 5 times as great as the working pressure, while it is rapped by hand hammers from end to end.

It would appear to be better policy to spend some fraction of the cost of the butt strap in some such rigorous test, and leave the full section of the plate unweakened by holes and without the objectionable rivets, than to weld up the pipe and then ignore the weld by covering it over with a butt strap. A further objection to this practice is that the pipe not being symmetrical, is deprived of some of its flexibility. Owing to these conditions imposed by the Board of Trade, iron steam pipes are used much more generally in merchant steamers than steel pipes, and have been fitted for all sizes of vessels from the "Campania" and "Lucania" downwards.

It was at first almost impossible to obtain rolled iron or steel pipes of large diameters, because of the fact that comparatively only a small quantity of each size was required, and consequently the cost of making, owing to special plant being required for each size, was very great.

The demand for steel pipes for water mains, however, has advanced so very rapidly as to provide the plant requisite for the making of steel pipes of all sizes.

For many years back, in the United States, the long distances which pipes have had to be transported has made it economically an advantage to use welded iron pipes in preference to cast-iron for the conveyance of water and oil; and more recently in our own colonies, or wherever freight is a considerable fraction of the cost, the steel pipe, which for the same strength is about a quarter of the weight of the cast-iron pipe (and where the pressure is small as compared with the diameter of the pipe not more than $\frac{1}{8}$ of the weight of the lightest cast-iron pipe which can be made), has been generally used.

Steel pipes are also demanded wherever lightness in comparison with strength is a desideratum, and for such purposes as boring wells and for piles on land and in submarine work. Piers have been built upon tubular columns which have been used to bore out their own seats on the submarine rock.

Beginning with what is probably the most important purpose which a pipe is required to serve, namely, the transmission of high pressure steam, the first requisite is durability; the material must be capable of sustaining the daily tension of work, with all attendant vibrations and shocks, without any appreciable loss of strength. To a large extent this condition will vary, and will depend upon the skill with which the line has been designed. If it is self-strained by expansion, and if condensed steam is allowed to collect and lie in the pipes, very heavy stresses will be put upon the joints, which will consequently always give trouble.

Although the author has seen arrangements of steam pipes which appeared to be of most faulty design, and is of opinion that that part of the steam engine which connects the cylinders and boilers does not receive the attention which it ought to have, it would scarcely fall within the province of this paper nor the knowledge of the writer to adequately deal with the question of design of steam lines.

Whether the design of the steam line be good or bad, the material of which the pipes are made will be deserving of some attention. The steel must be suitable, and must not be impaired by the treatment it has been subjected to in welding it into a pipe. Good steel will be spoilt by a careless or inexperienced heater, and result in a bad pipe, but bad steel will turn out a bad pipe in spite of all the care and experience imaginable.

Siemens Martin open-hearth steel is the best material for large pipe-making, being more generally equal in its composition and qualities than that made by the Bessemer process.

The welded steel pipe made of the right material and heated with care can, and ought to be, welded so as to show at the welded part an average strength and elasticity not inferior to the rest of the tube.

If it is thought necessary or advisable to test the material of the steel pipes, strips should be cut from some or all of the finished pipes, which must be left longer for this purpose. Tests made upon the steel plates before being manufactured into tubes afford no guarantee whatever of the state of the material after it has been rolled into a pipe, nor yet of, what is perhaps more important, the soundness of the weld. In this respect many engineers who specify tests have followed the course adopted in boilermaking, but there is a very much greater possibility of the steel being injured in pipemaking than in boilermaking. As a consequence, these tests, if they are to be of any value, ought in all cases to be repeated upon strips cut from the welded pipes and containing the weld transversely. This causes the first series of tests made upon the plates to be unnecessary.

A table of tests given below, and taken from various tubes, would suggest that the strip cut from the steel tube and containing the weld should have a minimum tensile strength of 21 tons and a maximum tensile strength of 26 tons, with an elongation of not less than 20 per cent. upon 3 inches.

The elastic limit of these tests, it will be noticed, varies from 14·8 to 16·6.

No. of test.	Breadth.	Thickness.	Area.	Elastic limit.	Ultimate tensile stress.	Elongation % on 3 inches.	Specimen broke	Remarks.
1	1·46	·14	·204	14·8	25·8	17½	Near weld	—
2	1·47	·14	·205	15·1	25·1	19	At weld	—
3	1·49	·27	·402	15·6	22	22½	At weld	Weld defective.
4	1·49	·24	·358	16·5	24·7	23½	At weld	—
5	1·5	·32	·48	16	24·3	23	Near weld	—
6	1·48	·32	·474	16·1	24·7	29	Near weld	—
7	1·49	·31	·462	15·8	21·7	35	Near weld	—
8	1·48	·33	·488	16·6	24	30½	At weld	—
9	1·51	·34	·514	15·5	24·5	31	Near weld	—
10	1·49	·33	·491	15·7	24·7	32½	At weld	—
11	1·49	·36	·536	15·9	25	30	Near weld	—
12	1·5	·365	·547	15·8	24·3	33	Near weld	—

It will be observed from this table that the thickest plates give the best results, and that the strength of the weld is quite as great as that usually specified for good steel plates.

The test piece No. 7, which has broken at 21·7 tons, and is consequently the weakest of the specimens, has given the highest percentage of elongation on the list, which shows that the low strength is due to the excellent quality and mildness of the material, and not in any way to weakness of the weld. Test piece No. 3, which broke at 22 tons, was not a good-looking weld, and one which might have been rejected from its external appearance. It broke, like all the rest, however, straight across the solid. The steel out of which these pipes were made is specified to have a strength of from 22 to 26 tons, with an elongation of at least 20 per cent. This elongation in plates so thin as the first two specimens is not always easy to obtain, and a little less elongation will generally be accepted when the plate is less than ¼-inch thick.

A second table of tests was taken some time ago to ascertain if the particular steel being dealt with was satisfactory, as it had been reported difficult to heat and weld.

No. of piece.	Breadth.	Thickness.	Area.	Ultimate tensile strength.		Elongation % on 3 inches.		Remarks.
				On piece.	Per sq. in.			
1	1·41	·32	·45	11	24·5	28	Weld	All broke at weld, or close to it.
2	1·57	·24	·376	8·8	23·5	17	,,	
3	1·58	·24	·379	9·1	24	17·5	,,	
4	1·57	·27	·424	10·1	23·9	30	,,	
5	1·56	·27	·42	9·7	23	30·5	,,	
6	1·57	·27	·424	10·76	25·4	23	Plate	Cut from plates previous to dealing with them.
7	1·58	·27	·426	10·5	24·6	21	,,	
8	1·58	·27	·426	9·9	23·2	29	,,	
9	1·57	·33	·518	12·48	24·1	28·5	,,	
10	1·57	·25	·39	9·13	23·4	17	,,	

The result of these tests would appear to show that the steel was only of fair quality, but the average elongation got from the welds is higher than that got from the plates, so that the welding seems in some cases to have rather improved its quality, which was certainly not what had been expected.

At the same time, two of the pieces show an elongation of only 17 per cent., which is decidedly below what would be expected of good steel pipes, and in some measure explains the report of those who were responsible for the work, that they were unable to heat the steel.

A condition of durability of great importance is the resistance to corrosion. This question was at first a great bugbear in the attempt to introduce iron and steel steam pipes.

It seems rather strange that while engineers used nothing but mild steel for boilers and boiler tubes, subject to much greater heat and in contact with water containing possibly impurities, they should have dreaded so much the effect of comparatively dry and pure steam upon the steam pipes. However, that fear existed, and was the principal difficulty to be overcome.. Copper coating was suggested, and this, by electro-depositing, was comparatively easily managed. But it was discovered that the film of copper was easily removed, and then the possibility of pitting going on at an increased rate at any part where the copper deposit might be accidentally broken was considered a still greater danger. Eventually, when practical experience revealed no such destructive effects, confidence gradually replaced doubt, and now there are sufficient cases to convince the honest doubter that the iron or steel pipe is perfectly durable.

With reference to the comparative corrosion of steel and iron plates when exposed to the action of water, air, and steam, some interesting experiments and results are taken from Mr Parker's paper, read before the Iron and Steel Institute in 1881.

Twelve pieces were got from each of 11 different makers, making 132 in all, half being left with the oxide scale on and one half turned bright; 11 bright and 11 black, from the different manufacturers, were made up into a series carefully insulated from each other by glass tubes, and each series, of which there were six, was subjected

1°, To the atmosphere in London for 455 days,
2°, To sea water at Brighton for 437 days,
3°, To bilge water for 240 days,

4°, To hot water in a marine boiler where zinc was used for 361 days,

5°, To hot water in a marine boiler where no zinc was used for 264 days, and

6°, To hot water in a marine boiler in a coasting steamer fed with foul fresh water for 336 days.

The loss suffered by the bright pieces, the loss of Lowmoor best iron being taken as 1, is given, copied from Mr Parker's paper in Table I.

The absolute ratio of surface of the black desks, corroded to total surface, is given by Table II., and the analysis of the pieces in Table III.

Table I.

Comparative Loss of Bright Iron and Steel by Corrosion.

1·33	Brown's mild steel.
1·20	Steel Company of Scotland mild steel.
1·18	Bolton mild steel.
1·12	Landore mild steel.
1·00	Lowmoor best iron.
·98	Farnley best iron.
·91	Bowling best iron.
·90	Taylor's best iron.
·86	Leeds Forge best iron.
·86	Parkhead common iron.
·85	Skerne common iron.

Table II.—Black Pieces.

Ratio of Surface Corroded to Total Surface.

·99	Lowmoor best iron.
·82	Brown's mild steel.
·79	Leeds Forge best iron.
·77	Parkhead common iron.
·77	Bowling best iron.
·72	Steel Company of Scotland mild steel.

·71	Farnley best iron.
·55	Skerne common iron.
·54	Bolton mild steel.
·44	Taylor's best iron.
·42	Landore mild steel.

Table No. III.

Analysis arranged according to Manganese present.

	Mn.	Carbon.	Sulphur	Phosphorus.	Si.	Density.
Steel—						
Landore,	·64	·18	·074	·077	·013	7·861
Bolton,	·52	·19	·068	·041	·060	7·849
Steel Co.,	·26	·10	·035	·057	·032	7·872
Brown & Co,	·11	·12	·077	·056		7·654
Best Iron—						
Leeds Forge,	·03	·14	·028	·085	·110	7·764
Lowmoor,	·01	·10	·022	·142	·120	7·689
Farnley,	·01	·11	·012	·096	·090	7·779
Bowling,	trace	·11	trace	·101	·100	7·791
Taylor,	trace	·12	·005	·136	·013	7·745
Common Iron—						
Parkhead,	trace	·09	·027	·316	·020	7·618
Skerne,	·01	·10	·027	·193	·100	7·705

It will be noticed that, dealing with Table II., the pieces which suffered the least by corrosion were those of Landore steel, and that looking through the table the steel on the whole did not lose more than the iron.

In Tables I. and II. the steel which contained the most manganese suffered the least, and their order in both tables is the same as their order in Table III., arranged according to the proportions of manganese present.

It is stated by Mr Parker in his paper that deep pitting only took place in the pieces exposed to the action of bilge water and in the marine boiler where no zinc was used, and which was filled with sea water at each port. The most distinct marks of pitting were noticed in two specimens, one of which was Farnley iron and the other Brown's steel, which behaved much worse than any other specimen, and which on analysis showed only a mere trace of manganese and an undue amount of sulphur.

Mr Parker states, in concluding his paper, that after carefully weighing the results of his experiments, the effect has not been to raise any apprehension that steel boilers or ships are likely to corrode to any serious extent more rapidly than iron ones.

It is worthy of being noticed that steel is a much better material for large pipes than iron. The principal reasons for this are that much larger plates can be made of steel than are obtainable in iron, and that the quality of very broad plates of steel is better than similar iron plates.

An iron plate of large size rarely shows any great strength or ductility across the grain or at right angles to the direction of rolling, and this is the direction in which strength is required in a pipe—that is, circumferentially; on the contrary, a steel plate has the advantage of being equally strong in all directions.

Large plates of steel are more uniform in their qualities than iron, and consequently can be handled at a high heat for welding or for bending with as little risk and more easily than iron plates, and they retain all their qualities of strength and ductility, less impaired after treatment of this kind than iron plates, provided that the heaters have been accustomed to deal with steel. A steel weld made by the process customary in tube making is in every way as reliable as an iron weld.

Some tests taken from iron pipes and plates are given below in order to enable a comparison of iron and steel welds to be made.

No. of test.	Breadth	Thickness.	Area.	Ultimate tensile strength.		Elongation.	Remarks.
				On piece.	Per sq. in.		
1	1·34	·26	·348	6·45	18·45	3·7	Across weld
2	„	·3	·402	7	17·4	3·7	„
3	„	·29	·388	8·65	22·3	15	Along pipe
4	„	·31	·415	9·4	22·6	16·25	„
5	„	·395	·523	12·7	24·2	6·25	„
6	„	·395	·523	12·8	24·47	7·5	„
7	„	·41	·549	11·7	21·3	2·5	Across weld
8	„	·4	·536	10·15	18·93	2·5	„
9	1·52	·43	·65	6·8	10·4	1·7	„
10	1·51	·47	·71	7	10·0	1·5	Across plate
11	1·46	·22	·321	5	15·6	4·5	Across weld
12	1·48	·25	·37	5·6	15·2	6·6	Across plate
13	1·44	·23	·33	4·75	14·4	4·6	Across weld
14	1·48	·25	·37	5·46	14·8	7·4	Across plate
15	1·5	·28	·42	7·7	18·3	6·6	Across weld
16	1·5	·3	·45	7·1	16	3·7	Across plate
17	1·5	·3	·45	7·1	16	5·2	Across weld
18	1·5	·39	·585	9·6	16	3	Across plate
19	1·5	·38	·57	9·3	16·3	1	„
20	1·51	·38	·574	8·8	15·35	1·3	„

Nos. 1, 2, 3, and 4	were cut from pipe	8 inches diameter.
„ 5, 6, 7, and 8	„	11¼ „
„ 9, 10, 11, and 12	„	16 „
„ 13, 14, 15, 16, 17 and 18	„	15 „

„ 19 and 20 were cut from plate for 15-inch pipe.
„ 9 and 10 of common iron, with very little strength across fibres.

While the general results from these tables would seem to demonstrate that a steel weld can be made in ordinary circumstances perfectly strong and dependable, some engineers, including the technical advisers of the Board of Trade and the Admiralty, do not appear to place much reliance upon it, and with such the name (for it is practically, up to the present, but a name) of weldless tubes has been used to conjure. The results of the conjuring have been in many cases very disappointing. While, after considerable expense and experimenting with different systems of manufacture, tubes of small diameter have been made with some degree of success, it has still to be proved that these are of better quality than welded tubes, and the progress which has been made in the manufacture of weldless tubes is far from being sufficient to ensure any great reliability or to lead us to suppose that large pipes are within any measurable distance of being made from a solid steel ingot without a weld. There are practically three methods which have been pursued, with more or less success, of making weldless tubes; one is to begin by casting a hollow ingot, the second is by piercing or drilling a solid ingot or bar, the third is by dishing a steel plate and subsequently pressing it to a cylindrical shape and cutting out the end to produce a hollow cylinder. From this point the hollow block is drawn by rolling upon a mandril until it obtains something like the required length and the walls are reduced to something like the required thickness, after which, by successive drawings through a die and with a mandril inside, it is brought to the diameter and thickness which is wanted.

A considerable number of operations are therefore required to produce these small tubes which, up to the present, have been made, and any one who considers the powerful and expensive plant which would be required to make weldless pipes as large as 3 feet in diameter must admit that the cost would be so very great as to make it necessary to have a very great inducement in superior quality in order that pipes made in this fashion could be produced.

A great number of joints have been used for connecting pipes together. In designing a joint for piping, it is not altogether or only the simple pressure upon the ends of the pipes which has to be considered. There is always a bending action at the joint, due to the unequal temperature of parts of the pipe and to expansion and vibration. The form of joint or flange which is usually preferred for steam pressure is the flange which is welded on to the pipe, and which is shown in Fig. 6 (see Plate XI.).

Various experiments have been made from time to time to test this type of flange by attempting to burst it from the pipe by hydraulic pressure, but in all such cases that have come under the notice of the writer it has been found that the pipes have burst before the flanges could be moved. Out of many such tests, two may be quoted.

A tube of steel 3½ inches external diameter and 3 inches internal diameter, with flanges of steel ¾-inch thick, has been tested up to a pressure of 5000 lbs. per square inch, at which pressure the flange bolts, though as many were put in as possible, commenced to stretch. The flanges thus withstood a pulling-off pressure of 15¾ tons.

A 9-inch diameter pipe, with flanges welded on, burst at 2400 lbs. per square inch. In this case it was possible to get 16 1⅛-inch steel bolts into the flange. The pressure on this flange was over 70 tons. The faces of the flanges were made very slightly concave by the pressure, but the weld was intact.

Fig. 5 illustrates a form of joint well suited for steam pipes, and one which, owing to the comparative economy with which it can be made, combined with simplicity, strength, and reliability, when properly formed, has probably been more used for steam pipes than any other type.

The steel flange is screwed on to the pipe with a conical and vanishing thread, so as to weaken by only the smallest appreciable extent the strength of the pipe, which is afterwards rivetted over the face of the flange.

A recess is made on one of the flanges which holds the jointing material, and into which a projection on the neighbouring flange is allowed to enter. From a number of tests made to determine the adhesion of this flange to the pipe, the following may be quoted:—

An iron pipe 12⅞ external diameter × 12″ internal, with this type of flange screwed on each end, and blind flanges bolted on, sustained a pressure of 3000 lbs. per square inch, at which pressure the pipe burst. The total pulling of stress upon the flange was consequently 144 tons, or 27,000 lbs. per circumferential inch of screwed surface.

Another form of joint used for steam pipes is shown by Fig. 3. The flanges are of cast steel, and a recess similar to that of Fig. 5 is formed, which contains the inner flanges made very simply by bulging and turning over the ends of the pipe. This type has the advantage of being able to be made in two halves which are cast with projections and recesses, dovetailing together when fixed in position, and held as securely when bolted up as if the flanges were solid. The principal advantage of this is that it enables the flanges to be shipped separately from the pipes. The slight recess formed where the flanges meet allows of water collecting in the lower part of the joint, which may have a prejudicial effect upon the jointing material. Fig. 2 shows a form of flange made of stamped steel, very useful in cases of thin pipe, and extensively used for water mains. Fig. 1 shows the very lightest form of flange; it is formed by bulging and turning over the pipe. It is apparent that the metal of the pipe is much too thin to make a proper flange, as it forms an unstayed thin surface between the bolts, unless it were thickened up very much. This has been done, but not with pipes of large diameter, as the cost of forming such a flange, owing to the time and the great pressure which would be required to thicken up the tube, would be prohibitive.

The rivetted-on flange is not generally regarded as suitable for steam pipes, as the steam has the effect of eroding the head of the rivet, and the rivets are also liable to leak; but for water this form of joint (as illustrated by Fig. 4 and Fig. 9) is very largely used in cases in which pipes may require to be shifted about, and also for vertical ranges of rising mains. Pipes of large diameter are sometimes connected together by screwing, either by screwed sockets or by forming the ends into spigot and faucet with internal and external threads. Such joints have been made for pipes as large as 30 inches diameter, but the labour involved on the field in putting together such large pipes with a fine thread makes it difficult to see how this joint can be used to advantage as a removable joint for water mains. It is used very commonly for boring purposes, as it is the only joint suited for that purpose.

For water mains generally there is the collar joint, formed by a rolled and welded steel collar enclosing a certain length of the ends of the two pipes to be joined, with a space between the collar and the pipe, which is filled with lead (see Fig. 7). The patent inserted lead joint, as in Fig. 8, is formed by bulging one end of the pipe so that it holds the other, or spigot, end of the neighbouring pipe, and making provision that the inside of this annular space is larger than the mouth, thereby forming a lock to prevent the lead from being blown out, and is an improvement upon the former joint, as it consists of only one joint, while the first considered consists of two, one on each side of the collar. This joint was first made for the Durban Water Works, where it proved very satisfactory, and has since been adapted for many other water lines, amongst others, the Buluwayo Water Works scheme, where a large number of 12-inch diameter pipes have been supplied less than ⅛-inch thick and weighing 39 lbs. per yard, as compared with the minimum weight of 12-inch cast-iron pipes of 245 lbs. per yard.

As the cost of carriage to Buluwayo was many times the cost of the pipes made here, it is evident that the total cost of the steel pipes when laid would be a mere fraction of the cost of cast-iron pipes. Further, it was a necessity of transport that no single pipe should weigh more than 200 lbs. If cast-iron pipes had been used they would, as a consequence, have required to be made in lengths of no more than 25 inches, and would have required eight times as many joints, which in itself would have been a large increase to the cost of the scheme. While we have not as yet got any great experience of the durability of such very light steel pipes, they have in some cases been in use for over 20 years, and if well coated with pitch, and receiving some attention after laying, there is no reason why they should not last.

Because a thick iron pipe will last longer than a thin one, it does not follow that a pipe one quarter of an inch thick will have but one-fourth of the life of a pipe one inch thick. This might be so if the two pipes were exposed to the air and weather, with no coating or surface protection, on the presumption that the most efficient and most economic method of protecting the pipe was to cover it with some layers of iron.

Iron being about the worst material to withstand the corrosive action of water and air, should be discarded as a protector to the pipe. If the two pipes are carefully coated with an efficient protective material, corrosion will not begin so long as the coating remains intact, and both pipes will be equally good. The life of the pipes will then be practically the life of the coating, as after this disappears corrosion sets in and proceeds at the rate of $\frac{1}{64}$ up to $\frac{1}{16}$ of an inch per annum.

In selecting the thinner pipe for economical reasons we strip off the three-quarters of an inch of iron, which serves no other purpose than that of for a time preventing the corrosion reaching the inner pipe proper quarter of an inch, and cover the pipe internally and externally with a material which will resist all natural chemical action, and will prevent any corrosion setting in until it is mechanically abraded or worn away on the inside.

In the after discussion,

Mr JAMES RILEY said that he had no intention to speak upon this paper at all, but in listening to it one could not but be struck with the admirable way in which Mr Stewart had marshalled the facts in favour of the use of pipes made of steel. He had been frequently very much astonished that so little had been done in this country in the use of steel for that purpose, when one bore in mind the great cost of removals that they read of having to be made in the large mains in the city. The statement in the paper recalled to his mind a fact that perhaps was not very well known, but which was perhaps one of the best illustrations of the use of steel water mains that might be found in Great Britain, although there were more recent ones. The tubes of the pipes to which he referred were made by the firm with which Mr Stewart was connected, and were laid across the Tay Bridge—two miles in length of 9-inch socket and spigot pipes. The joints were made in a manner not described in this paper, but which he (Mr Riley) designed, and which, he believed, had given every satisfaction. Not a single moment's trouble had been given with these pipes from the day on which they were put down (some ten years ago now), neither in respect of failure of the joints nor failure of the welds, which were admirably done by Mr Stewart's firm, nor of corrosion of the metal, so far as he had heard. The steel was made by the Steel Company of Scotland. Before that range of piping was put down, a number of pipes were sent from that firm (made of sheets only one-sixteenth of an inch thick) to Central America, and from time to time he had reports of the way in which they behaved. No fault was found, and corrosion was prevented by the admirably successful methods described by Mr Stewart, so that one would suppose that now when this metal was so cheap as compared with what it used to be, the inducements to use it and to obtain the safety which could be derived from its use should be very much greater, and, one would suppose, should lead to the adoption of the material in the large mains which were made from time to time in this country.

Professor **Jamieson** said that he would like to have Mr Stewart's opinion as to the best means of protecting against corrosion about 1000 feet of thin steel piping of from 3ft. to 4ft. diameter where the same would have to be buried in the ground for the greater part of its length. Further, he would like to know if it would be better and cheaper to have such large pipes welded or rivetted, and which would be the most convenient form of joint, seeing that the internal pressure was simply that due to 3 or 4 feet "head" of water.

Mr **Robert Laidlaw** said his firm had been making some of the heaviest cast-iron pipes that had ever been used, and he hoped that the trade would go on for some time. There were about 4000 tons of piping, which many of them might have seen on the streets, for the high pressure water supply in Glasgow. The main pipes were 7 inches in diameter, weighing 13½ cwts. each, and were proved in his works to 3000 lbs. per square inch, and he would be very glad if many engineers would use that weight of pipe. He had not had an opportunity of seeing many of these steel pipes. He knew that his friend, Mr Stewart, had cut him out sometimes with steel pipes in South Africa because of the very high carriage, and Mr Stewart had told them that the carriage came to about four or five times the value of the pipes. Professor Jamieson had been asking how long a steel pipe would stand in comparison with a cast-iron pipe. He supposed that that had to be found out yet, but they all knew that in certain ground malleable iron and steel corroded much quicker than cast-iron. He had seen cast-iron pipes in St. Petersburg which had been lying in the ground for over 100 years, and they seemed to be as good to-day as they were at first, but no one could tell yet how long light steel pipes would stand. He had come for information, and he thought they ought to be very much satisfied with the excellent paper Mr Stewart had put before them. He had no doubt that in time there would be a very large quantity of these steel pipes used, especially in foreign places where carriage was a large factor, because, if they sent pipes from this country, they might get them out to the seaboard pretty cheap, but the inland carriage, perhaps on mule or bullock back, increased the cost, although there was no doubt there would be a large market for them. Personally he hoped that cast-iron pipes were not yet done.

Mr SINCLAIR COUPER hoped that some engineers who had used these steel pipes under steam would give their experience, after Mr Stewart had gone to the trouble of providing for them this very interesting paper on the construction and manufacture of these pipes and joints. He himself had supplied some lines of steel pipes for steam purposes up to 13 inches diameter and for pressures up to 180 lbs. per square inch, and the form of joint used was that one described by Mr Stewart with the flange screwed on the end of the pipe and the face of the flange slightly bell-mouthed or bevelled, the edge of the pipe being rolled over on it. He had never had any trouble with these pipes, tested by hydraulic pressure to double the working pressure, nor had he heard of any trouble with them under the steam pressure. There was one advantage with the flange screwed on as described, and that was that sometimes, when putting up pipes abroad, men could not always get a pipe to come in dead true to the actual space at their disposal; but in this system, if one or two of the pipes in a line of piping were sent out with the ends screwed for a greater length on the body of the pipe than usual, and if the flanges were left unrivetted, the engineer then had a chance of adjusting the flanges on the pipe to make it occupy exactly the required space. There was one difficulty that Mr Stewart had mentioned, and that was the question of bends. Bends could not be made except of certain lengths according to the diameters of the pipes. That, of course, applied to pipes of any material; but in welded pipes of wrought steel the minimum length of a bend seemed to be very considerable. That was an objection, and they had been forced to get bends of cast steel or copper. This occasionally occurred where there was a long line of piping, and where an allowance had to be made for expansion. The ordinary expansion joint with the stuffing box and gland was objectionable, as it was very often found to be stuck fast when most needed. The expansion joint which his firm usually supplied had been in the form of a U bend or a circle, but that had to be made of copper when the pipes exceeded 6 inches diameter, because they could not get steel bends to the small radius sometimes required for such a purpose. Perhaps Mr Stewart would be able to tell them what was the minimum ratio which the radius of the bend must bear to the diameter of the pipe in his welded steel pipes. It was a pity that the paper had not been printed and circulated in the meeting, as they would then have seen the tables quoted by Mr Stewart, and would perhaps have been able to discuss it a little more fully.

Mr DURSTON, C.B., said Mr Stewart in his first remarks had stated that the Board of Trade had put on some restrictions in regard to butt strapping of welded steel pipes. He should like to say that the Admiralty also insisted on the same condition with regard to welded pipes, whether of steel or iron; but certainly, if Mr Stewart's tests as to the welds were correct and as to the welded portion of steel pipes, and if they could be sure that that could be said of all welded steel pipes, then their conditions would require reconsideration. He had quite an open mind on that matter, but the use of steel for steam pipes was only taken up in recent years, and now they were using it to a very great extent. From 1½ to 6 inches diameter they used solid drawn steel pipes; beyond 6 inches, the pipes were welded and strapped over the weld. As far as they had gone, they had no reason to regret the step they had taken in using steel. They felt very much safer with steel than with thick copper sheets. The main steam pipes of the "Great Eastern" were made in wrought-iron when steel was not in use for that purpose, but it was interesting to note that so many years ago a malleable pipe was used for steam pipe purposes. He agreed with Mr Stewart that the screwed-on flange appeared to be very suitable for steam-pipe purposes. As to his remark as to the value of tests before material was made into pipes, such tests would certainly be of value as giving some indication of the character of the steel used. He quite agreed that tests should be made also after the pipe was manufactured. That question of welded tubes had a very important bearing as used for water tube boilers. There was a considerable difference of opinion as to whether solid-drawn or lap-welded pipes were preferable; and although the Admiralty at the present moment were using solid drawn pipes for that purpose almost entirely, they knew that in two important vessels they had lapwelded tubes, viz., in the "Powerful" and the "Terrible."

The CHAIRMAN (Mr H. A. Mavor) said that this was one of those papers that were rather difficult to discuss without having been in one's hands, and he thought that, as usual, they had better carry forward the discussion till next meeting. Before passing to the next business, he would like to ask Mr Stewart to explain whether there had been any more experience in the use of Ferranti's expanded joints as used at Deptford Lighting Station, where a pipe was jointed by putting it into the flange and expanding it into three grooves which would be about three or four inches. These were used for very high pressures, and they did extremely well. Another form of joint was made by passing a sleeve over the end of the joint, simply grooving it by a tool which forced the groove also into the pipe itself. He understood also that these were subjected to a very high pressure, and that the joint ultimately gave way at something like 2000 lbs. The pipe did not burst, but jumped from one corrugation to the other. It would be interesting to know whether there had been any more experience during the last five or six years.

The discussion of this paper was resumed on 28th April, 1896.

Mr CHARLES P. HOGG said he would like to ask Mr Stewart what the minimum thickness of steel was which would make a good sound welded joint, and also whether that thickness depended to any extent on the diameter of the pipe. Last year he had had occasion to send some steel pipes to South Africa, ranging from 20 to 30 inches in diameter. He would have preferred to have sent welded pipes, but, unfortunately, they required to be of the somewhat unusual length of 16 feet 6 ins., and he found that the maximum length of welded pipes then obtainable was about 15 feet, which, everyone must admit, was a very good length indeed. There was one point in favour of sending steel pipes abroad, and it was this, that they gave very great facility for nesting inside each other, thus saving freight. That was a great advantage in addition to the convenience with which they could be transported up country. He did not think there was any other point to which he had intended to allude.

Mr ANDREW LAING said he had only used iron pipes for steam purposes; but, going through Mr Stewart's paper, he thought he was to be congratulated on the information that he had brought together in the way of data showing the strength of the metal welded and otherwise. When he started using iron pipes a number of years ago for steam purposes, there was a good deal of prejudice to be overcome on the part of the Board of Trade, the owners, and others, but, after several interviews and a good deal of correspondence, he had got the Board of Trade to accept them; and so well were they satisfied with the result of his tests, carried out at Messrs A. & J. Stewart & Clydesdale's Works, that the Board of Trade issued with their instructions to engineers a rule for iron pipes based on these experiments. He mentioned that the Board of Trade were willing to accept iron pipes lapwelded, but, if the pipes were to be of steel, the joints would require to be strapped and rivetted. Perhaps at that time they were justified in their decision, but with the great experience and the improved appliances at the makers' disposal for work of this class, there need not be the same reason for objecting to the welding of steel. This would to a great extent, however, depend upon the care with which the welding was done. It was not stated in the paper read whether the whole length of the pipe was welded in one heat or in stages. The latter was the usual practice with the welding of furnaces, but if the former method were used, he thought, a more uniform and reliable weld could be obtained and the straps dispensed with, if the weld was the only point in question. If the pipes were for steam purposes, made from steel, and welded in stages, then the strap came in as a safeguard. He had seen some steel tubes of large diameter welded on the stage principle with welds in such a condition that he should not have considered them safe without a strap, and this unsatisfactory work by some makers was the cause of good makers being hampered with precautionary fittings which should be unnecessary when the steel was suitable for welding. From what he had seen in connection with the amount of care necessary for the protection of steel and iron against corrosion, particularly in places difficult of access and where there was a good deal of wet and dry heat, iron, in his experience, had proved the best material. He was confirmed in his opinion for the use of iron for main steam pipes. Hard iron heated to a dull red heat and dipped in a heavy oil after the pipe was made was less subject to corrosion. Up to the time when he started the use of iron for large main steam pipes there was very little reliable information to be had on the subject, and any that he had was got from the examination of some iron pipes taken out of the "Great Eastern." He happened to procure some of those, which showed that after the years that they had been at work the amount of corrosion was very trifling. These pipes were made from good Yorkshire iron. From this, and his observations of corrosion generally, he thought he was justified in his choice of iron in place of steel. He mentioned that he had passed steam through iron steam pipes for about 200,000 I.H.P. After reading the author's paper, he had made inquiry at those who were using the iron steam pipes on shipboard, and who had had them at work and under their inspection for over five years, and he found that those iron pipes, after having been in the ship for that time, were as clean and sound as the day they were put in. There was no sign of corrosion anywhere, and the pipes internally were oil-coated, and the flanges quite tight at the screw. Some engineers feared that, when they set the pipes to work, they might have some scale or grit passing into the engines from the pipes, but up till now there had been no indication of that whatever. An objection was raised sometimes to the method of fixing the flanges on pipes. He might mention that in all cases he screwed the flanges on, the back of the flange being screwed hard up against the end of the thread of the pipe, the face of the flange countersunk and the end of the pipe rivetted over. The author showed several designs for joints, but the screwed on flange was a very convenient fitting, and so far had given no trouble. At the same time, the welded-on flange was a very neat piece of work, and it had the advantage of being lighter than the screwed-on flange. With a well-designed arrangement of iron steam pipes, a direct and simple and easily drained lead was obtained with simple fittings, and expansion was a simple matter to deal with. In the "Campania," where he carried one 20-inch main lead from each of the stoke holes to the engine-room, and had to provide for about 3 inches of end movement, he did so with one expansion stuffing-box, the pipe flanges at intervals being carried on rollers to allow the pipes to move freely. Even with this movement and the friction of a large stuffing box, no trouble was experienced either at the joints or the flange connection to the pipes. He only allowed there one expansion joint, and he found that with the working due to expansion not a joint gave way, and there was not the slightest sign of leakage at the screw of the flange. His experience with iron piping was that it was much superior in every respect to copper for main steam pipes. He would conclude by merely saying that the result of his experience for the number of years that he had used the iron pipes only confirmed the idea that he had when he started, viz., that iron and steel were safer than copper. With the introduction of the iron main steam pipes on shipboard, he felt that the lives of those on board were more secure than with steam pipes of copper, a material that had done good work for that purpose at low pressure; but with the increased pressure and higher temperature it was not so reliable as iron and steel. Perhaps, when they learned something more about nickel steel, pipes might be made from it with advantage over iron and carbon steel.

The CHAIRMAN (Prof. Jamieson, Vice-President) mentioned that Mr Laing had taken a radical departure in piping some years ago in the case of the "Campania" and "Lucania," and he was very pleased that Mr Laing was able to give them such good information.

Mr ROBERT T. MOORE said that he had read Mr Stewart's paper with great interest. There was much information in it which was of great value to any one who had to do with malleable-iron pipes. He had had a good deal of experience with malleable pipes for hydraulic pumping in mines, and there they used pipes up to 4 inches internal diameter, with pressure occasionally rising to a ton per square inch. In all cases he had used iron pipes, and not steel pipes. He had always found that about 3¾ tons per sectional inch of iron was a sufficiently high stress to put upon these pipes. Beyond that, there had been burst pipes. Steel pipes did not seem to him to be better than iron, as he found that the pipes which had burst had generally done so at the weld, and at stresses much below the breaking stress of the iron used. Before the pipes were put in, they were tested with a pressure of water of 4000 lbs. per square inch, and were rapped with a hammer while under the pressure; but he found that pipes sometimes burst at pressures which were not a ton to the square inch, and it had occurred to him that the bursting in those cases was due to imperfect welds, which were good enough to stand the steady pressure, but got separated with continued shocks. The joint used was the screw coupling tapering towards the centre.

They had had great satisfaction in the use of malleable-iron pipes.

Mr A. S. BIGGART said that after reading Mr Stewart's paper at least twice over, it seemed to him that he made some bold and plain statements, and with a good deal of reason supported these to a great extent. If they looked at the last paragraph on page 200, they found that Mr Stewart said "The welded steel pipes made of the right material and heated with care, can, and ought to be, welded so as to show at the welded part an average strength and elasticity not inferior to the rest of the tube." That was a very remarkable statement to make if it could be borne out by facts. If they considered that statement with the tables Mr Stewart had given them, they would find that, judged by these, it was not very far wrong. It would take too long time to analyse the tables on p. 201, and it would serve no good purpose to mention the figures; meantime, if, however, they looked at the ultimate strength of all those tests that had been broken with the weld at the centre portion of the test piece that fully bore out Mr Stewart's statement, that these tests were taken from steel with a tensile strength of 21 to 26 per square inch. Not one of these tests came under that, and on the whole they were a very fair average of what they would expect from steel before being treated by welding at all. It was borne out by another table on page 202. In face of results such as these, they would say that it was rather a hardship that the Admiralty or other authority should insist on having straps rivetted over the weld of such pipes, and it might be well that the committee they had appointed by their own Institution and some of the technical institutions of the country should bring this matter before the proper quarter and see if they would not reconsider any such decision with regard to whether it was essential or not to have such straps welded on all pipes used for steam pressure. They could quite well understand why the Admiralty or other Board should be conservative in many of their ways. One of their first maxims must be safety, and the tendency would always be that such a body should stand by what they had proved to be safe in the past and conservative in dealing with new ideas as to design or material; but if the manufacturers brought forward welded pipes such as those referred to by Mr Stewart, and were prepared to offer such tests as Mr Stewart said they were willing to do, it would be very difficult for any Board or committee to withstand the pressure that could be brought to bear upon them with such facts before them. Why should the Admiralty or any other committee object to use welded material? They did not object to welds in many parts of an engine. He supposed that there was no engine that had not many welds in some of its most important parts, any one of which giving way would cripple the entire ship. Many other instances might be brought to show that it was a mistake to object to a weld simply because it was a weld. With regard to the length of the pipes that could be welded, Mr Hogg had asked a question, and as Mr Stewart was not present he (Mr Biggart) might be able to answer it. They (his firm) had made all the machines for Mr Stewart for the welding of these pipes, and quite recently Mr Stewart had got mandrils for welding pipes, if his memory served him aright, which could weld up to some 20 feet in length with an internal diameter of pipe of about 12 inches. He believed that the success of this welding was very much due to the methods adopted. None of these pipes were welded under the ordinary conditions. They were heated by gas and passed underneath and over rollers, and the result was that they had on a practical scale what Mr Stewart said in these tables, and they not only had it at one part of the pipe, but practically in every part of every pipe that they turned out.

Mr FINLAYSON said that at the Clydesdale Works they had 600 feet of 24-inch welded pipes, and the flanges were screwed on in the same way as Mr Laing had explained. They had not had a single failure nor a leak in one of them. In the hydraulic pipes and the feed pipes they had the flanges and all the branches welded on. There was something like 3000 or 4000 feet of them, and they had had no difficulty with the welded branches nor anything else. They had not a single cast-iron pipe in the whole range. With regard to the bends that Mr Couper spoke about the other night, their 24-inch diameter bends were only 24 inches square, and they could make them perfectly sound. They had had no difficulty with them. They were steel bends, and they had no expansion joint in the range, but there were two U pipes for expansion in two places, where a short connection was made from the main pipes.

Mr JAMES GILCHRIST said he could corroborate what Mr Laing had said in connection with the superiority of iron pipes over those of copper or steel. He could not speak of putting 200,000 I.H.P. through his pipes, but he had done a small share of such work, say about 10,000 I.H.P., and he could quite recommend the use of iron pipes, both for steam and feed pipes, instead of copper. He would rather use iron pipes in steamships than copper ones, as was formerly the custom. Iron was much more reliable, and it did not oxidise as was expected it would do. He had not the same faith in steel pipes; he would rather use the iron. With reference to what Mr Biggart had said about the flanging and the strapping of pipes, he thought Mr Biggart must be under some misapprehension, because the Board of Trade were not now in the habit of insisting on straps in such tubes as plain furnaces where there was a weld. In all vessels having boilers which had not corrugated furnaces they were allowed to weld plain furnaces without any straps.

Mr BIGGART—Should I not have said the Admiralty? I believe I said the Board of Trade.

Mr GILCHRIST—Yes. There is no difficulty in welding, provided you make a good job.

Mr MOLLISON said he did not know if he could add very much to what had already been said. Within the last few years a great many vessels had been fitted with iron welded steam pipes, and personally he must say that, in going about boilers and engines when getting up steam for the first time, he had much greater confidence in those pipes than sometimes he had with regard to pipes made of copper. In the matter of safety, therefore, there was no doubt that iron or steel was a great improvement on copper, particularly in the case of large pipes for high pressures. With reference to the welding of steel pipes, in his opinion that could be done quite as efficiently as with iron; and in the case of certain water tube boilers approved by the Committee of Lloyd's Register the lower drums were all welded, and not afterwards fitted with butt straps, no restrictions being put on the welding of steel pipes or tubes for such purpose, experience from testing in many ways having proved the welding to be sound and reliable and much stronger than iron. This was borne out in the tables of tests given by Mr Stewart. The welding of steel furnaces referred to by Mr Biggart and Mr Gilchrist had for many years been successfully carried out. The conditions, however, under which they were worked were different from pipes, the former being in compression, while the latter were in tension. The subject was of much importance to engineers, and he had to thank Mr Stewart for bringing it before the Institution.

Mr THODE said that the paper was certainly most interesting. A great deal could be said for it, and he believed that everything that could be said would only be in favour of iron and steel pipes. The quality of the steel that was made nowadays seemed to be as suitable for welding as iron, and in those cases the welds were quite reliable, as Mr Stewart had clearly made out in his paper. His firm had used a great number of steel and iron pipes in installations for carrying steam, and to his knowledge there had been no failure. They had tried flanges screwed on and expanded over, and, all things considered, it seemed as if this was the most suitable practice, provided the flanges were made heavy enough. A great number of pipes would fail, and joints would leak through the screws if the flanges were not heavy enough. There was another point about which often a great number of questions were asked, and that was how to deal with the bends. It seemed as if they could be obtained without much difficulty provided the radii were fairly large. Another question was the matter of fittings. This was mostly overcome by introducing cast-iron elbows, or by introducing cast steel, but he understood that the Messrs Stewart were laying themselves out for producing this also in wrought-iron or mild steel. While the discussion was going, he had been running out a few figures. His company, as perhaps was known, made water tube boilers. In the construction of these, the staggered or sinuous headers at the front and rear end into which the tubes were expanded were made of mild steel and welded together longitudinally. He had been taking the numbers, and had found that they welded in the last year about 65,000 running feet, and the failures in the welds on test amounted to less than 1 per cent. The total horse-power that would be represented by these headers, through which water and steam circulated all the time, amounted to about 80,000 horse-power. He thought that nothing could speak better than this in favour of the adoption of welded iron or steel pipes for all conditions and under all circumstances.

On the motion of the Chairman, a hearty vote of thanks was given to Mr Stewart for his excellent paper.

Mr J. G. STEWART, replying to the discussion, writes:—

As to Mr James Riley's remarks "referring to Tay Bridge, which was, I believe, the earliest case of steel water mains with lead joints in this country," the joint used was similar in appearance to that shown on Fig. 8, but the socket was made separately from the pipe, and afterward fixed to it. Mr Riley's supposition that engineers would have by this time adopted steel as a material for water pipes in this country as better than cast-iron, is unfortunately not yet fulfilled, and the reason given by Mr Laidlaw, who has no doubt considered the advantages of cast-iron pipes, is that he has seen cast-iron pipes in use for 100 years, but no one knows how long light steel pipes would stand. If engineers, however, are going to be so very cautious as to wait until we have steel pipes tried in this country for 100 years, Mr Laidlaw has still many years of good business before him, and this paper will prove to be somewhat premature. In America lately I was told by an iron pipe founder that the general opinion there was quite the opposite, and as a matter of fact a far greater quantity of pipes has been laid down of wrought-iron and steel than of cast-iron, and this at higher prices for the wrought-iron pipe.

In reply to Professor Jamieson, the coating for steel pipes recommended is composed of a mixture of oil, tar, and natural pitch put on at a temperature of about 250 deg. Fahr. For a pressure of 4 feet head of water, welded pipes about $\frac{1}{8}$-in. thick have been supplied jointed by rings and cement, but it is possible rivetted sheets, much thinner and consequently cheaper, would serve for such a pressure.

Mr Sinclair Couper raises the question of the minimum radius of bends. Generally a bend of large radius is preferable to one of smaller, as being more easily bent and with less thinning of the outside; the joints are also less liable to be injured by the strains caused by the expansion of the pipes. Bends of very short radius, as short as desired, could be made, but not by bending a straight pipe, but it is comparatively rarely that such have been demanded.

In reply to Mr Durston, it may be pointed out that if the tests were made on the pipes, as recommended, these would indicate the quality of the steel quite as satisfactorily or more so than the preliminary tests of the material. I have not heard of any further use of the Ferranti system of joint referred to by Mr Mavor. There would be some risk in using such a joint if it were made carelessly.

In reply to Mr Charles P. Hogg, perfectly sound joints have been made with sheets of $\frac{1}{16}$-in. thick, but the most advantageous result of pipe welding is got by using somewhat thicker plates. For instance, for 12 in. pipes, $\frac{3}{16}$-in. thick is the usual thickness for test pressures up to 400 lbs., and $\frac{1}{4}$ up to 600 lbs. Pipes of greater length than 16 ft. 6 in. are frequently made.

Mr Laing has done so much to introduce iron steam pipes in the past that one would require to be on very sure ground to question his opinions. He, however, knows something of the difficulty of making a large iron pipe free from defects, and though the resulting pipe may be better than a copper pipe, it is far from faultless, and I can assure him far inferior in strength and reliability to a steel pipe. The only admissible reason for preferring wrought-iron is the idea of some engineers that steel is more easily corroded. From the experiments of Mr Parker, quoted in this paper, it appears that this is only true to a very slight extent with bright surfaces, and that where the oxide has not been removed the steel plate does not become corroded to a greater extent than the iron plate. I think it will not be going too far to say that had the "Campania" been fitted with steel steam pipes Mr Laing would have had quite as good a report to make of their condition, and would have been as much assured of their superiority to iron pipes as I am pleased to note he is of the superiority of iron to copper for this purpose. As Mr Laing states that iron is more reliable than copper at high temperatures, I wish to quote a few tests on steel welded pipes made recently at the temperature of very high pressure steam. The specimens were able to melt lead when broken, and were consequently tested at a temperature of 620 degs.

Steel welds cut from pipes and broken transversely while hot.

Dimensions of piece.		Area.	Tensile stress.		Elongation.
Breadth.	Thickness.		On piece.	Per sq. in.	Per cent.
1·5	·325	·488	13·3	27·2	12
1·53	·50	·765	20·1	26·3	13
1·5	·405	·608	16	26·3	12
1·55	·58	·9	27·7	30·8	10
1·54	·38	·585	15·1	25·8	11
1·53	·35	·536	17·2	32	16

Mr Moore's experience with iron pipes for hydraulic purposes shows the welds to be so weak that I suggest it is possible that the actual pressure has been under-estimated. In the case of a small pipe such as alluded to, sustaining a pressure of 4000 lbs., the blow of a hammer might cause a momentary increase of pressure at the point struck which it is impossible to estimate. The general idea I have got of the strength of a good iron welded pipe is for a minimum 14 tons per square inch of section. The thicker the pipe is, after a certain thickness proportionate to its diameter, the weaker its sectional area becomes owing to the weld, and the material not being so solid as in a thinner pipe. For example, if six tons per square inch is a safe burden for the weld of a 4 in. pipe ¼-in. thick, it will be too much for a 4 in. pipe 1 in. thick. As shocks are generally inseparable from hydraulic pressure, I think Mr Moore's practice of hammering pipes, while under test pressure, is advisable, and as the pipes must be thick, the working tension ought to be kept to a moderate figure.

In reply to Mr Biggart, the Board of Trade and the Admiralty both object to steel welds in boilers and steam pipes being subjected to tensional stress, although not to compression as in a furnace flue, as Mr Gilchrist stated, but both of these authorities make exceptions to this law when they are in a difficulty and have no other way of getting out of it. The doctrine of infallibility appears to require the practice of indulgences. As a mistaken impression has arisen from Mr Biggart's remark with reference to the machines made by his firm, I have no doubt he will allow me to correct it here. The machines in question, parts of which were made by Mr Biggart's firm, were designed for a special purpose, which they fulfilled very well, but the work turned out by them is but a very small proportion of the welded pipes made and of the pipes upon which the tests were given in this paper.

I am glad to find that Mr Mollison and Mr Thode are at one with me in the reliability of steel welding. The bending and shaping of the header tubes referred to by Mr Thode is the most severe test I know that the welding could be subjected to, and I believe that attempts to make these of iron tubes have generally resulted in failure.

On "Nickel Steel."

By Mr WILLIAM BEARDMORE, M.I.M.E.

(SEE PLATES XII. AND XIII.)

Received and Read 24th March, 1896.

WITH the growing demand for ships to steam 30 knots an hour, boilers to work at a higher pressure, greater strength with lighter sections, the idea is being borne in on us that if we would keep pace with the times, we must obtain for structural purposes a material possessing a higher tensile strength, with greater toughness and ductility, than ordinary carbon steel.

Up till now this metal has been more than equal to all that was required of it, but it would seem as if "a better iron" were needed to supply the latest wants of engineers and shipbuilders.

If not carbon steel, then what metal must we use to meet the ever-increasing demands?

Many opinions seem to point to nickel steel.

I have recently made a series of tests of nickel steel of different qualities, and desire to submit the results of these to the members of this Society, in the hope that they may not be without interest.

It may be well to remark at the outset that the various test pieces were not in any way specially prepared, but were taken from plates, etc., passing through the ordinary routine in the fulfilment of orders. No special material was cast for this purpose.

That nickel steel can be made as regular in composition, and in every respect as reliable as ordinary carbon steel, needs no demonstration, and the fact that I am at present, and have been for the past three years, making large quantities of this metal for a variety of purposes, is sufficient proof, if indeed any were needed, that nickel steel has passed the experimentnl stage.

This alloy is being largely used by engineers in America, and its use there, like everything else in that wonderful country, has proved a big success.

Like all other new things, nickel steel will doubtless be associated with some uncertainty in the minds of engineers who have not had an opportunity of studying its character and the many advantages it offers as a structural material.

It is with a view to removing this dubiety, and proving that what can be done with carbon steel can be more advantageously accomplished with nickel steel that I venture to put before you the results of my investigation.

Plates of two grades of steel were experimented upon (1) mild steel—charge D300—corresponding to ordinary boiler plate quality, and (2) steel of a higher grade — charge D266 — suitable for such work as the shells of torpedo boat destroyers, etc., where lightness of section, combined with great strength, are the desiderata.

The tests of these two qualities were taken from thicknesses varying from ⅛ to 1 in., and comprised tensile tests, ordinary and punched; bends, cold, temper, and punched; drift, rivetting and welding tests.

Bars of mild quality were also subjected to fatigue tests, and their behaviour under this treatment compared with ordinary carbon steel.

Nickel steel rivet bars and rivets were also tested, and steel of a quality suitable for engine forgings.

A series of tests were also carried out by Messrs D. Kirkaldy & Sons on a bar of nickel steel of mild quality, and on two samples of nickel steel sheets, the results of which are given in Tables I. and II.

Beginning with the ordinary tensile tests of the mild grade on Table III., we find that we have in this quality a steel which will stand a tensile strain of 38 tons per square inch whilst giving an elongation of 19 per cent. on 8 in.

Passing on to Table IV., and taking the averages of the results given there, we find that this quality of steel has a tensile strength of 52 tons, and an elongation of 13 per cent. on 8 in.

The British Admiralty requirements for the shells, etc., of torpedo boat destroyers are 37-43 tons, with 10-15 per cent. of extension in 8 in.

In this—D266—steel we have a metal which gives all the extension required, and in the thinner sections, 51 to 54 tons per sq. inch, an increase of 31 per cent. over the Admiralty requirements.

A number of test pieces from the various thicknesses were prepared from these two charges, 3 in. by 18 in., having holes punched in the centre.

These were pulled in the testing machine, and the results, which are given on Table V., elicited this valuable information, that the loss of strength due to punching in nickel steel is very much less than in carbon steel.

Comparison of the results on Tables III. and IV. with those on Table V. will show that the loss of strength due to punching in the test pieces from D266 is equal to 20 per cent. of its original tensile strength, and in the case of the steel from D300 to 15·5 per cent. of the original. If only the four heavier sections of D300 be taken into account, the loss due to this treatment is reduced to about 10 per cent.

When it is remembered that the steel from D266 was of 52 tons tensile, these results are somewhat remarkable.

If the loss of strength due to punching in ordinary mild steel be taken as 33 per cent. of the original, the superiority of nickel steel under this treatment is apparent.

Carrying the investigation further, I had a number of holes punched in pieces of ½-in. plates, from each of the two charges, as close to the edge and to each other as possible, and the results proved nickel steel to stand punching better than ordinary steel of the same carbon content.

Fig. 1, Plate XII., shows these punching tests.

Having satisfied myself that nickel steel was reliable as regards punching, I had some rivets made of this metal, and these were found to be considerably tougher than ordinary rivets, and as you will see from the specimens on the table—which gave a tensile strength of 35·7 tons per square inch, with an elongation of 36 per cent. in 1¼ in., with a contraction of area of 60 per cent.—they are very ductile. Results of tests of rivet bars and rivets are given on Table VI.

An ordinary and a nickel steel rivet were nicked with a chisel and hand hammer and then broken; you will notice the difference in the appearance of the fracture. In the case of the nickel steel the fracture is fibrous, and the metal appears to have torn gradually, whilst the ordinary carbon steel rivet has broken short.

A single rivetted butt joint 6 in. wide was made from ¾-in. plates from D266 with double ½-in. butt straps, having three rivets on each side ¾-in. diameter 1⅞ in. pitch, the holes being punched.

On pulling in the testing machine four rivets sheared at 82·6 tons, equal to 23·4 tons per square inch.

A double-rivetted lap joint 6 in. wide was made from ¾-in. plates from D300, having three rivets in one line and two in the other, ¾-in. diameter 2 in. pitch, the holes being drilled.

On pulling in the testing machine the five rivets sheared at 69·85 tons, equal to 31·07 tons per square inch.

The bend tests from D300, Figs. Nos. 2 and 3, call for no remark.

They in no way differed from carbon steel, but the results of the bends from the other quality, Fig. 4, Plate XIII., are superior to anything I have ever seen in carbon steel of the same grade. Fig. 5 shows miscellaneous kinds.

Drift tests were made in pieces 6 in. square, of various thicknesses, having holes punched or drilled (1) in centre of test piece, and (2) one diameter from each edge.

Some of these test pieces will be found on the table, from which it will be seen that nickel steel can be satisfactorily drifted.

The experiments with the fatigue tests brought out one very interesting fact of considerable importance to marine engineers.

A bar of nickel steel 1¼ in. square was nicked with a chisel and hand hammer on one side, and then put under the tup and hammered till it showed signs of fracture, which it did after five blows, the experiment was continued till, after thirty blows, the bar broke.

A piece of carbon steel of the same section was subjected to similar treatment, but showed signs of fracture after five blows, and broke after thirteen blows.

Weight of tup 10 cwt. falling through 27½ in. supports 9 in. apart, test pieces reversed after each blow.

These experiments proved nickel steel to offer greater resistance to breaking after being nicked than carbon steel, but they also proved something else. Whilst the carbon steel broke off *short*, the fracture of the nickel steel, as in the case of the rivets, was *fibrous*.

From this we may reason that if a crack were to appear, say in a propeller shaft made of nickel steel, it would not develope so readily as in a shaft forged from carbon steel.

The importance of this fact to marine engineers is obvious.

When considering the question of the cylinder for a large hydraulic press, which I am at present putting down at my works, I decided to have this cast of nickel steel. The casting weighed 64 tons, and was in every respect satisfactory, and I have as yet no reason to regret my decision. This casting is shown in Fig. 6.

Ingots of nickel steel show less piping and honeycombing than ordinary carbon steel ingots, the metal being more solid when cast.

Tests from billets of nickel steel 6 in. by 5 in., cogged from an ingot 18 in. by 23 in., gave the following results :—

Tons per square inch.	Elongation per cent. 8 in.	Elastic Limit per cent. B.S.	Contr. of Area.
44·8	20	73·8	54·6

This is a quality of metal well adapted for engine forgings, and certainly if metal of this kind were used for the working parts of high-speed engines, these might be very materially reduced in weight.

It seems to me that for such work as torpedo boat destroyers, if the shell were made of metal similar to that of D266, and the working parts of the engines of such material as we are now considering, a substantial saving in weight might be effected.

Probably the most striking feature of nickel steel is its high elastic limit, which, in the case of a steel such as I recommend for engine forgings, may be taken as 70 per cent. of the breaking strain.

The yield point of nickel steel of D226 grade is about equal to the ultimate tensile of ordinary steel, as is shown in Table VII. The British Admiralty requirements for ship plates are 26 to 30 tons tensile. D266 gives 52 tons tensile, and the *yield point* is 28 to 30 tons, equal to the *ultimate* tensile strength required by the Admiralty.

In nickel steel we have a decided gain in tensile strength, without the dangers attendant on this result when obtained by raising the percentage of carbon.

There seems to be a considerable diversity of opinion regarding the welding properties of nickel steel. In my experience this alloy can be welded as easily and as satisfactorily as carbon steel.

You will find on the table some pieces of nickel steel plates which I had welded and broken in the testing machine.

An examination of these will show that without doubt nickel steel can be welded.

On Table VIII. will be found the results of the tests of the welded pieces compared with the same steel in the normal condition.

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Table II.—Results of experiments to ascertain the elastic and ultimate tensile strength, etc., of two pieces of nickel steel sheets.

Test No.	Description.	Original.		Stress.		Ratio of Elastic to Ultimate	Fractured.				Extension in ten ins.		Appearance of Fracture.
		Size.	Area.	Elastic per sq. inch.	Ultimate per sq. inch.		Size.	Area.	Difference. Area.	Difference. %	Inch.	%	
DD	Both marked N. S. A.	inches.	sq. in.	lbs. tons.	lbs. tons.	%	inch.	sq. in.					
3516	Plate 30" × 30" × ⅛"	2·00 × ·130	·260	47,800=21·3	73,910=33·0	64·7	1·72 × ·100	·172	·088	33·8	1·80	18·0	Silky
3517		„ × ·125	·250	48,500=21·7	74·040=33·1	65·5	1·65 × ·082	·135	·115	46·0	1·85	18·5	do.
3514	Plate 30" × 30" × $\frac{1}{16}$"	„ × ·066	·132	44,500=19·9	72,140=32·2	61·7	1·74 × ·047	·082	·050	37·9	1.77	17·7	do.
3515		„ × ·066	·132	45,800=20·4	73,320=32·7	62·5	1·68 × ·049	·082	.050	37·9	1·56	15·6	do.

Table III.

Dimension of Test Piece.			Tons.	Elongation.	Elastic Limit.	Contraction	Remarks.
Breadth.	Thickness.	Area.	Per Square Inch.	Per cent. in 8 Inches.	Per cent. of breaking strain	of Area per cent.	Charge D 300
1·27	·12	·152	41·4	18·5	47·5	43·1	Length.
1·28	·23	·294	39·9	19·0	53·1	45·6	Length.
1·28	·235	·300	39·6	17·0	52·5	34·0	Cross.
1·05	·39	·409	37·1	18·0	55·7	48·1	Length.
1·05	·50	·525	37·1	21·0	56·3	49·7	Length.
1·06	·51	·54	36·4	18·0	53·4	49·6	Cross.
·95	·76	·722	36·7	21·0	55·3	49·4	Length.
·95	·76	·722	36·4	19·0	54·9	47·0	Cross.
·94	·98	·921	36·2	23·0	55·8	46·0	Length.

Table IV.

Dimension of Test Piece.			Tons.	Elongation.	Elastic Limit.	Contraction	Remarks.
Breadth.	Thickness.	Area.	Per Square Inch.	Per cent. in 8 Inches.	Per cent. of Breaking Strain.	of Area per cent.	Charge D 266.
1·29	·18	·232	51·7	10·0	56·0	18·1	Length.
1·29	·18	·232	54·3	14·0	51·5	23·7	Cross.
1·29	·24	·309	54·3	14·0	52·1	26·8	Length.
1·29	·27	·348	53·1	11·0	55·3	14·6	Cross.
1·29	·38	·49	52·6	15·0	58·1	35·5	Length.
1·29	·39	·503	51·6	12·0	59·6	36·3	Cross.
1·29	·475	·612	52·1	15·0	54·8	29·9	Length.
1.29	·475	·612	49·8	15·0	57·4	42·8	Cross.
·99	·72	·712	50·8	12·0	56·4	32·1	Length.
1·02	·72	·734	53·1	14·0	54·4	36·7	Cross.
1·02	·99	1·009	48·9	15·0	59·7	33·3	Length.

Table V.

Diameter of Hole.	Dimension of Test Piece.			Tons per Square Inch.	Elongation per cent. in 8 Inches.	Contraction of Area per cent.	Remarks.	Charge.
	Breadth	Thickness.	Area.					
1·22—1·1	3·47	·96	2·217	36·0			Punched tensiles holes punched in centre of test piece.	D266
1·04— ·96	3·49	·73	1·817	39·5		1·90		,,
·90— ·82	3·51	·485	1·285	36·4	1·00	4·20		,,
·90— ·82	3·51	·395	1·046	42·9	1·62	9·10		,,
·75— ·71	3·51	·265	·736	43·7	2·75	10·00		,
·62— ·60	3·48	·150	·430	41·27	2·75	16·70		,,
1·03— ·95	3·51	1·00	2·520	33·17	1·00	3·90		D300
1·03— ·95	3·48	·765	1·904	33·90	5·25	15·80		,,
·90— ·83	3·50	·520	1·370	33·30	4·00	18·80		,,
·90— ·83	3·49	·400	1·050	31·60	3·50	21·90		,,
·79— ·73	3·49	·230	·627	30·30	3·50	22·40		,,
·58	3·50	·115	·335	29·40	4·00	26·50		,,

Table VI.

Dimension of Test Piece.		Tons per Square Inch.	Elongation per cent.		Contraction of Area per cent.	Remarks.
Diameter	Area.		in 8 Ins.	in $1\frac{1}{4}$ Ins.		
·72	·407	35·8	25		59·2	Rivet bars.
·72	·407	35·6	25		59·2	
·51	·204	35·7		36	60·7	Rivets.
·51	·204	35·7		40	65·4	

Table VII.

Comparison of yield points and breaking strain of nickel and carbon steels.

Thickness.	Carbon Steel.		Nickel Steel.	
	Ultimate	Yield Point	Ultimate	Yield Point
	Tons per Square In.	Tons per Square In.	Tons per Square In.	Tons per Square In.
3/16	27·5	13·7	51·7	29·0
"	27·4	13·7	54·3	28·0
1/4	27·8	13·9	54·3	28·3
"	27·6	13·8	53·1	29·4
3/8	27·9	14·0	52·6	30·6
"	28·0	14·3	51·6	30·8
1/2	28·5	14·3	52·1	28·6
"	28·4	14·2	49·8	28·6
3/4	28·5	14·1	50·8	28·7
"	28·4	14·0	53·1	28·9
1	27·9	14·3	48·9	29·2

Table VIII.

Comparison of normal and welded tests.

Dimensions of Test Piece.			Tons per Square Inch.	Elongation per cent. in 8 Inches.	Remarks.
Breadth.	Thickness.	Area.			
1·05	·39	·409	37·1	18·0	Normal.
1·06	·38	·402	35·5	16·0	Welded in centre, broke 4″ from weld.
1·05	·50	·525	37·1	21·0	Normal.
1·07	·52	·556	33·8	14·0	Welded in centre, broke 4″ from weld.
·95	·76	·722	36·4	21·0	Normal.
·97	·75	·727	34·2	16·0	Welded in centre, broke 4″ from weld.

On the suggestion of the Chairman (Mr H. A. Mavor, Vice-President), and owing to the lateness of the hour, the discussion of this paper was postponed till next meeting.

The discussion on this paper took place on 28th April, 1896.

Mr **James Riley** said he desired to make some remarks on Mr Beardmore's paper, and in order that he might say as much and not more than he intended, he had written down what he wished to say, and requested to be excused if he read what he had prepared. Now that they had the printed matter before them, it was easier for them to grasp the points the author desired to make than was possible when the paper was read. It would be remembered that the author apologised for the embarrassment which characterised its delivery on the ground that it had been very hurriedly prepared. It might be that to the same cause was due the fact that not the least reference was made to what had been done by others in the same field, not the slightest recognition of the lead which it was his (Mr Riley's) privilege to have afforded to the author and others in this new branch of metallurgical industry. Nickel steel was first made on the large scale at the Newton Works of the Steel Company of Scotland—very small ingots had been made in France by the crucible process, but until he took the matter in hand on behalf of that Company there was no certainty that the alloy could be properly made on the large scale in the open hearth furnace. After a few trials their anxiety as to the manufacture was removed, and seven years ago he had the honour of reading before the Iron and Steel Institute a paper in which he entered fully into the description of the valuable properties of the new metal. Perhaps that paper was much too frank, for he did not content himself (as others had and as he well might have done) with describing the characteristics of the new alloy, but he gave full information as to the chemical constituents and the process of manufacture. No long time elapsed before it came to the knowledge of himself and others interested in the new metal that not only in the United States, but also in this country, several eminent steelmakers had manifested that facility for assimilating the ideas of others which was too often apparent and of which he regretted to say he had had more than one unpleasant experience. However, time healed many wounds, and the original inventors and introducers of this exceedingly valuable metal—who had not received the slightest pecuniary recompense or financial recognition—had had to make the best they could of the position, but it was surely not unreasonable to expect that in papers such as the one under consideration there should be some recognition of the source of inspiration that had led to the results detailed. In the United States this had been done gracefully, if not gratefully, and no doubt if the paper had not been so very hurriedly prepared one might have expected a similar acknowledgment from a neighbouring manufacturer. He had referred to the early connection of the Steel Company of Scotland with this new alloy, and he had been frequently asked why that Company did not go further with its manufacture. It was neither proper nor necessary that he should explain why the Company relinquished the pre-eminent position it had attained in that, as in many other branches of the steel manufacture, but he might say that such action was not taken because of any doubt as to the valuable properties and characteristics of the metal. They would have gathered from the paper under consideration that there were many varieties of nickel steel. The author had chiefly referred to two. In the paper he (Mr Riley) read in 1889, he described several varieties of the alloy, including two with all the properties described by the author. It was satisfactory to know that after several years' experience in the production of this metal since he gave his results, the author was able to confirm their accuracy. The author added to their knowledge the results of two tests on rivetted joints as well as notes on the behaviour of the metal under drift tests and under tests of its resistance to fatigue, and it was satisfactory to know that under the latter tests the metal maintained its superiority to carbon steel. If the tests of rivetted joints could have been extended to include others with different sizes and spacings of rivets, the results would have been most valuable, and he might perhaps be permitted to point out that until this was done it was comparatively useless to urge the adoption of the more tenacious steel the author so strongly recommended for use in torpedo-boat destroyers, etc. In 1889 Sir William White pointed out that unless the rivetted joints could be made with strength proportionate to that of the metal of which the plates were made, the superior strength would not become available. This position was unassailable, and the results obtained by the author did not help to overcome the difficulty, for it would be seen that notwithstanding the use of his very fine rivet steel the strength of the joints was far below that of the plates. In view of these facts and others on which he need not dwell, he would hesitate to modify the recommendation he had given in the past that for these purposes the 40 ton material was preferable to that with 50 tons strength. There were in some of the series of nickel steels some most valuable properties to which the author had not referred. In all of them the susceptibility to corrosion was less than that of carbon steel, and it decreased as the contents of nickel increased until with 25 per cent. and upwards the material was practically non-corrodible. Then this latter alloy—25 per cent. nickel steel—had some striking properties in addition. It had great strength, together with wonderful ductility—it could therefore be flanged and stamped into forms with great facility, and it could also be drawn into tubes or wire without difficulty. A specimen was drawn into wire of a fineness which might surprise them—a piece weighing 1 kilo being drawn into a thread 21 kilometres long. Unfortunately that particular alloy was very difficult to machine, it would punch with the greatest ease, but it was almost impossible to drill a hole through it. He expected that before long great use would be made of this most interesting one of the series of these alloys. With great strength, very great ductility joined to non-corrodibility, it recommended itself for use in a thousand forms, notwithstanding that very peculiar tough hardness which made it so difficult to machine. In 1889 he very strongly recommended the use of these metals to the marine engineer, as had been done by the author of the paper. He also pointed out the great service they might be to the civil engineer, and remarked, "this is strongly brought out in considering the immense advantage to be derived from their use in large structures. Think for a moment of this in connection with the erection of the Forth Bridge or the Eiffel Tower. If the engineers of those stupendous structures had had at their disposal a metal of 40 tons strength and 28 tons elastic limit instead of 30 tons strength and 17 tons elastic limit in the one case and, say, 22 tons strength and 14 to 16 tons elastic limit in the other, how many difficulties would have been reduced in magnitude as the weight of the materials was reduced? The Forth Bridge would have become even more light and airy, and the tower more net-like and graceful, than they are at present." With regard to the military engineer, he said that "I am inclined to state firmly that there has not yet been placed at his disposal materials so well adapted to his purposes, whether for armour or armament, as those I have now brought under your notice. In what may be called their natural condition, these alloys have many properties which will recommend them for these purposes; and, when the best method of treatment by hardening or tempering has been arrived at, I believe that their qualities for armour will be unsurpassed." It was now matter of common knowledge that these anticipations had been fully realised in so far as related to guns and armour plates. It was true that the British Government did not think the addition of nickel to armour plates which were submitted to the "Harveyising process" was of great advantage, but in that opinion they stood alone. In the United States, and on the Continent, the contrary opinion was strongly held and was fortified by practical experience. He was glad to know that his original statements and recommendations were so strongly corroborated and supported by the testimony of the author after these years of experience, as well as by the very beautiful specimens of the metals he had submitted, and it was to be hoped that their marine engineers would give these recommendations more earnest attention, especially in view of the fact that nickel was now obtainable at less than half the price they had to pay for it seven years ago, and that nickel steel could therefore be supplied at a price less than was paid for mild carbon steel fifteen years ago. In a paper he read before a kindred institution some months ago, he was glad to avail himself of Mr Beardmore's permission to describe the magnificent casting which was illustrated in the paper, and which, he might be permitted to say, was a fine illustration of that gentleman's enterprise as well as of his confidence in the new metal. It would add greatly to their information if he could give them the results of tests made on the metal as it existed in the casting, those given in the paper having been taken from metal which had been subjected to treatment in the mills. In conclusion, he would add that they were much indebted to Mr Beardmore for his paper, and especially for the exhibition he had made of such beautiful specimens of this most valuable metal.

Mr CAREY said that he had read Mr Beardmore's paper with great interest; nor was he ashamed, even before such an Institution as this, to confess that any acquaintance which he himself might have with nickel steel was of comparatively recent origin, so new and modern was this material. When Mr Beardmore was able to produce 40 tons nickel steel, with an elongation of 30 per cent. on 8 inches, with absolute certainty over and over again, no one could doubt the future of the material. The harder quality of carbon steel in the Forth Bridge ranged from 34 to 37 tons, with an elongation of 18 per cent. on 8 inches; and he thought he might say, without exaggeration, that its production had caused no small consideration, perhaps he might add anxiety also, and yet new bridge builders found a material being offered them several tons stronger and with far better extension. The question of cost was of course an important one, and he trusted manufacturers would see their way to reduce that of nickel steel to enable it to compete with carbon steel. He was unable to say from actual knowledge how far the reputation of nickel steel as impervious to rust was well founded. Mr Whyte, of Leith, was, however, carrying out some practical experiments by placing some 6-inch squares of nickel and carbon steel in the sea, which he (Mr Carey) had recently forwarded to Leith through the courtesy of Mr Beardmore. He trusted these experiments might elicit information of practical value. Criticism was always easy, and to point out defects was invariably a lighter task than to remedy them. But, without being captious, he would like to draw attention to the trouble often met with in regard to nickel steel surfaçes; trusting that more able hands would find a remedy for this not unusual drawback to a material which, in his judgment and limited experience, had a very extended future.

Mr Archer said he thought nickel steel was very suitable for the purpose of constructing the hulls of torpedo-boat destroyers, but there were certain limitations which must be kept in mind in considering the matter. It depended very much, he thought, on what the size of the ship was, in the first place, and also what part of the ship they were going to use it for. For example, if they considered the 27-knot destroyers which were recently built for the British Government, they would find that the shell plating of these boats was of the ordinary mild steel, having a tensile strength of from 26 to 30 tons per square inch, and the thickness was about one-eighth of an inch amidships, and less at the ends. He did not think that anybody would be prepared, even using a high tension steel with all the admirable properties of this nickel steel, to reduce that thickness very much. He meant to say that, besides providing for the stresses which were brought upon the plates in a sea way, and which brought into play the tensile and compressive properties of the metal, there must be, in the first place, a certain minimum thickness for rigidity and a certain thickness to allow for corrosion. But when they came to bigger ships, supposing they were going to increase that ship to make it 250 feet long instead of 200 feet, no doubt that was a case in which this metal would be exceedingly valuable, for they could perhaps in a larger ship get all the strength they wanted without increasing the thickness of the shell. There was another point with regard to the part of the ship in which they were going to use this steel. For example, there was a large portion of the structure of the ship, such as the water-tight bulkheads, the lower deck plating, and the bunker plating, in which it was not so very much a question of getting a great amount of longitudinal strength or compressive strength as a certain amount of rigidity. For example, in some ships that he was speaking of, the lower deck, on which the crew were berthed, was formed of steel plates about 3½ lbs. per square foot, considerably less than one-eighth of an inch in thickness, and they could not very well reduce the thickness of such plates, however strong the steel might be. The main thing was to give the deck rigidity, so that it would not buckle when subjected to water pressure and local stresses. With regard to the remarks that had been made about the cost of this steel, he thought there was no doubt that for marine purposes it would be more largely used than for land purposes. Metallurgists had a wide field before them in producing metals which would have the exact properties that were required for marine purposes, even although they might be more costly than they were accustomed to consider as commercially economical; because by the use of these materials, which had the special properties they required, they could so much lighten the structure that they could attain a given speed, with a given load on board, with a smaller vessel, and therefore reduce the power of the machinery as well as the size of the whole structure. In these small vessels running at these very high speeds the cost of the machinery was considerably greater than the cost of the hulls, and, therefore, by reducing the power of the machinery in that way, they could very likely build the whole structure at the same or a lower cost, even although the material of which they built the hull might be very much more costly.

Professor WATKINSON said he would like to ask Mr Beardmore as to the effect of high temperatures on nickel steel. When used for boilers and other purposes, steel was subjected to high temperatures, and, unless it could withstand these successfully, there would be no gain due to its higher tensile strength. Another matter that he wished to ask about was as to its resistance to corrosion. The special kind of steel containing 25 per cent. of nickel exhibited by Mr Riley seemed to withstand corrosion perfectly at ordinary temperatures, but the action of water on metal and other substances was much greater at highor temperatures than at lower temperatures, and he would be very glad if Mr Beardmore could give them information on these points.

Mr **Riley** asked to be allowed to add a word to what he had said. He had stated in his remarks that in all cases nickel steel was less susceptible to oxidation. With 3 to 5 per cent. of nickel present, the rate of corrosion was about half that of carbon steel, and as the nickel increased it was still less affected. He had had for seven years the small wire which he had produced, and no great care had been taken of it. They could see the amount of corrosion that had taken place on it. That metal was practically non-corrodible.

Mr **George C. Thomson** asked Mr Riley what effect magnetisation had on nickel steel.

Mr **Riley** said that the properties, electrical and magnetic, varied according to the contents of nickel. Dr John Hopkinson had made a number of experiments in that direction some five or six years ago, and had detailed the results before the Royal Institution or the Royal Society. Singularly, he believed that this particular metal—25 per cent.—was non-magnetic, but the others were magnetic to a greater or less degree. This one was practically non-magnetic.

Mr **James Welsh** asked if it was the case that there was a bad surface on the nickel steel plates. If they adopted nickel steel for boiler shells, was the surface sufficiently clean to be perfectly caulked to stand the pressure? From a remark made by Mr Carey, he thought that there might be some difficulty. He had seen one specimen of nickel steel which was kept in an exposed situation where the ordinary steel bars corroded very quickly, and he noticed that the surface of the nickel steel bar was still as clean as when delivered from the works several months ago.

The **Chairman** (Professor Jamieson, Vice-President) said he was sorry that Mr Beardmore was not present to hear Mr Riley's remarks, but the Secretary would give him an opportunity to reply by writing. He would have great pleasure in testing the "permeability" and "hysteresis" of nickel steel, and in comparing his results with those of Dr Hopkinson. Mr Riley's remarks constituted an excellent contribution to this subject, and, although severe, they were duly tempered with praise. He now asked them to give Mr Beardmore a hearty vote of thanks for the paper which he had brought before the Institution.

The vote of thanks was heartily accorded.

The CHAIRMAN, continuing, said this was the last evening of the present session. He was sorry that Sir Wm. Arrol could not be present, for he (Sir Wm.) had fully intended to be in the chair, had he not been telegraphed for to go at once to London. He hoped that all the members had been benefitted by the work of the past session. They had some excellent papers brought before them, and the discussions had been well sustained in many cases. Since last session they had been able to procure several good books. Each member had received a slip containing a list of the books recently purchased and now placed in the library. There was one matter, however, that (as convener of the Library Committee) he wished to bring before them, viz., the apathy with which members attended to the privilege of intimating to the librarian the names of the best and most recent books on engineering. They, unfortunately, left the matter too much to the Library Committee. The Library Committee specially desired to select the best books, but, to do so most effectually, they must receive the assistance of the members of the Institution, who naturally represented a wider range of engineering sections. He hoped that before the opening of next session the extension to the Library would be completed, all the books duly shelved, and a new catalogue started, all of which would materially add to the ease and pleasure of consulting and reading in their Library. He also hoped that the whole of the Institution's rooms would be cleaned and painted, so that the members might return with renewed interest and spirit to the work of a fresh session.

Mr BEARDMORE, in reply, writes :—

I am indebted to those gentlemen who have criticised my paper, and if I have succeeded in interesting any of the members in what appears to me to be a most interesting alloy, the object I had in view is accomplished. The paper was not written in support of any theory, but the figures given are the result of experiments which I had recently carried out for the Admiralty, Lloyds', and the Board of Trade. The surveyors attended at my works and witnessed the tests, the results of which I have been privileged to put before the Institution. I regret that Mr Riley should think it necessary at this time of day to speak as he does. His investigations on the properties of nickel steel being already so well known, I did not consider it expedient "to gild refined gold." While I am not desirous of entering into any controversy on this subject, it is due to myself to say that Mr Riley's experiments, valuable as these were, were not the source of my inspiration. There can be no doubt that nickel steel does not corrode so readily as carbon steel, and, as Mr Riley has pointed out, the rate of corrosion varies with the percentage of nickel. This subject, as also the question raised by Professor Watkinson, is at present under consideration, and I hope at some future date to be able to say something further on these very interesting aspects of the question. I may be permitted to add that since reading this paper I have obtained from a nickel steel forging the following tests:—

Tons per Square Inch.	Per Cent. Elong. 2in.	Elastic Limit.	Con. Area.
46·0	28	62 per cent. B.S.	40 per cent.

And I hope yet to improve on these results.

THE JAMES WATT ANNIVERSARY DINNER

Was held on Saturday, the 18th January, 1896, in the Windsor Hotel, Glasgow—Sir William Arrol, LL.D., M.P., President, in the chair.

The meeting was a most successful one, and was largely attended by members and distinguished guests.

Note received from Mr F. P. Purvis, 25th June, 1896.

After the reading of his paper on the 26th November, 1895, Mr Purvis illustrated by actual experiment upon a model the curious alternations of stability and instability which are sometimes to be met with. The model was floating at a light draught, and had a high freeboard, the proportionate dimensions represented being approximately 50 feet beam, 42 feet depth, and 12 feet draught. As ballasted, the model was stable in the upright; when inclined to 8 degrees, she moved further from the vertical, and, if allowed to do this slowly, she came to rest again at 15 degrees. When again slowly listed to 28 degrees, she again moved further from the vertical, coming to rest once more at 63 degrees. These peculiarities were traceable in whichever direction the inclination took place, whether to port or starboard, there being thus five positions of stable equilibrium, viz., the upright, two at 15 degrees, and two at 63 degrees.

The accompanying diagram (see Fig. 6, Plate II$^{A.}$) shows the variation of righting arms involved in the foregoing phenomena. Measurements above the base line show positive G.M., and measurements below the base line negative G.M. Wherever the curve of stability or righting arms crosses the base line from below to above (viz., at 0 deg., at 15 deg., and at 63 deg.), stable equilibrium exists.

Institution of Engineers and Shipbuilders
IN SCOTLAND
(INCORPORATED).

THIRTY-NINTH SESSION, 1895-96.

MINUTES OF PROCEEDINGS.

THE FIRST GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd October, 1895, at 8 P.M.

Sir WILLIAM ARROL, LL.D., M.P., President, in the Chair.

The Minute of Annual General Meeting held on 30th April, 1895, was read and approved, and signed by the President.

The PRESIDENT delivered his Inaugural Address. On the motion of Mr JOHN INGLIS, Past President, a vote of thanks was awarded the President for his Address.

The Premiums awarded at Annual General Meeting of 30th April, 1895, were presented, viz. :—

Premiums of Books to Mr WILLIAM ARNOT, for his paper on "The Glasgow Corporation Electric Light Supply." And to

Mr ALEXANDER MORTON for his paper on "Rotatory and Re-action Engines."

The adjourned discussions of the following papers took place and were terminated, viz. :—

On "A New Departure in Steam Engine Economy, with a Description and Tests of Field's Combined Steam and Hot Air Engine," by Professor ANDREW JAMIESON, M.Inst.C.E., F.R.S.E.; and

On "The Extension of the Loch Katrine Water Works," by Mr JAMES M. GALE, M.Inst.C.E.

The President announced that the following Candidates had been unanimously elected, viz.:—

AS MEMBERS:—

Mr CARL MUMME, Shipbuilder, 30 Newark Street, Greenock.

Mr E. GEORGE TIDD, Electrical Engineer, 137 West Regent Street, Glasgow.

AS GRADUATES:—

Mr JAMES REID, Engineering Draughtsman, 128 Dumbarton Road, Glasgow.

Mr JOHN MERCER, Mechanical Draughtsman, 111 Westerlea Terrace, Glasgow.

Mr J. ORR, Marine Engineering Draughtsman, 22 St. Vincent Crescent, Glasgow.

THE SECOND GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 26th November, 1895, at 8 P.M.

Sir WILLIAM ARROL, LL.D., M.P., President, in the Chair.

The Minute of General Meeting held on 22nd October, 1895, was read and approved, and signed by the President.

The following papers were read:—

On "Propeller Diagrams," by Mr ROBERT CAIRD.

The discussion of this paper was deferred till next General Meeting.

On "Period of Rolling of Vessels as an Index of Stability," by Mr F. P. PURVIS.

A discussion followed, and was continued to next General Meeting.

Votes of thanks were awarded the authors of these papers.

Mr JOHN THOM read part of his paper on "Comparisons of Systems of Mechanical Draught."

The discussion was deferred until next General Meeting.

The President announced that the following Candidates had been unanimously elected, viz.:—

AS MEMBERS:—

Mr NORMAN MACRAE, Civil Engineer, Northern Gold Fields' Company, Salisbury, South Africa.

Mr JAMES M'NAIR, Mechanical Engineer, Norwood, Prestwick Road, Ayr.

Mr C. R. LANG, Holm Foundry, Cathcart.

Mr THOMAS B. MACKENZIE, Dalzell Steel Works, Motherwell.

Mr JOHN WEIR, Messrs John Scott & Coy., Engineers and Shipbuilders, Kinghorn.

AS GRADUATES:—

Mr JOHN BOWDEN, Student Mechanical Engineer, Atlas Works, Glasgow.

Mr ALEXANDER CRAIG, Student Engineer and Shipbuilder, Netherlea, Partick.

THE THIRD GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 24th December, 1895, at 8 P.M.

Sir WILLIAM ARROL, LL.D., M.P., President, in the Chair.

The Minute of General Meeting held on 26th November, 1895, was read and approved, and signed by the President.

The following papers were discussed:—

On "Propeller Diagrams," by Mr ROBERT CAIRD.

On "Period of Rolling of Vessels as an Index of Stability," by Mr F. P. PURVIS.

On "Comparisons of Systems of Mechanical Draught," by Mr JOHN THOM.

The further discussion of these papers was adjourned to next General Meeting.

Mr E. G. CAREY'S paper on "Cast-Iron Segments for Railway and other Tunnels" was held as read, and the discussion deferred to next General Meeting.

The President announced that the following Candidates had been unanimously elected, viz. :—

AS MEMBERS :—

Mr ALEXANDER L. CARLAW, Mechanical Engineer, 81 Dunlop Street, Glasgow.
Mr DAVID CARLAW, Jr., Mechanical Engineer, 81 Dunlop Street, Glasgow.
Mr JAMES W. CARLAW, Mechanical Engineer. 81 Dunlop Street, Glasgow.
Mr J. M. RONALDSON, Mining Engineer, 44 Athole Gardens, Glasgow.
Mr OSBOURNE SMITH, Mechanical Engineer, Possil Engine Works, Glasgow.
Mr JOHN WILSON, Mechanical Engineer, 154 West George Street, Glasgow.
Mr WALTER M. THOMSON, Mechanical Engineer, Hayfield, Motherwell.

AS GRADUATES :—

Mr GEORGE C. ANDERSON, Electrical Draughtsman, Mavisbank. Partickhill, Glasgow.
Mr R. CLELAND GOURLAY, Draughtsman, 11 Crown Gardens, Glasgow.
Mr CORSAR PIRRET, Engineering Draughtsman, 9 Rosslyn Terrace, Kelvinside, Glasgow.
Mr ROBERT A. RAPHAEL, Draughtsman, 150 Renfrew St., Glasgow.
Mr WILLIAM SHARPE, Engineering Draughtsman, 21 Herriet Street, Pollokshields, Glasgow.

THE FOURTH GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 28th January, 1896, at 8 P.M.

Sir WILLIAM ARROL, LL.D., M.P., President, in the Chair.

The Minute of General Meeting held on 24th December, 1895, was read and approved, and signed by the President.

The following papers were again discussed:—

On "Propeller Diagrams," by Mr ROBERT CAIRD.

On "Period of Rolling of Vessels as an Index of Stability," by Mr F. P. PURVIS.

On "Comparisons of Systems of Mechanical Draught," by Mr JOHN THOM.

The discussions on these papers were terminated.

The discussion of Mr E. G. CAREY'S paper on "Cast-Iron Segments for Railway and other Tunnels" was adjourned to next General Meeting.

The paper by Mr ROBERT SIMPSON on "Tunnelling in Soft Material" was held as read, and the discussion of it deferred to next General Meeting.

The President announced that the following Candidates had been unanimously elected, viz.:—

AS AN HONORARY MEMBER:—

Mr A. J. DURSTON, C.B., Chief Engineer to the Admiralty, London.

AS MEMBERS:—

Mr THOMAS ELSEE, Engineer and Shipbuilder, 75 Buchanan Street, Glasgow.

Mr JAMES HINES, Mechanical Engineer, Dunedin Lodge, Lenzie.

Mr JOHN F. M'INTOSH, Locomotive Engineer, Caledonian Railway, St. Rollox, Glasgow.

Mr DAVID BOYD M'GEOCH, Shipbuilder, Messrs Blackwood & Gordon, Port-Glasgow.

Mr JOHN R. RICHMOND, Engineer, Holm Foundry, Cathcart.

Mr ALEXANDER WILSON, Engineer, Dawsholm Gasworks, Maryhill.

AS AN ASSOCIATE:—

Mr ROBERT G. WARREN, Engineering Agent, 115 Wellington St., Glasgow.

AS GRADUATES :—

Mr JAMES FLETCHER, Engineering Draughtsman, 11 Ibrox Place, Whitefield Road, Govan.

Mr WALTER GRAHAM, Draughtsman, 7 Royal Terrace, Glasgow.

Mr JOHN L. M'GREGOR, Assist. Lecturer on Mechanical Engineering, Glasgow Technical College.

Mr WILLIAM WEIR, Apprentice Engineer, Holm Foundry, Cathcart.

THE FIFTH GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 25th February, 1896, at 8 P.M.

Prof. ANDREW JAMIESON, F.R.S.E., Vice-President, in the Chair.

The Minute of General Meeting held on 28th January, 1896, was read and approved, and signed by the Chairman.

The discussions of the following papers took place and were terminated :—

On "Cast-Iron Segments for Railway and other Tunnels," by Mr E. G. CAREY; and

On "Tunnelling in Soft Material, with special reference to the Glasgow District Subway," by Mr ROBERT SIMPSON, C.E., B.Sc.

The following papers were read :—

On "Rates of Speed and Rates of Freight," by Mr JOHN INGLIS, a discussion followed, and was adjourned to next General Meeting.

On "The Recovery of Tar and Ammonia from Blast Furnace Gases," by Mr ANDREW GILLESPIE. The discussion of this paper was deferred to next General Meeting.

The Chairman announced that the following Candidates had been unanimously elected, viz. :—

AS MEMBERS :—

Mr **FREDERICK TEED MURDOCH**, Mechanical Engineer and Founder, Mansourah, Egypt.

Mr **THOMAS ROBERTS MURRAY**, Engineer, The Crown Iron Works, Glasgow.

Mr **A. HUMBOLDT SEXTON**, Professor of Metallurgy, Glasgow and West of Scotland Technical College, 204 George St, Glasgow.

AS A GRADUATE :—

Mr **JOSEPH WOODS**, Draughtsman, 5 Chisholm Street, Glasgow.

THE SIXTH GENERAL MEETING of the THIRTY-NINTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 24th March, 1896, at 8 P.M.

Mr HENRY A. MAVOR, Vice-President, in the Chair.

The Minute of General Meeting of 25th February, 1896, was read and approved, and signed by the Chairman.

The discussion of Mr JOHN INGLIS' paper on "Rates of Speed and Rates of Freight" was continued and terminated.

There being no remarks upon Mr ANDREW GILLESPIE'S paper on "The Recovery of Tar and Ammonia from Blast Furnace Gases," the consideration of the subject was terminated.

Votes of thanks were awarded the authors.

The following papers were read :—

On "The Manufacture of Welded Iron and Steel Pipes," by Mr J. G. STEWART, B.Sc. A discussion followed, and was adjourned to next General Meeting.

On "Nickel Steel," by Mr WM. BEARDMORE. The discussion of this paper was deferred to next General Meeting.

The Chairman announced that the following Candidates had been unanimously elected, viz.:—

AS MEMBERS:—

Mr D. H. MACDONALD, Civil Engineer, Brandon Works, Motherwell.
Mr ARCHIBALD MARTIN, Mechanical Engineer, 100 Elderslie Street, Glasgow.
Mr WILLOUGHBY C. WARDEN, Engineer, 25 Gordon St., Glasgow.
Mr JAMES WILLIAMSON, Marine Superintendent, Gourock.

AS AN ASSOCIATE:—

Mr CHARLES WM. WILD, Representative, Broughton Copper Coy., Limited, 16 St. Enoch Square, Glasgow.

AS A GRADUATE:—

Mr JOHN ARNOLD FEIST, Draughtsman, 122 Holland St., Glasgow.

AN EXTRAORDINARY GENERAL MEETING of the INSTITUTION was held in the Hall of the Institution, 207 Bath Street, on Tuesday, 28th April, 1896, at 7-45 p.m.

Professor ANDREW JAMIESON, Vice-President, in the Chair.

The CHAIRMAN read the Resolution to be submitted, as set forth in the Notice calling the Meeting, viz.:—

> "*First.*—That after 40 Annual Subscriptions, Members and "Associates shall thereafter *de facto* become *Life Members* "and *Life Associates* without any further subscription.

"*Second.*—That Members and Associates may become *Life* "*Members* and *Life Associates* by Single Payments as "follows:—

	Members.	Associates.
"On Election, ...	£20	... £15
"After Payment of 20 Annual Subscriptions,	10	... 7 10/
Do. 30 do.	5	... 3 15/."

On the motion of the CHAIRMAN, seconded by Mr GEORGE RUSSELL, the Resolution was unanimously adopted by the Meeting.

THE THIRTY-NINTH ANNUAL GENERAL MEETING of the INSTITUTION was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 28th April, 1896, at 8 P.M.

Professor ANDREW JAMIESON, Vice-President, in the Chair.

The Minute of General Meeting of 24th March, 1896, was read and approved, and signed by the Chairman.

The following gentlemen were unanimously elected Vice-Presidents, viz., Messrs MATTHEW HOLMES and WILLIAM FOULIS.

Also, the following gentlemen, by a majority of votes, were elected Councillors:—Messrs WILLIAM MORISON, JAMES GILCHRIST, ANDREW STEWART, Professor W. H. WATKINSON, and JAMES MOLLISON.

Premiums of Books were awarded—

To Professor WATKINSON, for his paper on "Water Tube Boilers."

To Mr J. M. GALE, for his paper on "The Extension of the Loch Katrine Water Works."

And to Mr W. CARLILE WALLACE, for his paper on "Electrical Transmission of Power in Shipyards and on board Merchant Steamers."

The Treasurer's Annual Financial Statement, duly audited, was submitted and adopted.

A vote of thanks was awarded the Auditors, Messrs PETER STEWART and W. A. CHARLTON.

The discussion of Mr J. G. STEWART'S paper, on "The Manufacture of Welded Iron and Steel Pipes," was continued and terminated, a vote of thanks being awarded Mr Stewart.

The discussion of Mr WM. BEARDMORE'S Paper, on "Nickel Steel," was proceeded with and terminated, and a vote of thanks awarded Mr Beardmore.

The Chairman announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows :—

AS GRADUATES :—

Mr MATTHEW A. ADAM, Engineering Student, 235 Bath Street, Glasgow.

Mr GEORGE KINCAID LENNOX, Student Engineer, 34 Lynedoch Street, Glasgow.

AN EXTRAORDINARY GENERAL MEETING of the INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND was held in the Hall of the Institution, 207 Bath Street, Glasgow, on Tuesday, the 19th May, 1896, at 8 p.m.

Professor JAMIESON, Vice-President, in the Chair.

The Minute of Extraordinary General Meeting held on 28th April, 1896, was read and approved, and signed by the Chairman.

The SECRETARY read the notice calling the Meeting.

The CHAIRMAN moved that the Special Resolution adopted at the Extraordinary General Meeting of 28th April, 1896, should be now confirmed, that Resolution being as follows :—

"*First.*—That after 40 Annual Subscriptions, Members and "Associates shall thereafter *de facto* become *Life Members* and *Life* "*Associates* without any further subscription.

"*Second.*—That Members and Associates may become *Life Members* "and *Life Associates* by Single Payments as follows:—

	Members.		**Associates.**
"On Election, ...	**£20**	**...**	**£15**
"After Payment of 20 Annual Subscriptions,	**10**	**...**	**7 10/**
Do. 30 do.	**5**	**...**	**3 15/."**

This motion was seconded by Mr Matthew Holmes, and was unanimously adopted.

TREASURER'S STATEMENT—1895-96.

GENERAL FUND.

Dr.

	£	s.	d.	£	s.	d.
To Balance in Union Bank at close of Session 1894-95,				£535	13	0
Subscriptions received :						
Session 1895-96, ...	£727	10	0			
Arrears of Previous Sessions,	97	5	0			
	£824	15	0			
Deduct Entry Money transferred to Building Fund, ..	9	0	0			
				815	15	0
Sales of Transactions, ...				12	2	0
Interest from Clyde Trust, ...				9	8	6
Inst. C.E., and Students' Inst. C.E., for use of Library, ...				26	16	0
James Watt Dinner Surplus, 1896, ...				3	17	8
				£1403	12	2

Cr.

	£	s.	d.		£	s.	d.
By Amount paid Treasurer of House Committee as Institution's proportion of Expenditure, for Session 1895-96,...					£243	0	0
Printing, ...					228	0	0
Lithography, ...					115	0	11
Premiums for Papers, ...					5	11	6
Salary to Secretary, ...					150	0	0
Commission Collection of Arrears of Subscriptions, viz. :—							
For Session 1895-96, ...	£432	0	0				
For Previous Sessions, ...	97	5	0				
	£529	5	0	at 5%	26	9	3
Postages, ...					42	11	9
Delivery of Annual Volumes, ...					9	13	8
Stationery, Insurance, &c., ...					10	0	1
New Books to Library, ...					38	6	1
Binding Periodicals in Library, ...					6	9	2
Reporting, ...					13	14	0
Cash to New Buildings Account to meet Interest on Loan, from Medal Funds, ...					16	0	0
Petty Cash, ...					1	2	8
Balance in Union Bank, ...					497	13	1
					£1403	12	2

MARINE ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95, ...	£30 1 11	*By* Balance in Union Bank, ...	£42 16 5
Interest on Capital lent to New Buildings Account,	10 0 0		
,, Mortgage, Glasgow Corporation,	2 14 6		
	£42 16 5		£42 16 5

RAILWAY ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95, ...	£32 2 9	*By* Balance in Union Bank, ...	£39 7 9
Interest on Capital lent to New Buildings Account,	6 0 0		
,, Mortgage, Glasgow Corporation,	1 5 0		
	£39 7 9		£39 7 9

GRADUATE MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95,	£2 12 0	*By* Balance in Union Bank, ...	£3 7 6
Interest on Mortgage, Glasgow Corporation,	0 15 6		
	£3 7 6		£3 7 6

TREASURER'S STATEMENT—1895-96.

GENERAL FUND.

Dr.

	£	s.	d.	£	s.	d.
To Balance in Union Bank at close of Session 1894-95,				£535	13	0
Subscriptions received :						
Session 1895-96, ...	£727	10	0			
Arrears of Previous Sessions,	97	5	0			
	£824	15	0			
Deduct Entry Money transferred to Building Fund, ..	9	0	0			
				815	15	0
Sales of Transactions, ...				12	2	0
Interest from Clyde Trust, ...				9	8	6
Inst. C.E., and Students' Inst. C.E., for use of Library, ...				26	16	0
James Watt Dinner Surplus, 1896, ...				3	17	8
				£1403	12	2

Cr.

	£	s.	d.		£	s.	d.
By Amount paid Treasurer of House Committee as Institution's proportion of Expenditure, for Session 1895-96,...					£243	0	0
Printing, ...					228	0	0
Lithography, ...					115	0	11
Premiums for Papers, ...					5	11	6
Salary to Secretary, ...					150	0	0
Commission Collection of Arrears of Subscriptions, viz. :—							
For Session 1895-96, ...	£432	0	0				
For Previous Sessions, ...	97	5	0				
	£529	5	0	at 5 %	26	9	3
Postages, ...					42	11	9
Delivery of Annual Volumes, ...					9	13	8
Stationery, Insurance, &c., ...					10	0	1
New Books to Library, ...					38	6	1
Binding Periodicals in Library, ...					6	9	2
Reporting, ...					13	14	0
Cash to New Buildings Account to meet Interest on Loan, from Medal Funds, ...					16	0	0
Petty Cash, ...					1	2	8
Balance in Union Bank, ...					497	13	1
					£1403	12	2

MARINE ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95, ...	£30 1 11	*By* Balance in Union Bank, ...	£42 16 5
Interest on Capital lent to New Buildings Account,	10 0 0		
,, Mortgage, Glasgow Corporation,	2 14 6		
	£42 16 5		£42 16 5

RAILWAY ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95, ...	£32 2 9	*By* Balance in Union Bank, ...	£39 7 9
Interest on Capital lent to New Buildings Account,	6 0 0		
,, Mortgage, Glasgow Corporation,	1 5 0		
	£39 7 9		£39 7 9

GRADUATE MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95,	£2 12 0	*By* Balance in Union Bank, ...	£3 7 6
Interest on Mortgage, Glasgow Corporation,	0 15 6		
	£3 7 6		£3 7 6

BUILDING FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1894-95,	£109 12 6	*By* Balance in Union Bank, ...	£155 12 6
Life Member, ...	20 0 0		
Entry Money, ...	9 0 0		
Interest on Mortgage, Glasgow Corporation,	17 0 0		
	£155 12 6		£155 12 6

NEW BUILDINGS ACCOUNT.

Dr.			Cr.		
To Capital to meet Cost of New Buildings, viz. :—			*By* Paid on New Buildings, ...		£2047 8 1
From General Fund, ...	£542 15 7		Interest on Loans, viz.:—		
,, Marine Engineering Medal Fund, ...	351 11 2		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				16 0 0
		£2047 8 1			
Cash received from General Fund to meet Interest on Loans, ...		16 0 0			
		£2063 8 1			£2063 8 1

Glasgow, *13th April, 1896.*—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.
W. A. CHARLTON, }

Dr. HOUSE EXPENDITURE ACCOUNT. (ABSTRACT 1895-96.) Cr.

To Rents for Letting Rooms, ...		£72 19 0
Amounts Received by Treasurer to meet Expenses, viz.:—		
From Institution of Engineers and Shipbuilders, ...	£243 0 0	
From Philosophical Society, ...	211 14 0½	
		454 14 0½
		£527 13 0½

By Balance due Treasurer, ...	£31 3 5
Interest on Bond, ...	116 0 0
Salary to Curator, ...	122 10 0
Salary to Attendant at Library, Cleaning, &c., ...	27 4 11½
Taxes, ...	19 19 9½
Feu-duty, etc., ...	0 19 3
Gas Rates, ...	14 14 9
Electric Light, ...	6 11 4
Water Rates, ...	6 6 8
Coals, ...	6 10 0
Insurance, ...	7 15 0
Repairs and Additions, ...	123 10 0
Stationery, ...	1 13 0
Balance in Treasurer's hands, ...	42 14 10½
	£527 13 0½

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.*

OBITUARY.

Members.

Mr DAVID CUNNINGHAM was elected a Member of the Institution in 1872.

He was born in Dundee, where he was partly educated. In 1855 he was apprenticed to the firm of Messrs Blyth, C.E., in Edinburgh, and at the end of his apprenticeship became resident engineer on the Portpatrick Railway, then being made.

After further railway experience, he was appointed, in 1869, Harbour Engineer at Dundee, where he carried out considerable improvements by dredging and the formation of new docks. Mr Cunningham introduced hydraulic machinery, such as hoists, capstans, and other arrangements, to facilitate the work at the docks: he also devoted much attention to the Tay ferries, and made an elaborate survey of the currents and sand banks of that river.

Mr Cunningham was much consulted by other Corporations in connection with Parliamentary Bills.

Mr Cunningham took much interest in the social welfare of Dundee and neighbourhood, and was the author of several important papers and books. He contributed a paper on "Swing Bridges, etc.," to the Institution in 1873, and, in 1874, one on "Harbours."

He died at Dundee on the 13th of June, 1896, aged fifty-seven.

Mr JOHN FRAZER joined the Institution as a Member in 1879.

Mr Frazer was born in 1833, at Inverness, educated at Bell's school there, and was apprenticed to Messrs Frazer & Sons, and afterwards to Messrs Smith, iron founders.

On the completion of his apprenticeship he went to Messrs James Bertram & Co., Leith Walk, Edinburgh. From there he went to Messrs Tulloch & Denny, Dumbarton.

In 1861 he went to sea, his first voyage being to America. He was several times successful in running the blockade during the American war, but was also twice taken prisoner when blockade running. At the termination of the American war he returned home, and entered the Bombay and Bengal Steam Ship Company as engineer. He remained in this firm for three years, running between Bombay and Suez on the "Krishna." When this engagement came to an end, after remaining two years at home, he entered the service of Messrs P. Henderson & Co., running between Glasgow and Rangoon. He was appointed superintendent engineer of this company in 1877, where he remained up to the time of his death, which took place after a short illness at Millport, on July 31st, 1895.

Mr WILLIAM HENDERSON became a Member of the Institution in 1878. He was born at Pittenweem, Fifeshire, and, after some experience at sea, became associated with his brothers in the well-known shipping and shipbuilding enterprise in connection with the Anchor Line.

Mr William Henderson was the chief partner of the shipbuilding firm of Messrs D. & W. Henderson, Meadowside Works, Partick, where most of the Anchor Line steamers were built. Many well-known vessels and yachts have been launched from the Works, notably the swift passenger steamer "Lord of the Isles," which, on going to the Thames, was replaced on the Clyde by a larger vessel of the same name. The "Britannia," "Valkyrie," and other notable yachts were also built at Meadowside Works.

Mr Henderson died at his residence, Dowanhill, on 7th April, 1895, aged sixty-nine years.

Mr J. ANTHONY INGLIS became a Graduate of the Institution in 1883, and in 1891 was elected a Member. He was born in Glasgow on 21st April, 1862, and received his education at the Glasgow Academy and Edinburgh Institution. He commenced his apprenticeship to his father's business at Whitehall Foundry in 1879, passing through all the different departments. On the death of his father, the late Mr John Inglis, in 1888, he was assumed a partner in the firm of Messrs A. & J. Inglis, but did not remain long in business, retiring three years afterwards. Mr Inglis died on the 5th of July, 1896.

Mr **Andrew Johnston** was elected a Member of tho Institution in 1891. He was born at Stranraer, Wigtownshire, and received his education there. He served an apprenticeship of five years, from 1861, with Messrs W. & A. M'Onie, Glasgow. In 1867 he went to China, and for eighteen months superintended the erection of new machinery in Nankin Arsenal. From 1869 to 1875 he was employed as marine engineer on steamships trading on tho coast of China. In 1875 he was appointed manager of the West Point Foundry, Hong-Kong, and later on to be superintendent engineer and manager of the Cosmopolitan Docks there. In 1881 he superintended the erection and fitting up of the Lee Yuen Sugar Refinery, Hong-Kong, of which he continued manager till 1886. From 1886 he was established as a consulting engineer at Hong-Kong, and acted also as Lloyd's surveyor at that port. During 1889 he personally superintended the floating of the steamer "Ardgay," which had gone on shore while going full speed in the Gulf of Tonquin.

Towards the end of 1895 he was in indifferent health, and in February of the following year left for a trip to America, in hopes of benefitting by the change; but he became worse during tho voyage, and, on arriving at San Francisco, was taken to the German Hospital, where he died on 27th March, 1896.

Mr **Walter Neilson** joined the Institution as a Member in 1891.

Mr Neilson belonged to a family well known in connection with the iron and coal industries of Scotland, and latterly with the development of the more recent steel industries.

Some years ago Mr Neilson started the Clydebridge Steel Works near Cambuslang.

He died on 17th April, 1896.

Mr **Patrick Stirling** was an Original Member of the Institution, being one of its founders in 1857.

He was born in 1820 at Kilmarnock, and was the son of the Rev. Robert Stirling, inventor of the hot air engine which bears his name, and is specially described in Rankine's "Manual of the Steam Engine and Other Prime Movers."

After serving his apprenticeship in the Dundee Foundry, Mr Stirling worked as an engineer both in England and Scotland, acting for several years as foreman in the locomotive works of the Hydepark Foundry, Glasgow. In 1855 Mr Stirling was appointed Locomotive Superintendent of the Glasgow and South-Western Railway, and in 1866 he was appointed to the same post in the Great Northern Railway.

In 1859 Mr Stirling contributed a paper to the Institution on "Coal Burning Locomotive Engines," in 1860 one on "Stirling's Air Engine," and in 1862 one on "A Lubricating Apparatus."

As a locomotive engineer, Mr Stirling's name is well known, as for a long period he held the important charge referred to in the locomotive workshops at Doncaster belonging to the Great Northern Railway Co., in the design of whose engines Mr Stirling was eminently successful. He died at Doncaster on 11th November, 1895.

Mr **Francis Willcox** joined the Institution in 1876. He was born at Birmingham in 1840, and was educated at Birmingham Grammar School. He was apprenticed in 1855 to Messrs Robert Napier & Sons, shipbuilders and engineers, Glasgow, and often made voyages to sea in charge of machinery. During his stay in Glasgow he attended Professor Rankine's lectures at the University, and became thoroughly conversant with the theory and mathematics of engineering generally. He was appointed assistant to the late Sir John Anderson, C.B., Superintendent of Machinery at H.M. Royal Arsenal, Woolwich, taking charge in that capacity of machinery at home and at out stations, as well as of the steam vessels of the War Department. In 1866 he joined the firm of Messrs J. & G. Rennie, engineers and shipbuilders, London, as managing draughtsman and chief designer, going to Egypt for that firm in connection with the fitting of the Khedive Company fleet with the then newly introduced compound engines. In 1870 he was appointed manager and designer to Messrs T. R. Oswald & Co., engineers and shipbuilders, Pallion, Sunderland, whom he left in 1872 to commence practice as consulting and superintending engineer and naval architect in Sunderland with his partner, Mr Mason. This business soon became a most important one.

Mr Willcox also had the superintendence of a large fleet of steamers, and was the patentee of several mechanical devices, including a steam and hydraulic steering gear, ventilators for ship holds, and an improved screw propeller, with which he was very successful.

Mr Willcox died at Sunderland on the 30th April, 1896.

Associate.

Captain John Bain joined the Institution as an Associate in 1888. He was born at Nairn, and, choosing a seafaring life, he was apprenticed to a coasting vessel. His first charge as captain was in the "County of Nairn," a three masted sailing ship. Ultimately he became captain in the Clan Line of steamers. On retiring from the sea, he became a marine surveyor, and held the appointment of Nautical Assessor to the Board of Trade.

Capt. Bain took much interest in the welfare of seamen, and was a valuable supporter of the lifeboat service, aiding the Lifeboat Saturday movement in Glasgow with his enthusiasm. His services in a rescue by the lifeboat at Nairn on one occasion were acknowledged by a medal from the King of Sweden.

In 1893 Captain Bain read a paper to the Institution on "The Effect of Reversing the Screw Propeller of a Steamship upon the Steering."

Capt. Bain died at Glasgow on 1st November, 1895.

Graduates.

Mr GILBERT GOODWIN, junr., only surviving son of Mr Gilbert S. Goodwin, Consulting Engineer and Naval Architect, Liverpool, joined the Institution as a Graduate in 1895.

He served his apprenticeship as engineer with Messrs David Rollo & Sons, Liverpool, and, after being through the various departments, went to sea to gain increased experience in marine engine work.

In the beginning of 1895, Mr Goodwin went to Messrs Dunsmuir & Jackson's Engineering Works, Govan, to further improve himself in his profession.

He died at Liverpool on 26th November, 1895, aged 24 years.

Mr WILLIAM D. SHIELDS joined the Institution as a Graduate in 1892. He was born on the 10th of October, 1870, at Glasgow, and was educated at Allan Glen's School. He attended science classes at the Technical College, Bath Street, gaining a first class certificate in nearly every subject he took up. As practical engineer, he began with the firm of Messrs Turnbull, Grant, & Co., Canal Basin Works, and finished an apprenticeship with Messrs Sharp, Stewart, & Co., "Atlas" Works. Having a strong desire for electrical engineering, he sent a list of certificates gained from the Science and Art Department to Messrs Siemens Brothers, London, and immediately got an appointment to their Works at Woolwich, and was with Dr O'Bach doing interesting experimental and testing work very successfully. His health giving way, he made a long sea voyage to New Zealand and Australia in 1895, and returned during March, 1896. He died at Glasgow on 2nd April, 1896.

REPORT OF THE LIBRARY COMMITTEE.

THE additions to the Library during the present session include 39 volumes by purchase, 13 volumes, 4 parts, and 4 pamphlets by donation, while 76 volumes and 25 parts were received in exchange for the Transactions of the Institution. Of the periodical publications received in exchange, 19 are weekly, 12 monthly, and 2 quarterly.

53 volumes were bound during the session.

The Library now consists of 2245 volumes.

On behalf of the Institution, the Committee begs to tender its best thanks for the presentations made.

DONATIONS TO LIBRARY.

Three Packets of Geological Survey Maps. From Geological Survey of Canada.

Subject Index of Minutes of Proceedings of the Institution of Civil Engineers,Vols. 59-118, 1879-94. From the Institution.

Steamships and their Machinery from First to Last, by J. W. E. Haldane. From the Author.

Illustrated Official Journal of Patents. From the Patent Office.

The Use and Screening of Side Lights, by Sir Digby Murray, Bart. From the Author.

Engineering and Shipbuilding in the Far East, by W. C. Jack; 8vo pamphlet. From the Author.

Mètre *versus* Pace; or, Arguments in favour of a Decimal System of British Weights and Measures, founded on a 30-inch Base, by James Dickson; 8vo pamphlet, 1896. From the Author.

Growth of Population of Great Cities, by E. L. Corthell; 8vo pamphlet, 1895. From the Author.

Official Gazette of the United States Patent Office; vol. 72, part 13 1895, and continued. From United States Patent Office.

Transactions of the Society of Naval Architects and Marine Engineers; Vol. 3, 1895, and continued, 4to; New York. From the Society.

The Handling of Ships, by Capt. D. Wilson Barker. From the Author.

Life of Sir Richard Burton, 2 vols. From the Executors of the late Lady Burton.

Engineering and Mining Journal of New York; vol. 6, part 15, for 1896, and continued. From the Manager.

Annual Catalogue of the Massachusetts Institute of Technology, 1895-96, and Annual Report, 1895. From the Institute.

Canals: with Maps of Canals and Navigable Rivers of England and Wales, by Lionel B. Wells, M.I.C.E.; 8vo pamphlet, 1895. From the Author.

Gleanings from Patent Laws of all Countries, by W. L. Wise; 8vo. London, 1895. From the Author.

Queensland Water Supply—Report of the Hydraulic Engineer, 1895. From Mr J. B. Henderson, M.I.C.E.

Bulletin de l'Association Technique Maritime; vols. 1-6, 1890-95, and continued, 8vo; Paris.

NEW BOOKS ADDED TO THE LIBRARY.

Anglin, S., Design of Structures: A Practical Treatise on the Building of Bridges, Roofs, etc.; 2nd edition; 8vo. London, 1895.

Blount, B. and A. G. Bloxam, Chemistry for Engineers and Manufacturers, a Practical Text-Book; 8vo. London, 1896.

Chase, J. M., Screw Propellers and Marine Propulsion; 8vo. New York, 1895.

Cromwell, J. H., Belts and Pulleys, a Treatise on; 8vo. New York, 1894.

Davies, E. H., Machinery for Metalliferous Mines; 8vo. London, 1894.

Eissler, M., Cyanide Process for the Extraction of Gold; 8vo. London, 1895.

Foster, C. Le Neve, Text-Book of Ore and Stone Mining; 8vo. London, 1894.

Greenwell, A. and W. T. Curry, Rural Water Supply, a Practical Handbook on the Supply of Water and Construction of Waterworks for Small Country Districts; 8vo. London, 1896.

Hatch, F. H. and J. A. Chalmers, Gold Mines of the Rand, being a description of the Mining Industry of Witwatersrand, South African Republic; 8vo. London, 1895.

Jamieson, Professor, Text-Book on Applied Mechanics; vol. I.; 8vo; London, 1895.

Mackay, J. C., Light Railways for the United Kingdom, India, and the Colonies: A Practical Handbook setting forth the principles on which Light Railways should be Constructed, Worked, and Finished; 8vo. London, 1896.

Maclean, Magnus, Physical Units; 8vo. London, 1896.

Reagan, H. C., Locomotive Mechanism and Engineering; 8vo. New York, 1894.

Redwood, B. and G. T. Holloway, Petroleum, a Treatise on; 2 vols., 8vo. London, 1896.

Robinson, H., Sewerage and Sewage Disposal; 8vo. London, 1896.

Shield, W., Principles and Practice of Harbour Construction; 8vo. London, 1895.

Spangler, H. W., Valve Gears; 2nd edition; 8vo. New York, 1895.

Tuit, J. E., Tower Bridge, its History and Construction; 4to. London, 1894.

Clark, D. K., Tramways: Their Construction and Working; 2nd edition; 8vo. London, 1894.

Day, C., Indicator Diagrams and Engine and Boiler Testing; 8vo. Manchester, 1895.

Donisthorpe, W., System of Measures of Length, Area, Bulk, Weight, Value, Force, etc.; 4to. London, 1895.

Eissler, M., Metallurgy of Gold; 4th edition; 8vo. London, 1896.

Foster, H. A., Central Station Book-Keeping and Suggested Forms, with an Appendix for Street Railways; 8vo. New York, 1896.

Greenhill, A. G., Treatise on Hydrostatics; 8vo. London. 1894.

Hawkins, C. C. and F. Wallis, The Dynamo: Its Theory, Design, and Manufacture; 8vo. London, 1893.

Lockwood, T. D., Practical Information for Telephonists; 8vo. New York, 1891.

Mach, E., The Science of Mechanics, translated from 2nd German Edition by T. J. M'Cormack; 8vo. Chicago, 1893.

Meyer, J. G. A., Modern Locomotive Construction. New York, 1894.

Official Year-Book of the Scientific and Learned Societies of Great Britain and Ireland. 1896.

Pullen, W. W. F., Injectors: Their Theory, Construction, and Working; 8vo. Manchester, 1893.

Reckenzaun, A., Electric Traction on Railways and Tramways; 8vo. London, 1892.

Rhead, E. L., Metallurgy: An Elementary Text-Book; 8vo. London, 1895.

Tait, P. G., Dynamics; 8vo. London, 1895.

Taylor, D. W., Resistance of Ships and Screw Propulsion; 8vo. London, 1893.

Thompson, S. P., Dynamo Electric Machinery; 5th edition; 8vo. London, 1896.

Thomson, J. J., Elements of the Theory of Electricity and Magnetism; 8vo. Cambridge, 1895.

Walton, T., Know Your Own Ship: A simple explanation of the stability, construction, tonnage, and freeboard of ships; 8vo. London, 1896.

Fry, H., History of North Atlantic Steam Navigation; 8vo. London, 1896.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C. :—

Bristol Naturalists' Society, Bristol.

Institution of Civil Engineers, London.

Institution of Civil Engineers of Ireland, Dublin.

Institution of Mechanical Engineers, London.
Institution of Naval Architects, London.
Institute of Marine Engineers, London.
Iron and Steel Institute, London.
Liverpool Engineering Society, Liverpool.
Liverpool Polytechnic Society, Liverpool.
Literary and Philosophical Society of Manchester, Manchester.
Lloyd's Register of British and Foreign Shipping, London.
Manchester Association of Engineers, Manchester.
Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Patent Office, London.
Philosophical Society of Glasgow.
Royal Dublin Society, Dublin.
Royal Scottish Society of Arts, Edinburgh.
Shipmasters' Society, London.
Society of Arts, London.
Society of Engineers, London.
South Wales Institute of Engineers, Swansea.
The Hull and District Institution of Engineers and Naval Architects, Hull.
Institution of Junior Engineers, London.
The Sanitary Institute of Great Britain, London.
West of Scotland Iron and Steel Institute.
Edinburgh Architectural Association.
Engineering Society of the School of Practical Science, Toronto.
American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
Association des Ingénieurs, Gand, Belgium.
Association Technique Maritime, Paris.

Austrian Engineers' and Architects' Society, Vienna.
Bureau of Steam Engineering, Navy Department, Washington.
Canadian Institute, Toronto.
Canadian Society of Civil Engineers, Montreal.
Engineers' and Architects' Society of Naples, Naples.
Geological Survey of Canada, Montreal.
Master Car Builders' Association, Chicago, U.S.A.
Royal Academy of Sciences, Lisbon.
Royal Society of Tasmania, Hobart.
Smithsonian Institution, Washington, U.S.A.
Society of Naval Architects and Marine Engineers, Washington, U.S.A.
Société des Ingénieurs Civils de France, Paris.
Société Industrielle de Mulhouse, Mulhouse.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Anciens Elèves des Ecoles Nationales d'Arts et Métiers, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Scientific Library, U.S. Patent Office, Washington.
The Engineering Association of New South Wales, Sydney.
The Technical Society of the Pacific Coast, San Francisco, U.S.A.
The Franklin Institute, Philadelphia, U.S.A.
American Institute of Electrical Engineers.
Society of Arts, Massachusetts Inst. of Technology, Boston.

COPIES OF THE TRANSACTIONS ARE FORWARDED TO THE FOLLOWING COLLEGES, LIBRARIES, &C.:—

Cornell University, Ithaca, U.S.A.
Dumbarton Free Public Library, Dumbarton.
Glasgow University, Glasgow.
Lloyd's Office, London.
Mercantile Marine Service Association, Liverpool.
M'Gill University, Montreal.
Mitchell Library, Glasgow.
Royal Naval College, Greenwich.
Stevens Institute of Technology, Hoboken, U.S.A.

Stirling's Library, Glasgow.
The British Corporation for the Survey and Registry of Shipping, Glasgow.
The Advocates' Library, Edinburgh.
The Glasgow and West of Scotland Technical College, Glasgow.
The Yorkshire College, Leeds.
Trinity College, Dublin.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
University College, London.

Publications Received Periodically in Exchange for Institution Transactions :—

Cassier's Magazine.
Colliery Guardian.
Engineering.
Engineers' Gazette.
Industries and Iron.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Machinery.
Nature.
The Colliery Engineer, U.S.A.
The Contract Journal.
The Engineer.
The Engineering Review.
The Machinery Market.
The Marine Engineer.
The Mechanical World.
The Practical Engineer.
The Steamship.
The Mariner.
Indian Engineering.
Journal de l'Ecole Polytechnic.
L'Industria.

Portfeuille Economique des Machines.
Revue Industrielle.
Stahl und Eisen.
The American Manufacturer and Iron World.
The Indian Engineer.
Transport.

ANDREW JAMIESON,
Hon. Librarian and Convener.

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 the Library.

Copies of Library Catalogue and Supplement, price 6d; or separately, 3d each, may be had at the Library, 207 Bath Street, or from the Secretary.

A List of the Papers read and Authors' Names, from the First to the Thirty-third Sessions, will be found in Vol. XXXIII.

As arranged by the Council, a Register Book for Graduates now lies in the Library for the inspection of Members, the object being to assist Graduates of the Institution in finding suitable appointments.

Annual Subscriptions are due at the commencement of each Session, viz. :—

MEMBERS, £1 10s; ASSOCIATES, £1; GRADUATES, 10s.
LIFE MEMBERS, £20; LIFE ASSOCIATES, £15.
(For Graduated Scale of Life Membership, see page 259.)

Membership Application Forms can be had from the Secretary or from the Librarian, at the Rooms, 207 Bath Street.

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.

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),

AT CLOSE OF SESSION 1895-96.

HONORARY MEMBERS.

1859 Professor CHARLES PIAZZI SMYTH, LL.D., F.R.S.E., Clova, Ripon.

1859 Lord KELVIN, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow.

1884 Lord ARMSTRONG, C.B., LL.D., D.C.L., F.R.S., Newcastle-on-Tyne.

1891 Lord BRASSEY, K.C.B., D.C.L., 4 Great George Street, Westminster, London, S.W.

1891 Sir HENRY BESSEMER, F.R.S., 165 Denmark Hill, Surrey.

1891 Lord BLYTHSWOOD, Blythswood, Renfrewshire.

1891 Professor A. B. W. KENNEDY, LL.D., F.R.S., 19 Little Queen Street, Westminster, London, S.W.

1891 Sir DIGBY MURRAY, Bart., Hothfield, Parkstone, Dorset.

1894 Sir WILLIAM HENRY WHITE, K.C.B., F.R.S., LL.D., Admiralty, London.

1896 A. J. DURSTON, C.B., Admiralty, London.

MEMBERS.

DATE OF ELECTION.			
G. 1890, Mar. 25: M. 1895, Jan. 22:	J. Millen	Adam,	Ibrox Iron Works, Glasgow.
1889, Nov. 19:	William	Adam,	98 Dixon Avenue, Crosshill, Glasgow.
1889, Apr. 23:	James	Adamson,	58 Romford Road, Stratford, Essex.
1883, Mar. 20:	Geo. A.	Agnew,	Woodland Villa, Govan, Glasgow.
1889, Oct. 22:	William	Aitchison,	Mauritius Assets & Estates Co., Port Louis, Mauritius.
1872, Feb. 27:	A. B.	Allan,	Burgh Surveyor, Burgh Chambers, Govan, G'gow.
1890, Jan. 21:	John M.	Allan,	Oak Bank, Shandon.
1895, Apr. 30:	Robert	Allan,	Demerara Foundry, George Town, Demerara.
1869, Jan. 20:	William	Allan, M.P.,	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.
1895, Mar. 26:	O. R.	Anbull,	8 St. Alban's Ter., Partick, Glasgow.
G. 1874, Feb. 24: M. 1880, Nov. 23:	James	Anderson,	100 Clyde St., Glasgow.
1892, Dec. 20:	James H.	Anderson,	Caledonian Ry., Glasgow.

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

1894, Apr. 24:	Prof. Mohamed	Anis, Bey,	Ministère des Travaux Publics, Cairo.
1860, Nov. 28:	Robert	Angus,	Lugar, Ayrshire.
1887, Dec. 20:	W. David	Archer,	Ravenswood, Dalmuir.
1894, Jan. 23:	William	Arnot,	Engineer, Corporation Electric Lighting, City Chambers, Glasgow.
1875, Dec. 21:	Thomas A.	Arrol,	Germiston Works, Glasgow.
1894, Nov. 20:	Thomas	Arrol, Jun.,	101 Armadale St., Glasgow.
1885, Jan. 27:	Sir Wm.	†Arrol, LL.D., M.P., *(President.)*	10 Oakley Terrace, Glasgow.
Original:	David	Auld,	13 Broompark Drive, Dennistoun, Glasgow.
1885, Apr. 28:	John	Auld,	Whitevale Foundry, Glasgow.

1880, Feb. 24:	William N.	Bain,	40 St. Enoch Square, Glasgow.
1891, Apr 28:	Wm. P. C.	Bain,	Lochrin Iron Works, Coatbridge.
1881, Oct. 25:	Allan W.	Baird,	Eastwood Villa, St. Andrew's Drive, Pollokshields, Glasgow.
1887, Nov. 22:	Michael R.	Barnett,	Ashfield, Pateley Bridge, Yorkshire.
1882, Mar. 21:	Prof. Archd.	Barr, D.Sc.,	Royston, Dowanhill.
1881, Mar. 22:	George H.	Baxter,	Clyde Navigation Works, Dalmuir.
1875, Jan. 26:	Charles	Bell,	The Birches, Stirling.
	David	*Bell,	19 Eton Place, Hillhead, Glasgow.
1880, Mar. 23:	Imrie	Bell,	49 Dingwall Rd., Croyden, Surrey.
1895, Feb. 26:	Stuart	Bell,	41 Clyde Place, Glasgow.

1889, Jan. 22:	W. Reid	Bell,	Box No. 2263, Post Office, Johannesburg, S. African Republic.
G. 1883, Mar. 20: M. 1884, Nov. 25:	Andrew S.	Biggart, (*Member of Council.*)	Baltic House, Baltic Street, Bridgeton, Glasgow.
1884, Mar. 25:	Prof. John Harvard	Biles,	Glasgow University, Glasgow.
1890, Mar. 25:	John R.	Bird,	10 Morrison St., Glasgow.
1869, Feb. 17:	Geo. M'L.	Blair,	127 Trongate, Glasgow.
G. 1884, Jan. 22: M. 1889, Oct. 22:	H. MacLellan	Blair,	Clutha Iron Works, Vermont Street, Glasgow.
1867, Mar. 27:	James M.	Blair,	Williamcraigs, Linlithgowshire.
1883, Oct. 23:	William L.	Bone,	Ant and Bee Works, West Gorton, Manchester.
1891, Jan. 27:	William	Bow,	Thistle Works, Paisley.
1874, Jan. 27:	Howard	Bowser,	13 Royal Crescent, W., Glasgow.
1890, Mar. 25:	George R.	Brace,	William Denny & Sons, Dumbarton.
1880, Mar. 23:	James	Brand,	109 Bath Street, Glasgow.
1891, Dec. 22:	Henry	Brier,	13 Ailsa Drive, Langside, Glasgow.
G. 1873, Dec. 23: M. 1884, Jan. 22:	James	Broadfoot,	55 Finnieston St., Glasgow.
1895, Apr. 30:	Henry W.	Brock,	Engine Works, Dumbarton.
1865, Apr. 26:	Walter	*Brock,	Engine Works, Dumbarton.
1893, Apr. 25:	Thomas M.	Broom,	Oakfield, East Greenock.
1859, Feb. 16:	Andrew	*Brown,	London Works, Renfrew.
G. 1876, Jan. 25: M. 1885, Nov. 24:	Andrew M'N.	Brown,	Strathclyde, Dalkeith Avenue, Dumbreck, Glasgow.
G. 1879, Feb. 25: M. 1891, Oct. 27:	Alexr. T.	Brown,	18 Glencairn Drive, Pollokshields, Glasgow.
G. 1883, Dec. 18: M. 1895, Feb. 26:	Eben.	Hall-Brown,	Helen St. Engine Works, Govan, Glasgow.

1886, Mar. 23:	George	Brown,	Kirklee, Dumbarton.
G. 1886, Oct. 26: M. 1892, Jan. 26:	James	Brown,	Engine Department, Astilleros del Nervion, Bilbao, Spain.
G. 1881, Jan. 25: M. 1894, Dec. 18:	Matt. T.	Brown, B.Sc.,	194 St. Vincent Street, Glasgow.
1885, Apr. 28:	Walter	Brown,	Castlehill, Renfrew.
G. 1874, Jan. 27: M. 1884, Jan. 22:	William	Brown,	Meadowflat, Renfrew.
1880, Dec. 21:	William	Brown,	Albion Works, Woodville Street, Govan, Glasgow.
1889, Dec. 17:	William	Brown,	Dubs & Coy., Glasgow Loco. Works, Glasgow.
1890, Mar. 25:	William	Brown,	Old Hall, Kilmalcolm.
G. 1872, Oct. 24: M. 1885, Nov. 22:	Hartvig	Burmeister,	Rahr & Raundrup, 1 Princess Street, Manchester.
1880, Dec. 21:	James W.	Burns,	74 Broomielaw, Glasgow.
1881, Mar. 22:	Thomas	Burt,	60 St. Vincent Crescent, Glasgow.
1878, Oct. 29:	Edward B.	Caird,	777 Commercial Rd., Limehouse, London.
1894, Feb. 20:	Robert	Caird, *(Member of Council.)*	Caird & Co., Greenock.
1878, Dec. 17:	James	Caldwell,	130 Elliot Street, Glasgow.
1885, Mar. 24:	John B.	Cameron,	111 Union Street, Glasgow.
1875, Dec. 21:	J. C.	Cameron,	24 Pollok Street, Glasgow.
1890, Mar. 25:	William	Cameron,	Fereneze Ter., Barrhead.
1890, Jan. 21:	John	Campbell,	8 Broomhill Drive, Partick, Glasgow.
1895, Mar. 26:	W. S.	Campbell,	1 Thornwood Ter., Partick, Glasgow.
1889, Oct. 22:	Evelyn G.	Carey,	4 Sunnyside Avenue, Uddingston.
1895, Dec. 24:	Alex. L.	Carlaw,	81 Dunlop Street, Glasgow.

1895, Dec. 24 :	David	Carlaw, Jr.,	81 Dunlop Street, Glasgow.
1895, Dec. 24 :	James W.	Carlaw,	81 Dunlop Street, Glasgow.
1881, Nov. 22:	John H.	Carruthers,	Ashton, Queen Mary Av., Crosshill, Glasgow.
1892, Feb. 23:	James	Chalk,	68 Bath Street, Glasgow.
1894, Jan. 23:	W. A.	Charlton,	96 Hope Street, Glasgow.
1893, Apr. 25:	R. Barclay	Christie,	123 Hope Street, Glasgow.
1883, Jan. 23:	John	Clark,	British India Steam Navigation Co., 9 Throgmorton Av., London, E.C.
1893, Apr. 25:	William	Clark,	208 St. Vincent Street, Glasgow.
1892, Nov. 22:	Alexander	Cleghorn,	Datcha, Scotstounhill, Glasgow.
1891, Oct. 27:	Charles	Clarkson,	Portland Harbour Torpedo-Works, Weymouth.
1884, Feb. 26:	James T.	Cochran,	Cochran & Co., Shipbuilders, Birkenhead.
1890, Mar. 25:	John	Cochrane,	Grahamstone Foundry, Barrhead.
1881, Oct. 25:	George	Cockburn,	24 Sussex Street, Glasgow.
G. 1876, Dec. 19: M. 1884, Mar. 25:	Charles	Connell,	Whiteinch, Glasgow.
G. 1877, Dec. 18: M. 1885, Nov. 24:	James	Conner,	Assistant Locomotive Engineer, Highland Railway, Inverness.
1893, Dec. 19:	James	Cooper,	Aberdeen Steam Navigation Company, Aberdeen.
1864, Feb. 17:	James	Copeland,	24 George Sq., Glasgow.
1864, Jan. 20:	William R.	Copland,	146 West Regent Street, Glasgow.
1868, Mar. 11:	S. G. G.	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1892, Oct. 25:	Elmer L.	Corthell,	71 Broadway, New York.

1880, Dec. 21 1891, Oct. 27	Sinclair	Couper, *(Member of Council.)*	Moore Park Boiler Works, Govan, Glasgow.
1866, Nov. 28:	M'Taggart	Cowan,	109 Bath Street, Glasgow.
1861, Dec. 11:	William	Cowan,	46 Skene Ter., Aberdeen.
1895, Mar. 26:	John	Craig,	Rosevale, Port-Glasgow.
1883, Dec. 18:	Samuel	Crawford,	John Scott & Co., Engineers & Shipbuilders, Kinghorn.
1894, Dec. 18:	James L.	Crichton,	3 East Park Terrace, Maryhill, Glasgow.
1881, Mar. 22:	William	Crockatt,	179 Nithsdale Rd., Pollokshields, Glasgow.
1884, Dec. 23:	Peter N.	Cunningham,	Easter House, Kennyhill, Cumbernauld Road, Glasgow.
1869, Jan. 20:	James	Currie,	16 Bernard Street, Leith.
1893, Apr. 25:	Thomas	Daniels,	Nasmyth, Wilson & Co., Ltd., Patricroft, near Manchester.
1888, Jan. 24:	John	Darling,	34 Queen Square, Glasgow.
G. 1881, Mar. 22: M. 1888, Dec. 18:	David	Davidson,	17 Regent Park Square, Strathbungo, Glasgow.
1861, Dec. 11:	Thomas	Davison,	248 Bath Street, Glasgow.
1869, Feb. 17:	James	Deas,	Engineer, Clyde Trust, Crown Gardens, Glasgow.
1882, Dec. 19:	J. H. L. Van	Deinse,	34 Binnenkant, Amsterdam.
1883, Nov. 21:	James	Denholm,	5 Derby Terrace, Sandyford Street, Glasgow.
G. 1883, Dec. 18: M. 1893, Nov. 21:	William	Denholm,	Meadowside Shipbuilding Yard, Partick, Glasgow.
1888, Feb. 21:	Archibald	Denny,	Braehead, Dumbarton.
1887, Oct. 25:	James	Denny, *(Member of Council.)*	Engine Works, Dumbarton.
1895, Apr. 30:	Leslie	Denny,	Leven Shipyard, Dumbarton.

1888, Feb. 21:	Peter	Denny,	Bellfield, Dumbarton.
1878, Mar. 19:	Frank W.	Dick,	Palmer's Steel Works, Jarrow-on-Tyne.
1890, Nov. 19:	B. Gillespie	Dickson,	c/o J. T. Sellar, 8 Blackfriars Street, Perth.
G. 1873, Dec. 24: M. 1878, Jan. 22:	James S.	Dixon,	97 Bath Street, Glasgow.
1895, Feb. 26:	Walter	Dixon,	164 St. Vincent St., Glasgow.
1871, Jan. 17:	William	Dobson,	The Chesters, Jesmond, Newcastle-on-Tyne.
1864, Jan. 20:	James	Donald,	Abbey Works, Paisley.
1892, Nov. 22:	Robert Hanna	Donald,	Abbey Works, Paisley.
1876, Jan. 25:	James	Donaldson,	Almond Villa, Renfrew.
1886, Nov. 23:	Patrick	Doyle, F.R.S.E.,	19 Lall Bazar St., Calcutta.
1890, Apr. 29:	Alexander	Drew,	Francis Morton & Co., Ltd., Garston, near Liverpool.
1895, Mar. 26:	Walter	Drummond,	The Glasgow Railway Engineering Works, Govan, Glasgow.
1884, Dec. 23:	John W. W.	Drysdale,	46 Circus Drive, Glasgow.
1882, Oct. 24:	Chas. R.	Dubs,	Glasgow Locomotive Works, Glasgow.
G. 1886, Nov. 23: M. 1894, Mar. 20:	George F.	Duncan,	Ardenclutha, Port-Glasgow.
1886, Nov. 23:	John	Duncan, *(Member of Council.)*	Ardenclutha, Port-Glasgow.
1881, Jan. 25:	Robert	Duncan,	Whitefield Engine Works, Govan, Glasgow.
1873, Apr. 22:	Robert	Dundas, (*Past President.*)	3 Germiston Street, Glasgow.
1869, Nov. 23:	David Jno.	Dunlop, (*Member of Council.*)	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 L.	Dunn,	1218 Hyde Street, San Francisco, U.S.A.
1883, Oct. 23:	Henry	Dyer, D.Sc., M.A.,	8 Highburgh Terrace, Dowanhill, Glasgow.
1885, Feb. 24:	Francis	Elgar, LL.D., F.R.S.E.,	Fairfield Shipbuilding and Engineering Co., Ltd., 113 Cannon St., London, E.C.
1896, Jan. 28 :	Thomas	Elsee,	75 Buchanan St., Glasgow.
1894, Apr. 24:	Wallace	Fairweather,	62 St. Vincent St., Glasgow.
G. 1869, Nov. 23: M. 1878, Mar. 19:	John	Ferguson,	Shipbuilder, Leith.
1889, Oct. 22:	Peter	Ferguson,	Phœnix Works, Paisley.
G. 1885, Jan. 27: M. 1894, Mar. 20:	William D.	Ferguson,	Albert Villa, Ravenhill Road, Belfast.
G. 1881, Feb. 22: M. 1895, Jan. 22:	Wm. R.	Ferguson,	Messrs Barclay Curle & Co., Whiteinch, Glasgow.
1874, Feb. 24:	Immer	Fielden,	2 Thornton Villas, Holderness Road, Hull.
1880, Jan. 27:	Alexander	Findlay,	Parkneuk Iron Works, Motherwell.
G. 1873, Dec. 23: M. 1884, Nov. 25:	E. Walton	Findlay,	Ardeer, Stevenston.
1884, Dec. 23:	Finlay	Finlayson,	Muirend Cottage, Dundyvan, Coatbridge.
1894, Jan. 23:	Andrew E.	Fleming,	Kandy, Ceylon.
1895, Jan. 22:	Thos.	Fleming,	Atlas Works, Springburn, Glasgow.
1895, Jan. 22:	George L.	Flett,	86 Sussex Street, Paisley Road West, Glasgow.
1883, Dec. 18:	Lawson	Forsyth,	10 Grafton Sq., Glasgow.
1870, Jan. 18:	William *(Member of Council.)*	Foulis,	Engineer, Corporation Gas Works, City Chambers, Glasgow.

1880, Nov. 2:	Samson	Fox,	Leeds Forge, Leeds.
1893, Dec. 19:	William	Fraser,	121 No. Montrose Street, Glasgow.
1858, Nov. 24:	James M. *(Past President; Member of Council, and Honorary Treasurer.)*	Gale,	Engineer, Corporation Water Works, City Chambers, Glasgow.
1893, Jan. 24:	William M.	Gale,	18 Huntly Gardens, Kelvinside, Glasgow.
1895, Jan. 22:	Charles S.	Galloway,	676 Dumbarton Road, Partick, Glasgow.
1887, Oct. 25:	Lewis P.	Garrett,	58 Broomielaw, Glasgow.
1888, Mar. 20:	Ernest	Gearing,	Fenshurst, Clarence Drive, Harrowgate.
1888, Dec. 18:	E. W.	Gemmell,	Board of Trade Offices, 7 York Street, Glasgow.
G. 1873, Dec. 23: M. 1882, Mar. 21:	Andrew	Gibb,	30 South Street, Greenwich, London, S.E.
1886, Nov. 23:	Paterson	Gifford,	101 St. Vincent Street, Glasgow.
1859, Nov. 23:	Archibald	*Gilchrist,	5 Montgomerie Crescent, Glasgow.
G. 1866, Dec. 26: M. 1878, Oct. 29:	James	Gilchrist,	Stobcross Engine Works, Finnieston Quay, Glasgow.
1894, Nov. 20:	Andrew	Gillespie,	34 St. Enoch Sq., Glasgow.
G. 1874, Feb. 24: M. 1891, Mar. 24:	James	Gillespie,	21 Minerva St., Glasgow.
G. 1884, Dec. 23: M. 1893, Feb. 21:	D. C.	Glen,	Matheson & Coy., 3 Lombard St., London, E.C.
1866, Mar. 28:	Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.
1868, Mar. 11:	Joseph	Goodfellow,	3 Towerhill Terrace, Springburn, Glasgow.
1895, Mar. 26:	John	Gordon,	152 Craigpark St., Glasgow.
1882, Apr. 25:	H. Garrett	Gourlay,	Dundee Foundry, Dundee.

G. 1882, Jan. 24: M. 1895, Jan. 22:	A. B.	Gowan,	Naval Construction and Armaments Company, Barrow-in-Furness.
1893, Apr. 25:	David R.	Graham,	Messrs A. Stephen & Son, Engine Department, Linthouse, Govan, Glasgow.
1858, Mar. 12:	George	Graham,	Engineer, Caledonian Railway, Glasgow.
1876, Jan. 25:	Thomas M.	Grant,	322 St. Vincent Street, Glasgow.
1862, Jan. 8:	James	Gray,	Riverside, Old Cumnock, Ayrshire.
1881, Dec. 20:	L. John	Groves,	Engineer, Crinan Canal, Ardrishaig.
1881, Jan. 25:	William	Hall,	Shipbuilder, Aberdeen.
G. 1874, Feb. 24: M. 1885, Nov. 24:	Archibald	Hamilton,	New Dock Works, Govan, Glasgow.
G. 1873, Dec. 23: M. 1881, Nov. 22:	David C. *(Member of Council.)*	Hamilton,	Clyde Shipping Co., 21 Carlton Place, Glasgow.
G. 1866, Dec. 26: M. 1873, Mar. 18:	James	Hamilton, Jun.,	R. Napier & Sons, Govan.
	John	*Hamilton,	22 Athole Gardens, Glasgow.
G. 1880, Nov. 2: M. 1884, Jan. 22:	Bruce	Harman,	35 Connaught Rd., Harlenden, London, N.W.
G. 1874, Feb. 24: M. 1880, Nov. 23:	C. R.	Harvey,	6 Park Quadrant, Glasgow.
1887, Feb. 22:	John H.	Harvey,	Benclutha, Port-Glasgow.
1871, Jan. 17:	William	Hastie,	Kilblain Engine Works, Greenock.
1879, Nov. 25:	A. P.	†Henderson,	30 Lancefield Quay, Glasgow.
1895, Mar. 26:	Fred. N.	Henderson,	Meadowside, Partick, Glasgow.

1888, Dec. 18:	J. Bailie	Henderson,	Govt. Hydraulic Engineer, Brisbane, Queensland.
1873, Jan. 21:	John	†Henderson,	Meadowside, Partick, Glasgow.
1879, Nov. 25:	John L.	†Henderson,	——
1870, May 31:	Richard	Henigan,	Alma Road, Avenue, Southampton.
1877, Feb. 20:	George	Herriot,	Board of Trade Offices, 7 York Street, Glasgow.
1890, Oct. 28:	W. Scott	Herriot,	187 Osmaston Rd., Derby.
1892, Nov. 22:	Edward P.	Hetherington,	3 Westminster Gdns., Hillhead, Glasgow.
1888, Dec. 18:	Wm. Seymour	Hide,	Engine Depart., Medina Dock, West Cowes, Isle of Wight.
1895, Jan. 22:	Thomas	Hill,	3 Whitevale, Dennistoun, Glasgow.
1896, Jan. 28:	James	Hines,	Dunedin Lodge, Lenzie, Glasgow.
1880, Nov. 2:	Charles P.	Hogg,	175 Hope Street, Glasgow.
1883, Mar. 20:	John	Hogg,	Victoria Engine Works, Airdrie.
1880, Mar. 23:	F. G.	Holmes,	Burgh Surveyor, Stirling.
1883, Mar. 20:	Matthew	Holmes,	Netherby, Lenzie.
1894, Apr. 24:	A. Campbell	Holms,	Lloyd's Register, 2 Whitelion Court, Cornhill, London.
1890, Mar. 25:	Colin	†Houston,	Harbour Engine Works, 60 Portman Street, Glasgow.
Original:	James	Howden,	8 Scotland Street, Glasgow
1891, Dec. 22:	James Howden	Hume,	38 Keir St., Pollokshields, Glasgow.
Original:	Edmund	*Hunt,	121 West George St., Glasgow.

G. 1886, Oct. 26: M. 1889, Nov. 19:	Gilbert M.	Hunter,	Town Engineer, New Amsterdam, Berbice, British Guiana.
1881, Jan. 25:	James	Hunter,	Aberdeen Iron Works, Aberdeen.
1891, Feb. 24:	Joseph Gilbert	Hunter,	342 Argyle Street, Glasgow.
1895, Mar. 26:	James H.	Hutchison,	Shipbuilder, Port-Glasgow.
G. 1873, Dec. 23: M. 1885, Nov. 24:	Guybon	Hutson,	Kelvinhaugh Engine Works, Glasgow.
1893, Mar. 21:	Guybon	Hutson, Jr.,	47 Lilybank Gardens, Glasgow.
1861, May 1:	John	Inglis, *(Past President.)*	Point House Shipyard, Glasgow.
1890, Feb. 25:	William	Ireland,	7 Ardgowan Terrace, Glasgow.
1893, Nov. 21:	Alexander	Jack,	Dellburn Works, Motherwell.
1891, Mar. 24:	Peter	Jackson,	Consulting Engineer, 109 Hope Street, Glasgow.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan, Glasgow.
1889, Mar. 26:	Prof. Andw.	Jamieson, F.R.S.E., *(Vice-President.)*	The Glasgow and West of Scotland Technical College, Bath St., Glasgow.
1892, Oct. 25:	Llewellen	Jones,	Arborfield Rectory, New Reading, Berks.
1879, Feb. 25:	David	Johnston,	9 Osborne Terrace, Coplaw Road, Glasgow.
1883, Jan. 23:	F. C.	Kelson,	Angra Bank, Waterloo Park, Waterloo, Liverpool.
G. 1883, Feb. 20: M. 1892, Oct. 25:	Ebenezer D.	Kemp,	25 Grove Road, Rockferry, Birkenhead.
1875, Nov. 23:	William	Kemp,	101 St. Vincent St., G'gow.

1895, Apr. 30:	Alex. M'A.	Kennedy,	Rosslea, Dumbarton.
1877, Jan. 23:	John	Kennedy,	R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.
1876, Feb. 22:	Thomas	Kennedy,	Water Meter Works, Kilmarnock.
1894, Apr. 24:	William	Kennedy,	13 Victoria Cres., Dowanhill, Glasgow.
1894, Nov. 20:	Archibald	Kerr,	2 Kelvinside Gars., Glasgow.
1890, Jan. 21:	Alexander	Kidd,	Lloyd's Shipping Office, 74 Battery Rd., Singapore.
G. 1886, Dec. 21: M. 1894, Mar. 20:	Donald	King,	22 Rothesay Gardens, Partick, Glasgow.
1895, Mar. 26:	J. Foster	King,	The British Corporation, 69 St. Vincent St., Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	Tower Buildings, Water Street, Liverpool.
1885, Nov. 24:	Frank E.	†Kirby,	Detroit, U.S., America.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, 99 Southwark Street, London, S.E.
1885, Jan. 27:	Charles A.	Knight,	21 Bothwell St., Glasgow.
1880, Mar. 23:	Frederick	Krebs,	18 Fredericiagade, Copenhagen.
1891, Jan. 27:	James A.	Lade,	Inch Works, Port-Glasgow.
1884, Mar. 25:	John	Laidlaw,	98 Dundas Street, S.S., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 East Milton Street, Glasgow.
1880, Mar. 20:	Andrew	Laing,	5 Oswald Gardens, Scotstounhill, Glasgow.
1875, Oct. 26:	William	Laing,	17 M'Alpine St., Glasgow.
1880, Feb. 24:	James	Lang,	c/o George Smith & Sons, City Line, 75 Bothwell Street, Glasgow.

G. 1888, Nov. 20: M. 1895, Nov. 26:	C. R.	Lang,	Holm Foundry, Cathcart Glasgow.
1884, Feb. 26:	John	Lang, Jun.,	Church Street, Johnstone.
1888, Feb. 21:	George B.	Laurence,	Clutha Iron Works, Paisley Road, Glasgow.
1893, Apr. 25:	Jas. T. G.	Leslie,	21 Kelvingrove St., Glasgow.
1891, Feb. 24:	William	Leslie,	Post Restante, Perth, West Australia.
G. 1873, Dec. 23: M. 1876, Oct. 24:	Charles C.	Lindsay,	167 St. Vincent St., Glasgow.
1893, Feb 21:	William T.	Lithgow,	Port Glasgow.
1884, Feb. 26:	John	List,	3 St. John's Park, Blackheath, London, S.E.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.
1889, Dec. 17:	Alfred E.	Lonergan,	Whitefield Engine Works, Govan, Glasgow.
1888, Feb. 21:	Hugh D.	Lusk,	Rosebank, Greenock.
1885, Oct. 27;	John	Lyall,	69 St. Vincent Crescent, Glasgow.
1858, Feb. 17:	David	M'Call,	160 Hope Street, Glasgow.
1874, Mar. 24:	Hector	MacColl,	Strandtown, Belfast.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
G. 1881, Dec. 20: M. 1889, Oct. 22:	Hugo	MacColl,	Wreath Quay Engineering Works, Sunderland.
1883, Oct. 23:	James	M'Creath,	208 St. Vincent Street, Glasgow.
1871, Jan. 17:	David	M'Culloch,	Vulcan Works, Kilmarnock.
1891, Jan. 27:	Frank	M'Culloch,	Chief Builder, Her Majesty's Royal Indian Marine Dockyard, Bombay.
1896, Mar. 24:	D. H.	Macdonald,	Brandon Works, Motherwell.

1884, Feb. 26:	James	M'Ewan,	Cyclops Foundry, 50 Peel Street, London Road, Glasgow.
1891, Jan. 27:	Joseph	M'Ewan,	35 Houldsworth St., Glasgow.
G. 1874, Feb. 24: M. 1885, Nov. 24:	George	M'Farlane,	121 West George St., Glasgow.
1880, Nov. 2:	James W.	Macfarlane,	12 Balmoral Villas, Cathcart, Glasgow.
1886, Oct. 26:	Walter	Macfarlane,	12 Lynedoch Cres., Glasgow.
1896, Jan. 28:	David Boyd	M'Geoch,	Messrs Blackwood & Gordon, Port-Glasgow.
G. 1886, Dec. 21: M. 1891, Apr. 28:	J. Grant	M'Gregor,	Canadian Pacific Railway Engineering Department, Montreal.
1886, Jan. 26:	Thomas	M'Gregor,	10 Mosesfield Terrace, Springburn, Glasgow.
1894, Feb. 20:	Donald	M'Intosh,	Dunglass, Bowling.
1896, Jan. 28:	John F.	M'Intosh,	Caledonian Railway, St. Rollox, Glasgow.
1887, Nov. 22:	Hugh	M'Intyre,	128 Victoria St., Partick, Glasgow.
1887, Apr. 6:	Edward	Mackay,	8 George Square, Greenock.
G. 1882, Dec. 19: M. 1894, Mar. 20:	Allan	M'Keand,	17 Queen Margaret Drive, Kelvinside, Glasgow.
1893, Apr. 25:	John	M'Kenzie,	128 South Portland Street, Glasgow.
G. 1883, Jan. 23: M. 1895, Nov. 26:	Thomas B.	Mackenzie,	Dalzell Steel Works, Motherwell.
1881, Mar. 22:	William A.	Mackie,	Falkland Bank, Partickhill, Glasgow.
1888, Apr. 24:	James	M'Kechnie,	Naval Construction and Armaments Coy., Barrow in Furness.

1892, Feb. 23: John F. MacLaren, B.Sc., Eglinton Foundry, Canal Street, Glasgow.

G. 1880, Nov. 2:
M. 1885, Dec. 22: Robert MacLaren, Eglinton Foundry, Canal Street, Glasgow.

1891, Apr. 28: Prof. Alex. MacLay, B.Sc., Clairinch, Milngavie.

Sir Andw. *Maclean, Viewfield House, Partick, Glasgow.

1886, Dec. 21: William T. †Maclellan, Clutha Iron Works, G'gow.

1890, Feb. 25: Robert M'Master, Linthouse, Glasgow.

William *MacMillan, 1 Foremount Ter., Partick, Glasgow.

1895, Nov. 26: James M'Nair, Norwood, Prestwick Road, Ayr.

1884, Dec. 23: John M'Neil, Helen St., Govan, Glasgow.

1894, Nov. 20: John Macpherson, 5 Holland Place, Glasgow.

1895, Nov. 26: Norman Macrae, Northern Gold Fields' Co., Salisbury, Mashonaland, South Africa.

1891, Mar. 24: William M'Whirter, 1 Osbourne Place, Govan.

1895, Jan. 22: David Marshall, Glasgow Tube Works, Glasgow.

1896, Mar. 24: Archibald Martin, 100 Elderslie St., Glasgow.

1875, Dec. 21: George Mathewson, Bothwell Works, Dunfermline.

1895, Jan. 22: Robert C. Mathewson, Glenburn Iron Works, Greenock.

1884, Apr. 22: Henry A. Mavor, 57 West Nile St., Glasgow.
(*Vice-President.*)

1894, Nov. 20: Sam Mavor, 3 Elmbank Cres., Glasgow.

1876, Jan. 25: William W. May, 5 Edelweiss Terrace, Partickhill, Glasgow.

1887, Jan. 25: Henry Mechan, 13 Montgomerie Quadrant, Glasgow.

1891, Oct. 27: Samuel Mechan, 5 Kelvingrove Terrace, Glasgow.

G. 1876, Oct. 24: M. 1882, Nov. 28:	James	Meldrum,	3 Elmbank Street, Glasgow.
1883, Jan. 23:	William	Melville,	Engineer, Glasgow & South-Western Railway, St. Enoch Square, Glasgow.
1881, Mar. 22:	William	Menzies,	7 Dean Street, Newcastle-on-Tyne.
G. 1882, Jan. 24: M. 1890, Oct. 28:	R. A.	Middleton,	23 Kensington Terrace, Ibrox, 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,	Hayfield House, Springburn.
1888, Nov. 20:	Thomas	Mitchell,	284 Maxwell Road, Pollokshields, Glasgow.
1876, Mar. 21:	James	Mollison,	6 Hillside Gardens, Partickhill.
1869, Dec. 21:	John	Montgomerie,	1 Regent Place, Shawlands, Glasgow.
1883, Nov. 21:	Joseph	Moore,	c/o 13 Clairmont Gardens, Glasgow.
1862, Nov. 26:	Ralph	Moore,	13 Clairmont Gardens, Glasgow.
1891, Jan. 27:	Robert T.	Moore, B.Sc.,	13 Clairmont Gardens, Glasgow.
1888, Mar. 20:	William	Morison,	41 St. Vincent Crescent, Glasgow.
G. 1878, Dec. 17: M. 1883, Jan. 23:	Robert	Morton,	21 Bothwell St., Glasgow.
1892, Feb. 23:	Robert	Motion,	J. & P. Coats, Paisley.
1885, Mar. 24:	Edmund	Mott,	Board of Trade Surveyor, 7 York Street, Glasgow.
1864, Feb. 17:	Hugh	Muir,	7 Kelvingrove Terrace, Glasgow.
1882, Jan. 24:	John G.	†Muir,	———

1895, Oct. 22:	Carl	Mumme,	30 Newark St., Greenock.
1882, Dec. 19:	Robert D.	Munro,	Engineer, Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.
1896, Feb. 25:	Fred. Teed	Murdoch,	Mansourah, Egypt.
Original:	James	Murdoch,	42 Newark St., Greenock.
1880, Jan. 27:	William	Murdoch,	———
G. 1878, May 14: M. 1889, Nov. 19:	Angus	Murray,	Strathroy, Dumbreck.
1886, Jan. 26:	James	Murray,	94 Washington St., G'gow.
1891, Dec. 22:	Thos. Blackwood	Murray,	B.Sc., 20 Balmoral Crescent, Queen's Park, Glasgow.
1896, Feb. 25:	Thomas R.	Murray,	The Crown Iron Works, Glasgow.

1881, Jan. 25:	Henry M.	Napier,	Shipbuilder, Yoker, near Glasgow.
1857, Dec. 23:	John	†*Napier,	C. Audley Mansions, Grosvenor Square, London.
1881, Dec. 20:	Robert T.	†Napier,	Shipbuilder, Yoker, near Glasgow.
1883, Dec. 18:	Thomas	Nicol,	6 Rosevale Terrace, Partick, Glasgow.
1887, Apr. 6:	William	Nish,	$^{c}/_{o}$ W. L. C. Paterson, Finnieston Quay.
1876, Dec. 19:	Richard	Niven,	Airlie, Ayr.
1861, Dec. 11:	John	Norman,	131A St. Vincent Street, Glasgow.

1891, Jan. 27:	William	O'Brien,	21 Ibrox Terrace, Govan, Glasgow.
1882, Jan. 24:	Robert S.	Oliver,	Highland Railway Co., Inverness.
1860, Nov. 28:	John W.	Ormiston,	Douglas Gardens, Uddingston.

1885, Mar. 24:	Alex. T.	Orr,	Fletcher & Co., Tilbury Docks, Essex.
1890, Oct. 28:	Heinrich	Paasch,	27 Rue d'Amsterdam, Antwerp.
1883, Nov. 21:	W. L. C.	Paterson,	19 St. Vincent Crescent, Glasgow.
G. 1879, Nov. 25: M. 1894, Nov. 20:	Alex. R.	Paton,	Redthorn, Partick, Glasgow.
1887, Nov. 22:	Prof. George	Paton,	Royal Agricultural College, Cirencester.
1889, Feb. 26:	John	Paton,	299 Shields Road, Pollokshields, Glasgow.
1895, Jan. 22:	Alex. W.	Pattie,	University Gardens Terrace, Hillhead, Glasgow.
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,	John Dickie St., Kilmarnock
1894, Dec. 18:	James D.	Peat,	Finnieston Quay, Glasgow.
G. 1873, Dec. 23: M. 1888, Oct. 23:	Edward C.	Peck,	Yarrow & Co., Poplar, London.
G 1881, Oct. 25: M. 1891, Oct. 27:	Wm. T.	Philp,	Workman, Clark & Co., Belfast.
1887, Oct. 25:	Robt. Band	Pope,	Leven Shipyard, Dumbarton.
1877, Nov. 20:	F. P.	Purvis,	Don Villa, Gourock.
1868, Dec. 23:	Henry M.	Rait,	155 Fenchurch Street, London.
1873, Apr. 22:	Richard	Ramage,	Shipbuilder, Leith.
1872, Oct. 22:	David	Rankine,	238 W. George St., Glasgow.
1886, Mar. 23:	John F.	Rankin,	Eagle Foundry, Greenock.
G. 1880, Nov. 2: M. 1894, Mar. 20:	Matthew	Rankin,	Fassoula Iron Works, Smyrna.

G. 1886, Dec. 21: M. 1894, Dec. 18:	Andrew T.	Reid,	Hydepark Loco. Works, Glasgow.
1881, Jan. 25:	Charles	Reid,	Lilymount, Kilmarnock.
1883, Nov. 21:	George W.	Reid,	Locomotive Dept., Natal Govt. Railways, Durban, Natal, South Africa.
1869, Mar. 17:	James	Reid,	Shipbuilder, Port-Glasgow.
1891, Nov. 24:	James B.	†Reid,	Chapelhill, Paisley.
G. 1886, Dec. 21: M. 1894, Dec. 18:	John	†Reid,	Hydepark Loco. Works, Glasgow.
G. 1873, Dec. 23: M. 1881, Nov. 22:	Charles H.	Reynolds,	Sir W. G. Armstrong, Mitchell & Co., Walker Shipyard, Newcastle on-Tyne.
1896, Jan. 28:	John R.	Richmond,	Holm Foundry, Cathcart, Glasgow.
1886, Apr. 27:	James	Riley,	Glasgow Iron and Steel Co., Limited, 36 St. Vincent Place, Glasgow.
1890, Mar. 25:	James W.	Robb,	15 Huntly Terrace, Shettleston.
1876, Oct. 24:	Duncan	Robertson,	Baldroma, Ibrox, Glasgow.
1884, Apr. 22:	R. A.	Robertson,	8 Park Circus Place, Glasgow.
1863, Nov. 25:	William	Robertson,	123 St. Vincent Street, Glasgow.
1888, Apr. 24:	J. F.	Robinson,	Atlas Works, Springburn, Glasgow.
Original:	Hazltn. R.	*Robson, (*Past President.*)	14 Royal Cresct., Glasgow.
1893, Mar. 21:	Anderson	Rodger,	Glenpark, Port-Glasgow.
1895, Dec. 24:	J. M.	Ronaldson,	44 Athole Gardens, Glasgow.
G. 1882, Nov. 28: M 1891, Oct. 27:	J. MacEwan	Ross,	Ardenlca, Lenzie.
1861, Dec. 11:	Richard G.	Ross,	21 Greenhead St., Glasgow.

1892, Jan. 26: Fred. John Rowan, 121 West Regent Street, Glasgow.

Original: David *Rowan, (*Past President.*) 231 Elliot Street, Glasgow.

G. 1875, Dec. 21: M. 1885, Jan. 27: James Rowan, (*Vice-President.*) 231 Elliot Street, Glasgow.

1888, Dec. 18: Thomas Rowley, Board of Trade Offices, Virginia St., Greenock.

G. 1858, Dec. 22: M. 1863, Mar. 4: George Russell, (*Member of Council.*) Engineer, Motherwell.

1881, Feb. 22: Joseph Russell, Shipbuilder, Port-Glasgow.

1890, Jan. 21: Edward Mowbray Salmon, 2 White Lion Court, Cornhill, London, E.C.

1876, Oct. 24: Peter Samson, Board of Trade Offices, Bedford St., Covent Garden, London, W.C.

1885, Feb. 24: James Samuel, Jun., 185 Kent Road, Glasgow.

1883, Feb. 20: John Sanderson, Lloyd's Register, 342 Argyle Street, Glasgow.

1892, Oct. 25: Wm. Brooks Sayers, Glenwood, Bearsden.

G. 1879, Mar. 25: M. 1888, Oct. 23: John †Scobie, c/o Sen. Pouchard, M'Taggart, Lother, & Co., F.C., de Antioquia, Puerto Berrio Ria Magdalena, U. S. of Columbia.

1893, Apr. 25: James Scott, Philippine Villa, Park Corner, Whiteinch.

1872, Jan. 30: James E. Scott, 52 Coal Exchange, London.

1881, Jan. 25: John Scott, Abden Works, Kinghorn.

1893, Nov. 21: John D. Scott, Engineer, New Zealand Refrigeration Company, Oamaru, N.Z.

1860, Nov. 28: Thos. B. *Seath, 42 Broomielaw, Glasgow.

1896, Feb. 25 :	Prof. Humbolt	Sexton,	Glasgow and West of Scotland Technical College, 204 George Street, Glasgow.
1875, Jan. 26:	Alexander	Shanks,	Belgrade, Aytoun Road, Pollokshields, Glasgow.
1892, Apr. 26:	Alexander	Shanks, Jun.,	Eastwood Engine Works, Pollokshaws, Glasgow.
1895, Apr. 30:	Edmund	Sharer,	8 Belhaven Cres., Glasgow.
1889, Mar. 26:	John W.	Shepherd,	Carrickarden, Bearsden.
1858, Nov. 24:	William	Simons,	Tighnabruaich, Argyleshire.
1862, Jan. 22:	Alexander	Simpson,	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,	11 Randolph G'dens, Crow Road, Partick, Glasgow.
G. 1884, Mar. 25: M. 1891, Mar. 24:	Russell	Sinclair,	Consulting Engineer, 97 Pitt St., Sydney, N.S.W.
G. 1882, Nov. 28: M. 1889, Oct. 22:	Geo. H.	Slight, Jun.,	c/o Jas. Slight, 131 West Regent Street, Glasgow.
1880, Nov. 2:	Alexander D.	Smith,	5 Belmar Terrace, Shields Road, Pollokshields, Glasgow.
1888, Oct. 23:	James	Smith,	Orange Grove Estate, Tacarigua, Trinidad, B.W.I.
1895, Dec. 24 :	Osbourne	Smith,	Possil Engine Works, Glasgow.
1892, Nov. 22:	William	Smith,	Eglinton Engine Works, Glasgow.
1870, Feb. 22:	Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn, Glasgow.
1887, Jan. 25:	Peter A.	Somervail,	Dalmuir Ironworks, Dalmuir.
1883, Dec. 18:	Alex. E.	†Stephen,	9 Princes Gardens, Dowanhill, Glasgow.

1895, Apr. 30: Fred. J. †Stephen, Linthouse, Govan, Glasgow.
John †*Stephen, Linthouse, Govan, Glasgow.
1894, Jan. 23: William Steven, 18 Sandyford Place, Glasgow.
1894, Jan. 23: Alex. W. Stewart, Crescent, Dalmuir.
1890, Feb. 25: Andrew Stewart, 41 Oswald St., Glasgow.
1867, Jan. 30: Duncan Stewart, 47 Summer Street, Glasgow.
1890, Mar. 25: James †Stewart, Harbour Engine Works, 60 Portman Street, Glasgow.
1892, Mar. 22: John Graham Stewart, B.Sc., 17 Park Terrace, Glasgow.
1874, Oct. 27: Peter Stewart, 53 Renfield Street, Glasgow.
G. 1873, Dec. 23: } M. 1882, Oct. 24: } W. B. Stewart, 10 Buckingham Terrace, Hillhead, Glasgow.
1893, Apr. 25: C. E. Stromeyer, Lloyd's Register, 342 Argyle Street, Glasgow.
1889, Oct. 22: James Stuart, 115 Wellington St., Glasgow.
1877, Jan. 23: James Syme, 8 Glenavon Ter., Partick, Glasgow.

1879, Oct. 28: James Tait, County Buildings, Wishaw.
1885, Apr. 28: Peter Taylor, Dock Shipbuilding Yard, Port-Glasgow.
1879, Mar. 25: Staveley Taylor, Russell & Co., Shipbuilders, Port-Glasgow.
1885, Jan. 27: George W. Thode, 21 Bothwell Street, Glasgow.
1889, Feb. 26: John Thom, 93 Hope Street, Glasgow.
1887, Apr. 26: Prof. Arthur W. Thomson, D.Sc., College of Science, Poona, India.
1893, Oct. 24: G. Caldwell Thomson, 23 Elisabeth Street, Riga, Russia.

1882, Apr. 25:	Geo. P.	Thomson,	Clydebank, Dumbartonshire.
1883, Dec. 18:	George	Thomson,	14 Caird Drive, Partickhill, Glasgow.
G. 1874, Feb. 24: M. 1889, Oct. 22:	George C.	Thomson,	23 Kersland Terrace, Hillhead, Glasgow.
G. 1880, Nov. 23: M. 1894, Nov. 20:	George	Thomson,	35 Marchmont Crescent, Edinburgh.
1886, Mar. 23:	James	Thomson, M.A.,	22 Wentworth Place, Newcastle-on-Tyne.
1868, Feb. 12:	James M.	Thomson,	75 Bothwell St., Glasgow.
1882, Mar. 21:	James R.	Thomson,	Clydebank, Dumbartonshire.
1868, May 20:	John	Thomson,	3 Crown Terrace, Dowanhill, Glasgow.
1895, Feb. 26:	R. H. B.	Thomson,	Govan Shipbuilding Yard, Govan, Glasgow.
G. 1894, Nov. 20: M. 1895, Dec. 24:	Walter M.	Thomson,	Hayfield, Motherwell.
1864, Feb. 17:	W. R. M.	Thomson,	96 Buchanan St., Glasgow.
1878, May 14:	W. B.	Thompson,	Ellengowan, Dundee.
1895, Oct. 22:	E. George	Tidd,	137 West Regent Street, Glasgow.
G. 1887, Jan. 25: M. 1892, Oct. 25:	David R.	Todd,	Babcock & Willcox, 21 Bothwell St., Glasgow.
1876, Nov. 21:	Alexander	Turnbull,	St. Mungo's Works, Bishopbriggs, Glasgow.
1875, Nov. 23:	John	Turnbull, Jun.,	Consulting Engineer, 18 Blythswood Sq., Glasgow.
1892, Jan. 26:	John	Wallace,	12 Kelvingrove Street, Glasgow.
1883, Jan. 23:	Peter	Wallace,	Ailsa Shipbuilding Co., Troon.
1885, Mar. 24:	W. Carlile (*Member of Council.*)	Wallace,	20 Montgomerie Road, Sheffield.
1886, Jan. 26:	John	Ward,	Leven Shipyard, Dumbarton.
1896, Mar. 24:	Willoughby C.	Warden,	25 Gordon St., Glasgow.

1893, Dec. 19:	Prof. W. H.	Watkinson,	24 Albion Crescent, Dowanhill, Glasgow.
1875, Mar. 23:	G. L.	Watson,	108 W. Regent Street, Glasgow.
1864, Mar. 16:	Sir W. Renny	Watson,	16 Woodlands Ter., G'gow.
G. 1875, Dec. 21: M. 1886, Oct. 26:	R. G.	Webb,	Richardson & Cruddas, Byculla, Bombay.
G. 1878, Dec. 17: M. 1887, Nov. 22:	Prof. R. L.	Weighton, M.A.,	Durham College of Science, Newcastle-on-Tyne.
1874, Dec. 22:	George	Weir,	18 Millbrae Cres., Langside, Glasgow.
1874, Dec. 22:	James	Weir,	Holmwood, 72 St. Andrew's Drive, Pollokshields.
G. 1884, Apl. 22: M. 1895, Nov. 26	John	Weir,	John Scott & Coy., Engineers & Shipbuilders, Kinghorn.
G. 1876, Dec. 19: M. 1884, Feb. 26:	Thomas D.	Weir,	Towerhill, Kilmaurs.
1889, Apr. 23:	Thomas	†Weir,	China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China.
1869, Feb. 17:	Thomas M.	Welsh,	3 Princes Gardens, Dowanhill, Glasgow.
1868, Dec. 23:	Henry H.	West,	5 Castle Street, Liverpool.
1883, Feb. 20:	Richard S.	White,	Walker Shipyard, Newcastle-on-Tyne.
1888, Mar. 20:	George	Whitehall,	c/o Walsh, Lovett, & Co., Bombay.
1887, Apr. 6:	James	Whitehead,	6 Buchanan Ter., Paisley.
1884, Nov. 25:	John	Wildridge,	Consulting Engineer, Sydney, N.S.W., Australia.
1884, Dec. 23:	James	Williamson,	Director H.M. Dockyards, Whitehall, London.

1896, Mar. 24:	James	Williamson,	Marine Supt., Gourock.
1883, Feb. 20:	Robert	Williamson,	Lang & Williamson, Engineers, &c., Newport, Mon.
1890, Dec. 23:	Robert	Williamson,	Pott, Cassels & Williamson, Motherwell.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.
1896, Jan. 28:	Alexander	Wilson,	Dawsholm Gasworks, Maryhill, Glasgow.
1887, Oct. 25:	David	Wilson,	Arecibo, Porto Rico, West Indies.
1889, Oct. 22:	Gavin	Wilson,	16 Robertson St., Gl'gow.
1868, Dec. 23:	James	Wilson,	Engineer, Corporatn. Water Works, Edinburgh.
1870, Feb. 22:	John	Wilson,	165 Onslow Drive, Dennistoun, Glasgow.
G. 1883, Jan. 29: M. 1891, Feb. 24:	John	Wilson,	29 Waterloo St., Glasgow.
1895, Dec. 24:	John	Wilson,	154 West George Street, Glasgow.
1895, Apr. 30:	William	Wilson,	Lilybank Boiler Works, Glasgow.
1858, Jan. 20:	Thomas	†*Wingate,	Viewfield, Partick, G'gow.
1890, Mar. 25:	William G.	Wrench,	27 Oswald St., Glasgow.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.
G. 1888, Jan. 24: M. 1894, Jan. 23:	J. Denholm	Young,	West India House, 96 Leadenhall St., London, E.C.
1894, Mar. 20:	Thomas	Young,	58 Renfield St., Glasgow.
1895, Mar. 26:	Wm. And.	Young,	Millburn House, Renfrew.

ASSOCIATES.

	Thomas	*Aitken,	8 Commercial Street, Leith.
1883, Oct. 28:	John	Barr,	Secretary, Glenfield Co., Kilmarnock.
1882, Dec. 19:	William	Begg,	34 Belmont Gardens, Glasgow.
1884, Dec. 23:	W. S. C.	Blackley,	70 Wellington St., Glasgow.
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,	Hazel Bank, 62 Glencairn Drive, Pollokshields, Glasgow.
1893, Feb. 21:	William	Cassels,	Cairndhu, 12 Newark Drive, Pollokshields, Glasgow.
1895, Jan. 22:	A. L.	Claussen,	118 Broomielaw, Glasgow.
1885, Feb. 24:	Robert	Darling,	4 West George Street, Glasgow.
1895, Mar. 26:	Walter L.	Fisher,	Glenburn Ironworks, Greenock.
1863, Mar. 18:	Robert	Gardner,	136 George Street, G'gow.
1891, Oct. 27:	James	Galloway, Jun.,	Whitefield Works, Govan.
1860, Jan. 18:	George T.	Hendry,	79 Gt. Clyde St., Glasgow.
1895, Jan. 22:	John	Hunter,	2 Broomhill Terrace, W., Partick, Glasgow.

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

1882, Oct. 24:	Wm. A.	Kinghorn,	81 St. Vincent St., Glasgow.
1884, Feb. 26:	C. R. L.	Lemkes,	194 Hope Street, Glasgow.
1892, Nov. 22:	Alexander	M'Ara,	65 Morrison St., Glasgow.
1895, Mar. 26:	Lawrence	MacBrayne,	11 Park Circus Pl., Glasgow.
1893, Jan. 24:	T. W.	M'Intyre,	123 Hope Street, Glasgow.
1893, Feb. 21:	William	M'Kinnel,	234a Nithsdale Road, Pollokshields.
1886, Jan. 26:	Capt. Dun.	M'Pherson,	3 Cecil Street, Paisley Rd., W., Glasgow.
1874, Mar. 24:	James B.	Mercer,	Broughton Copper Works, Manchester.
	James S.	*Napier,	33 Oswald Street, Glasgow.
1889, Jan. 22:	William	Rigg,	3 Grantly Place, Shawlands, Glasgow.
1894, Mar. 20:	Thomas A.	Ross,	Glenwood, Bridge-of-Weir.
1888, Jan. 24:	Samuel	Smillie,	71 Lancefield St., Glasgow.
1876, Jan. 25:	George	Smith,	75 Bothwell St., Glasgow.
1896, Jan. 28:	Robert G.	Warren,	115 Wellington Street, Glasgow.
	H. J.	Watson,	5 Oswald Street, Glasgow.
1896, Mar. 24:	Chs. Wm.	Wild,	Broughton Copper Coy., Ltd., 16 St. Enoch Sq., Glasgow.
1882, Dec. 19:	John D.	Young,	Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.
	William	Young,	Galbraith Street, Stobcross Glasgow.

GRADUATES.

1896, Apr. 28 :	Matthew A.	Adam,	235 Bath Street, Glasgow.
1882, Nov. 28:	William H.	Agnew,	Laird Bros., Birkenhead.
1888, Jan. 24:	H. Wallace	Aitken,	Netherlea, Pollokshields, Glasgow.
1888, Jan. 24:	James	Allan,	144 Buccleuch St., Glasgow.
1895, Dec. 24 :	George C.	Anderson,	Mavisbank, Partickhill, Glasgow.
1888, Oct. 23:	Donald S.	Arbuthnot,	c/o Charles Brand & Son, 172 Buchanan Street, Glasgow.
1890, Dec. 23:	Arthur S. D.	Arundel,	Penn St. Works, Hoxton, London, N.
1894, Mar. 20:	Fred. W.	Baker,	149A Tremont St., Boston, U.S.A.
1888, Apr. 24:	Harry D.D.	Barman,	2 Gilmour Street, Byres Road, Glasgow.
1892, Nov. 22:	Edmund G.	Baxter,	Caledonian Railway, 3 Germiston Street, Glasgow.
1885, Dec. 22:	Peter M'L.	Baxter,	Chief Mechanical Engineer, Rio Tinto, Huelva, Spain.
1887, Apr. 26:	Thomas	Bell,	8 Lawrence Place, Partick, Glasgow.
1894, Feb. 20:	John H.	Bell,	29 Bentinck St., Glasgow.
1894, Mar. 20:	Richard	Bell,	17 Minerva St., Glasgow.
1885, Mar. 24:	Alexander	Bishop,	3 Germiston Street, Glasgow.
1892, Oct. 25:	John	Black,	7 Huntly Ter., Kelvinside, Glasgow.
1885, Oct. 27:	Archibald	Blair,	48 Overnewton St., Glasgow.
1891, Oct. 27:	Archibald	Blair, Jun.,	7 Corunna Street, Glasgow.
1892, Mar. 22:	Frank R.	Blair,	232 Renfrew St., Glasgow.

1884, Jan. 22:	George	Blair, Jun.,	4 Kinnoul Place, Dowanhill, Glasgow.
1885, Oct. 27:	William C.	Borrowman,	2 Thornwood Ter., Partick, Glasgow.
1895, Nov.26 :	John	Bowden,	Atlas Works, Glasgow.
1894, Nov. 20:	Robert	Bowie,	156 St. Vincent St., Glasgow.
1891, Dec. 22:	W. D.	Bowman,	102 Hill Street, Garnethill, Glasgow.
1888, Jan. 24:	Mark	Brand, B.Sc.,	Barrhill Cottage, Twechar, Kilsyth.
1888, Mar. 20:	James	Brown,	Simpson & Wilson, 175 Hope Street, Glasgow.
1894, Dec. 18:	J. Pollock	Brown,	2 Park Grove Ter., Glasgow.
1893, Oct. 24:	Johannes	Bruhn,	49 Sydenham Park, Sydenham, London, S.E.
1891, Jan. 27:	Walter G.	Buchanan,	17 Sandyford Pl., Glasgow.
1891, Feb. 24:	Bertram W.	Burnside,	11 Cowlairs Road, Springburn, Glasgow.

1890, Jan. 21:	William	Caird,	25 Woodside Quadrant, Glasgow.
1891, Feb. 24:	John	Calder,	6 Gladstone Place, Aberdeen.
1891, Jan. 27:	Hugh	Caldwell,	Glenrafon House, Pengam, near Mæsycwmmer, *via* Cardiff.
1892, Oct. 25:	Hugh	Cameron,	40 Gardner Street, Partick, Glasgow.
1888, Jan. 24:	Angus	Campbell,	9 John St., Southampton.
1890, Dec. 23:	Wm. H.	Carslaw, Jun.,	Parkhead Boiler Works, Parkhead.
1890, Oct. 28:	Robert D.	Cassells,	62 Glencairn Drive, Pollokshields, Glasgow.
1884, Feb 26:	John	Cleland, B.Sc.,	Woodhead Cottage, Old Monkland.

1893, Apr. 25:	W. A.	Cleland,	Yloilo, Philippine Islands.
1891, Oct. 27:	James	Cochrane,	Resident Engineer's Office, Harbour Works, Table Bay, Capetown.
1884, Feb. 26:	Alexander	Conner,	9 Scott Street, Glasgow.
1885, Dec. 22:	Benjamin	Conner,	9 Scott Street, Glasgow.
1885, Oct. 27:	Francis	Coutts,	25 Roslin Ter., Aberdeen.
1895, Nov. 26:	Alexander	Craig,	Netherlea, Partick, Glasgow.
1892, Dec. 20:	James	Craig,	35 Gardner Street, Partick, Glasgow.
1894, Nov. 20:	James	Craig,	14 Bridge Street, Glasgow.
1888, Dec. 18:	Harry L.	Davies,	The Vicarage, Kirkby-Lonsdale, England.
1891, Dec. 22:	Kristian S.	Dekke,	Bergen, Norway.
1883, Feb. 10:	Lewis M. T.	Deveria,	c/o P. M'Intosh & Son, 129 Stockwell Street, Glasgow.
1895, Jan. 22:	James A.	Diack,	10 Caird Drive, Partickhill, Glasgow.
1886, Nov. 23:	Thomas B.	Dick,	Post Office, Vallejo, California, U.S.A.
1888, Mar. 20:	B. B.	Donald,	275 Onslow Drive, Dennistoun, Glasgow.
1891, Feb. 24:	Patrick D.	Donald, B.Sc.,	72A George Street, Edinburgh.
1891, Feb. 24:	John	Dougan,	13 Leven Street, Pollokshields, Glasgow.
1884, Jan. 22:	William	Dunlop,	6 Chatsworth Terrace, Barrow-in-Furness.
1893, Feb. 21:	Turner	Dunn,	20 Park Circus, Glasgow.
1885, Mar. 24:	Robert	Elliot, B.Sc.,	8 Amblecote Road, Grove-park, London, S.E.

1896, Mar.24:	John Arnold	Feist,	122 Holland St., Glasgow.
1892, Oct. 25:	James M.	Ferguson,	———
1895, Jan. 22:	Lewis	Ferguson,	Fergus Villa, Paisley.
1895, Jan. 22:	Peter	Ferguson, Jr.,	Fergus Villa, Paisley.
1891, Dec. 22:	W. L.	Fergusson,	Hawcoat Lane, Abbey Rd., Barrow-in-Furness.
1891, Dec. 22:	Alexander	Fergus,	7 Ibrox Place, Glasgow.
1893, Feb. 21:	Louis	Findlay,	c/o Mrs Ferguson, 29 Bentinck Street, Glasgow.
1896, Jan. 28:	James	Fletcher,	11 Ibrox Place, Whitefield Road, Govan, Glasgow.
1886, Apr. 27:	J. Imbrie	Fraser,	13 Sandyford Pl., Glasgow.
1894, Dec. 18:	Tom J.	Fryer,	TotleyBrook, near Sheffield.
1892, Feb. 23:	Norman O.	Fulton,	Woodbank, Mount Vernon, near Glasgow.
1894, Dec. 18:	Chas.F.A.	Fyfe,	48 Rosebank Ter., Glasgow.

1893, Oct. 24:	Andrew	Galloway,	49 Prince's Square, Strathbungo, Glasgow.
1889, Apr. 23:	Hugh	Gardner,	Minas Schwager, Coronel, Chili.
1891, Oct. 27:	James	Gourlay,	11 Crown Gardens, Dowanhill, Glasgow.
1895, Dec. 24:	R. Cleland	Gourlay,	11 Crown Gardens, Glasgow.
1894, Dec. 18:	Wm. A.	Govan,	Thornton Hall, near Glasgow.
1884, Feb. 26:	Alexander	Gracie,	Willowbank, Yoker.
1896, Jan. 28:	Walter	Graham,	7 Royal Terrace, Glasgow.

1889, Feb. 26:	J. E.	Harrison,	21 Westminster Ter., G'gow.
1892, Dec. 20:	William	Hay,	36 Grove Street, Glasgow.
1883, Feb. 20:	David	Henderson,	Cardross Bank Villa, Cardross.
1890, Dec. 23:	Wm. G.	Henderson,	1 Radnor Terrace, Glasgow.

1894, Nov. 20: F. W. L.	Hepting,	2 Albert Mansions, Crosshill, Glasgow.
1892, Jan. 26: Wm. M'L.	Homan,	719 Great Western Road, Glasgow.
1891, Dec. 22: George	Howson,	c/o Robson, Lawrence St., Dowanhill, Glasgow.
1895, Jan. 22: Gerard	Hudson,	24 Willowbank Street, Glasgow.
1885, Feb. 24: John	Inglis,	Bonnington Brae, Edinburgh.
1894, Nov. 20: Arch. B.	Irvine,	3 Newton Terrace, Glasgow.
1891, Mar. 24: Harold D.	Jackson,	8 Ruthven St., Kelvinside, Glasgow.
1893, Oct. 24: Alex. J.	Kay,	38 Hill Street, Garnethill, Glasgow.
1886, Nov. 23: Daniel	Kemp,	69 Prince Edward Street, Crosshill, Glasgow.
1890, Oct. 28: John	Kemp,	1 Thornwood Ter., Partick, Glasgow.
1890, Oct. 28: Robert G.	Kemp,	2 Ravenscroft Avenue, Connswater, Belfast.
1895, Feb. 26: Irvine	Kempt, Jr.,	Foresthill, Kelvinside, Glasgow.
1893, Apr. 25: Charles A.	King, B.Sc.,	C. C. Lindsay, 167 St. Vincent St., Glasgow.
1891, Oct. 27: James	King,	Carrizal, Bago, Chili.
1886, Jan. 26: John	King,	15 Nesham Street, Newcastle-on-Tyne.
1894, Feb. 20: David W.	Kinmont,	3 Germiston St., Glasgow.
1894, Nov. 20: John	Kirk,	4 Minard Terrace, Partickhill, Glasgow.
1893, Feb. 21: Robert	Laing,	Northbank, Partickhill, Glasgow.

1892, Nov. 22:	Thomas W.	Lamont,	Hawkhead Works, Paisley.
1893, Dec. 19:	Thomas H.	Lauder,	Parkhead Forge, Glasgow.
1886, Jan. 26:	John	Lee,	15 St. John's St., Mansfield.
1886, Dec. 21:	Robert	Lee,	13 Hamilton Terrace, West Partick, Glasgow.
1891, Dec. 22:	Wm. Orr	Leitch, Jun.,	Cruden Railway, Ellon, Aberdeenshire.
1894, Jan. 23:	Alexander	Lennox,	34 Glasgow St., Hillhead, Glasgow.
1896, Apr. 28 :	George K.	Lennox,	34 Lynedoch St., Glasgow.
1892, Dec. 20:	John	Leslie,	29 Elder Park St., Govan, Glasgow.
1883, Nov. 21:	William R.	Lester,	4 Strathmore Gardens, W., Glasgow.
1885, Mar. 24:	Fred.	Lobnitz,	Clarence House, Renfrew.
1893, Jan. 24:	Archibald	M‘Arthur,	16 India Street, Partick, Glasgow.
1880, Nov. 2:	Patrick F.	Maccallum,	Milton House Works, Abbey Hill, Edinburgh.
1883, Dec. 18:	Peter	M‘Coll,	Stewartville Place, Partick, Glasgow.
1883, Dec. 18:	John	Macdonald,	6 Rupert Street, Glasgow.
1891, Oct. 27:	Henry	MacEwen,	5 Cathkin Terrace, Mount Florida.
1883, Dec. 18:	John Bow	M‘Gregor,	17 Bell Street, Renfrew.
1896, Jan. 28 :	John L.	M‘Gregor,	10 Mosesfield Ter., Springburn, Glasgow.
1895, Jan. 22:	George	M‘Intosh,	Dunglass Cottage, Bowling.
1895, Jan. 22:	John	M‘Intosh,	Oak Bank, Bowling.
1881, Oct. 25:	James	Mackenzie,	Fulton Engine Wks., Blackston Street, Liverpool.
1883, Feb. 26:	Robert	M‘Kinnell,	56 Dundas Street, S.S., Glasgow.
1885, Jan. 27:	John	M‘Millan,	26 Ashton Ter., Glasgow.

1886, Dec. 21:	Andrew	M'Vitae,	4 Clutha St., Paisley Road W., Glasgow.
1894, Dec. 18:	John	Macintosh,	7 Park Quadrant, Glasgow.
1886, Dec. 21:	James	Mack,	3 Germiston St., Glasgow.
1894, Nov. 20:	Robert D.	Mackintosh,	Bellevue Place, Garngad Hill, Glasgow.
1887, Feb. 22:	Cree	Maitland,	Manager, Sunger Ujong Railway, Port Dickson, Malay Peninsula.
1894, Nov. 20:	John	Maitland,	53 Bentinck Street, Glasgow.
1894, Mar. 20:	John Boyd	Mather,	Kirkhill, Mearns.
1889, Jan. 22:	George	Menzies,	26 Minerva Street, Glasgow.
1889, Jan. 22:	Robert	Menzies,	Chelmsford Hotel, Tongaat, Natal.
1895, Oct. 22:	John	Mercer,	111 Westerlea Terrace, Glasgow.
1889, Apr. 23:	John	Miller,	813 Govan Road, Govan, Glasgow.
1890, Feb. 25:	Robert F.	Miller,	10 Windsor Terrace, West, Glasgow.
1894, Nov. 20:	John S.	Millar,	3 Beaconsfield Street, Partick, Glasgow.
1889, Feb. 26:	Sidney	Millar,	32 Annette St., Govanhill, Glasgow.
1884, Nov. 25:	Thomas	Millar,	Sir W. G. Armstrong, Mitchell, & Co., Ld., Walker Shipyard, Newcastle-on-Tyne.
1883, Dec. 18:	Charles W.	Milne,	5 Park Terrace, Langlands Road, Govan, Glasgow.
1881, Jan. 25:	Ernest W.	Moir,	c/o S. Pearson & Son, 10 Victoria Street, Westminster, London.

1892, Nov. 22: Hector A. Mollison, B.Sc., 6 Hillside Gardens, Partickhill, Glasgow.
1889, Dec. 17: Arthur M. Morrison, Laurel Bank, Partick, Glasgow.
1892, Jan. 26: James H. Muir, 140 Bath Street, Glasgow.
1891, Apr. 28: Wm. Muirhead, Cloberhill, Maryhill, Glasgow.
1892, Nov. 22: Ernest C. Mumme, c/o Agent and Chief Engineer, Bengal & North-Western R'lway, Gorakpur, N. West Provinces, India.
1893, Feb. 21: Richard Munro, ———
1892, Oct. 25: John A. Murdoch, 7 Park Circus Pl., Glasgow.
1893, Oct. 24: B. Stewart Murphy, c/o H. Hogarth, 12 Great Clyde Street, Glasgow.
1887, Dec. 20: David Myles, Northumberland Engine Works, Wallsend-on-Tyne.

1892, Jan. 26: John S. Napier, Glencarron, Denny.
1886, Jan. 26: Thomas Nicholson, 6 Annfield Place, Glasgow.

1895, Mar. 26: John Orr, 24 North View, Heaton, Newcastle on-Tyne.
1895, Oct. 22: J. Orr, 22 St. Vincent Crescent, Glasgow.
1891, Dec. 22: Hugh Osborne, 30 Rose Street, Garnethill, Glasgow.
1891, Dec. 22: Marshall Osborne, 81 Manor Road, Brockley, London, S.E.

1888, Jan. 24: James V. Paterson, 307 Walnut Street, Philadelphia, U.S.A.
1892, Dec. 20: Thomas Paton, 1 Fairley Street, Govan, Glasgow.

1887, Nov. 22: James	Peacock,	2 Wilton Mansions, Glasgow.
1895, Dec. 24 : Corsar	Pirret,	9 Roslyn Terrace, Kelvinside, Glasgow.
1891, Jan. 27: Gilbert F.	Pollock,	10 Beechwood Drive, Tollcross, Glasgow.
1887, Apr. 6: John C.	Preston,	Assistant Engineer, Brisbane Board of Water Works, Brisbane, Queensland.
1893, Oct. 24: William S.	Pringle,	4 Rosebank Ter., Aberdeen.
1885, Jan. 27: James L.	Proudfoot,	Lanemark, New Cumnock.
1895, Dec. 24 : Robert A.	Raphael,	150 Renfrew St., Glasgow.
1887, Oct. 25: David H.	Reid,	Attiquin, Maybole.
1884, Dec. 23: James G.	Reid,	Renfield House, Renfrew.
1895, Oct. 22 : James	Reid,	128 Dumbarton Road, Glasgow.
1884, Feb. 26: Walter	Reid,	118 Ingleby Drive, Glasgow.
1894, Jan. 23: James	Richmond,	24 Sutherland Terrace, Hillhead, Glasgow.
1894, Jan. 23: John H.	Richmond,	37 Berkeley Ter., Glasgow.
1886, Oct. 26: Alexander	Robertson,	41 Darnley Street, Pollokshields, Glasgow.
1892, Nov. 22: Andrew R.	Robertson,	8 Park Circus Pl., Glasgow.
1890, Oct. 28: Edward F.	Robertson,	62 High Street, Galashiels.
1887, Dec. 20: Matthew	Robin,	15 Clifford Street, Glasgow.
1891, Nov. 24: James	Russell,	Sunnyside, Crawford Street, Motherwell.
1891, Dec. 22: James	Russell,	7 Broomhill Terrace, East, Partick, Glasgow.
1887, Apr. 6: Joseph W.	Russell,	Kilblain Engine Works, Greenock.
1888, Jan. 24: John A.	Rudd,	128 Hope Street, Glasgow.
1893, Dec. 19: Herbert C.	Sadler, B.Sc.,	2 Minard Terrace, Partickhill, Glasgow.

1885, Oct. 27:	Alexander	Scobie,	Culdees, Partickhill, Glasgow.
1886, Mar. 23:	Thomas R.	Seath,	Sunny Oaks, Langbank.
1886, Mar. 23:	William Y.	Seath,	Sunny Oaks, Langbank.
1882, Oct. 24:	John	Sharp,	147 East Milton St., Glasgow.
1895, Dec. 24 :	William	Sharpe,	21 Herriet Street, Pollokshields, Glasgow.
1894, Apr. 24:	John J.	Shaw,	12 Lynedoch Pl., Glasgow.
1893, Dec. 19:	Thomas S.	Shute,	34 Hayburn Cres., Partickhill, Glasgow.
1892, Dec. 20:	David C.	Simpson,	Westburn Place, Whiteinch, Glasgow.
1891, Nov. 24:	Alex.	Smith,	57 Nithsdale Road, S.S., Glasgow.
1894, Dec. 18:	James A.	Smith,	Union Bank House, Virginia Place, Glasgow.
1892, Dec. 20:	James	Smith,	20 Dumbarton Road, Glasgow.
1894, Apr. 24:	Charles	Smith,	8 Muirpark Gdns., Partick.
1892, Oct. 25:	William	Spalding,	532 St. Vincent St., Glasgow.
1891, Dec. 22:	James	Stark,	Summerlea, Thornliebank.
1894, Mar. 20:	William B.	Stearns,	Melville Fickens & Coy., 75 Lombard Street, London, E.C.
1892, Jan. 26:	James	Steel,	239 St. Vincent St., Glasgow.
1892, Dec. 20:	J. M.	Steven,	2 Hampton Court Terrace, Glasgow.
1881, Nov. 22:	John A.	Steven,	12 Royal Crescent, Glasgow.
1891, Dec. 22:	Clement H.	Stevens,	c/o Blandy Bros. & Co., Las Palmas, Grand Canary.
1894, Nov. 20:	Allan	Stevenson,	69 Cadder Street, Pollokshields, E., Glasgow.

1893, Apr. 25:	Archibald	Stevenson,	Yloilo, Philippine Islands.
1881, Jan. 25:	William	Stevenson,	6 West View, Wallsend-on-Tyne.
1875, Dec. 21:	Andrew	Stirling,	Denny & Co., Engine Works, Dumbarton.
1888, Jan. 24:	Archd.	Stodart,	Netherton, Newton Mearns.
1895, Feb. 26:	Thomas R.	Stove,	5 Craigmore Terrace, Partick, Glasgow.
1886, Dec. 21:	James R.	Symington,	Gladsmuir, Kilmalcolm.
1880, Dec. 21:	Stanley	Tatham,	Montrose, Bromley Park, Bromley, Kent.
1882, Nov. 28:	William	Taylor,	40 Derby Street, Glasgow.
1891, Mar. 24:	Ambrose H.	Thomson,	Surveyors' Department, Court House, Marylebone Lane, London, W.
1894, Nov. 20:	James	Thomson,	Hayfield, Motherwell.
1884, Dec 23:	William	Thomson,	1 University Gardens Terrace, Glasgow.
1892, Jan. 26:	Frederick	Thomson,	18 Westbank Ter., Hillhead, Glasgow.
1891, Dec. 22:	Cecil	Tickle,	131 Elder Park Terrace, Govan, Glasgow.
1885, Oct. 27:	Peter	Tod,	C. & H. Crichton & Co., Engineers, Victoria Road, Liverpool.
1891, Oct. 27:	Campbell	Turnbull,	18 Blythswood Square, Glasgow.
1892, Mar. 22:	James	Turnbull,	South Overdale, Langside, Glasgow.
1891, Oct. 27:	W. L.	Turnbull,	18 Blythswood Square, Glasgow.
1894, Nov. 20:	John	Walker,	Ferncliffe, Old Cathcart, Glasgow.

1893, Mar. 21:	G. Underwood	Walker	Cross Michael, Galloway.
1892, Jan. 26:	John	Wallace, Jun.,	12 Kelvingrove Street, Glasgow.
1885, Feb. 24:	Charles H.	Wannop,	Barclay, Curle & Co., Finnieston Quay, Glasgow.
1889, Oct. 22:	Bruce R.	Warden,	Sandeman & Moncrieff, C.E., Newcastle-on-Tyne.
1881, Mar. 22:	Robert	Watson,	1 Glencairn Drive, Pollokshields, Glasgow.
1892, Dec. 20:	Harry	Watt,	c/o The Tongaat Sugar Co., Tongaat, Natal, South Africa.
1880, Apr. 27:	Robert D.	Watt,	49 Quinsan Road, Shanghai, China.
1896, Jan. 28:	William	Weir,	Holm Foundry, Cathcart, Glasgow.
1885, Nov. 24:	James	Welsh,	3 Princes Gardens, Dowanhill, Glasgow.
1882, Nov. 28:	Geo. B.	Wemyss,	175 Comelypark Street, Dennistoun, Glasgow.
1892, Dec. 20:	Ernest Wm.	West,	13 Leven St., East Pollokshields, Glasgow.
1883, Dec. 18:	John	Whitehead,	M'Lelland Drive, Kilmarnock.
1890, Mar. 25:	C. Basil	Williams,	49 Park Rd., W., Glasgow.
1888, Apr. 24:	Alexander	Woodburn,	B.Sc., Assam Bengal Railway, c/o Grindlay & Co., Calcutta.
1896, Feb. 25:	Joseph	Woods,	5 Chisholm St., Glasgow.
1893, Dec. 19:	William	Wotherspoon,	Blytholm, Douglas Gardens, Uddingston.
1887, Oct. 25:	James Brown	Wyllie,	134 St. Vincent Street, Glasgow.

DECEASED DURING THE SESSION.

Members.

David	Cunningham,	Dundee.
John	Fraser,	Glasgow.
William	Henderson,	Glasgow.
J. Anthony	Inglis,	Glasgow.
Andrew	Johnston,	Hong Kong.
Walter	Neilson,	Glasgow.
Patrick	Stirling,	Doncaster.
Francis	Willcox,	Sunderland.

Associate.

Capt. John	Bain,	Glasgow.

Graduates.

Gilbert	Goodwin, junr.,	Liverpool.
William D.	Shields,	Glasgow.

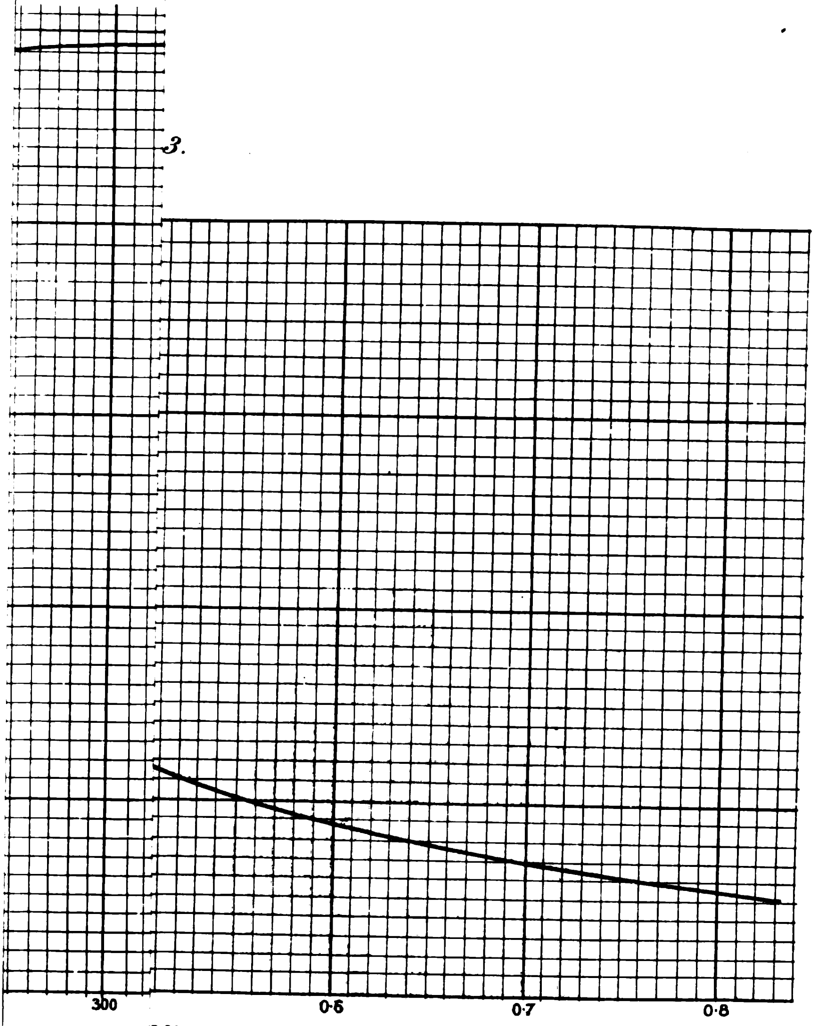
INDEX.

William Asher, Central Printing Works, 80 Gordon Street, Glasgow.

PROPEL

PLATE I

Diag



OCK COEFFICIENTS.

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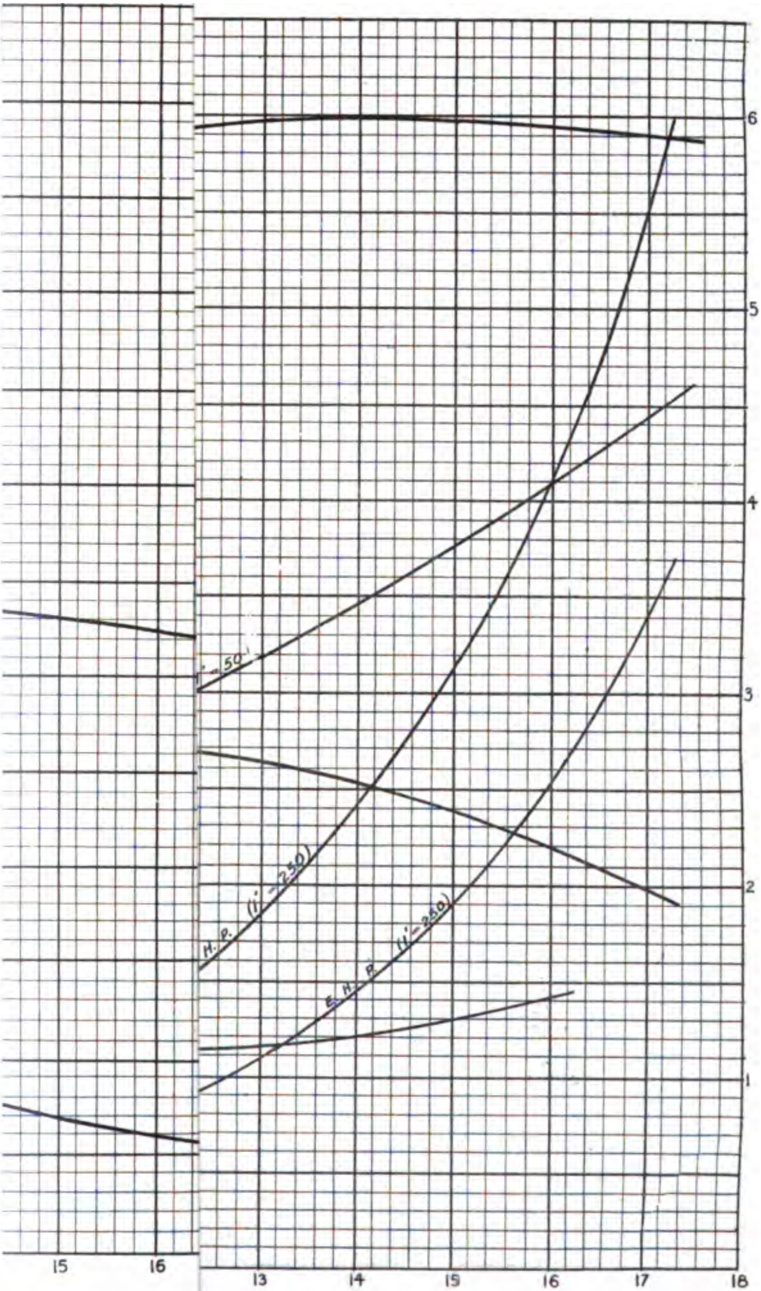
ENGINEERING LITHOGRAPHERS, GLASGOW.

PROP

PLATE II



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ENGINEERING LITHOGRAPHERS, GLASGOW.

PLATE II A

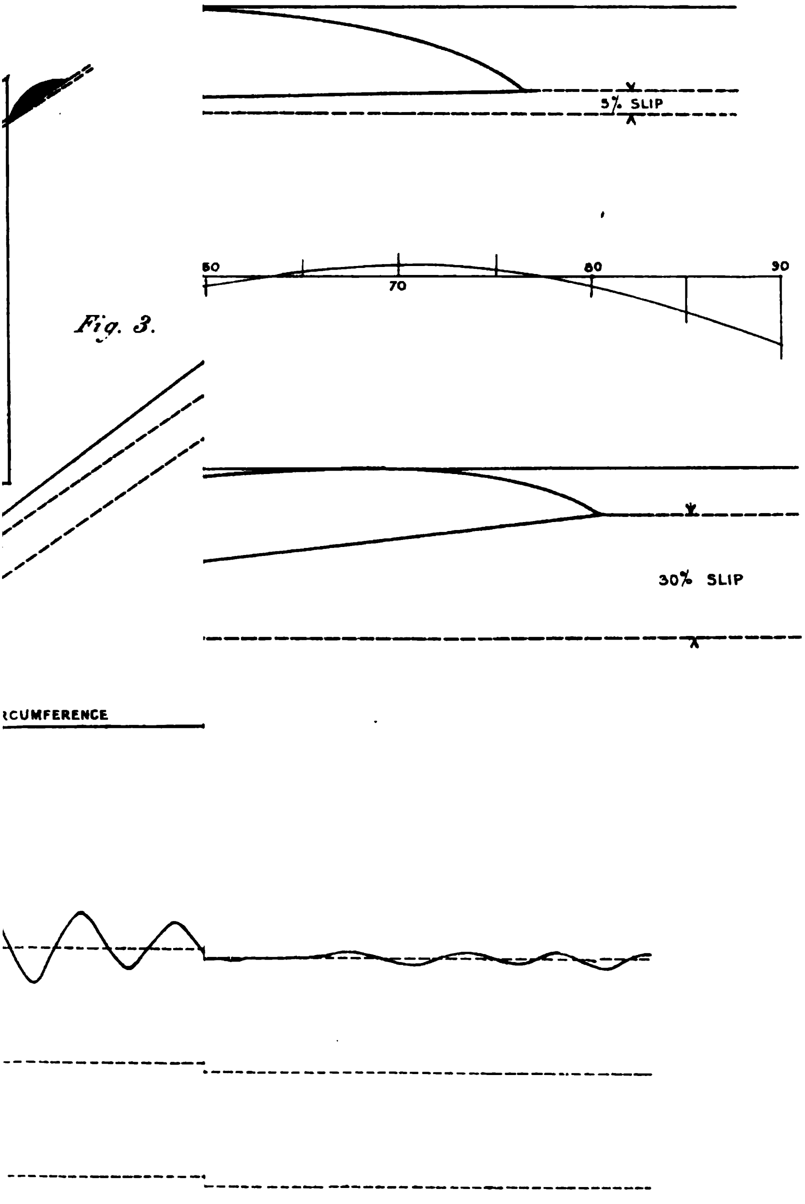

Fig. 3.

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ENGINEERING LITHOGRAPHERS, GLASGOW.

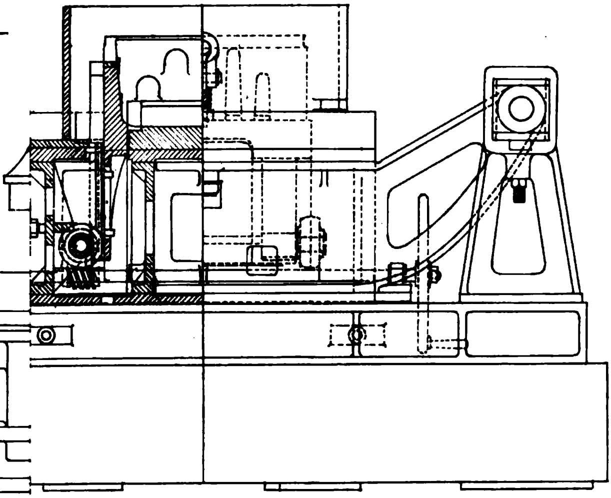
PLATE III

N SEGMEN

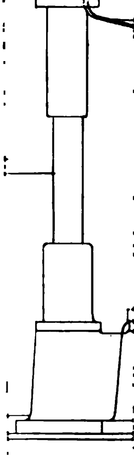
TUNNEL

LATES

BLACKWALL. TUNNEL PLATES



g. 4. HALF SECTIONAL END ELEVATION



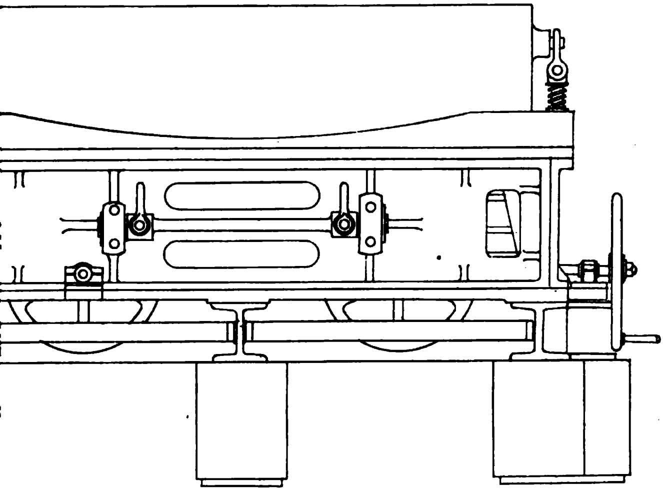


Fig. 5. BACK ELEVATION

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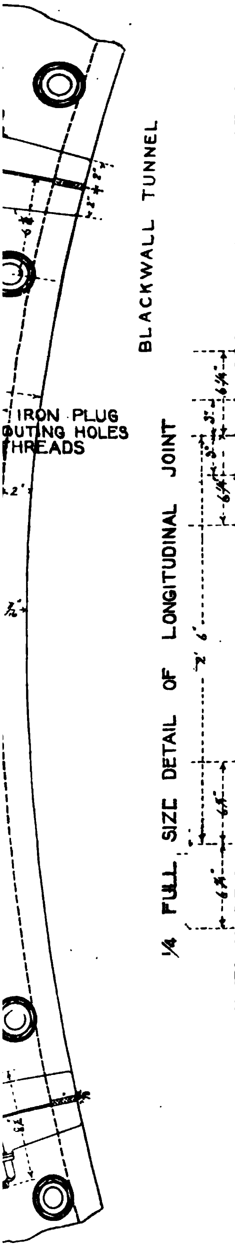
SEGMENTS—FOR

PLATE IV



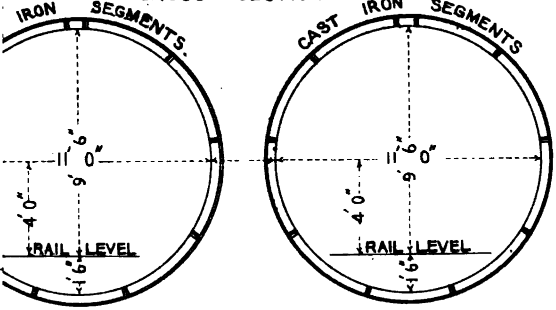
BLACKWALL TUNNEL

¼ FULL SIZE DETAIL OF LONGITUDINAL JOINT

GLASGOW DISTRICT SUBWAY.

Fig. 8.

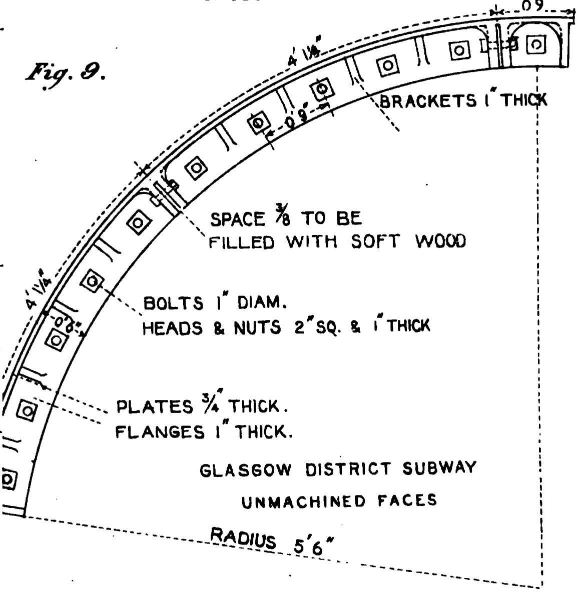
CROSS SECTION



.CAST IRON SEGMENTS

CROSS SECTION

Fig. 9.

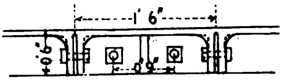


GLASGOW DISTRICT SUBWAY

UNMACHINED FACES

GLASGOW DISTRICT SUBWAY

LONGITUDINAL SECTION



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ENGINEERING LITHOGRAPHERS, GLASGOW.

AND OTHER

PLATE V.

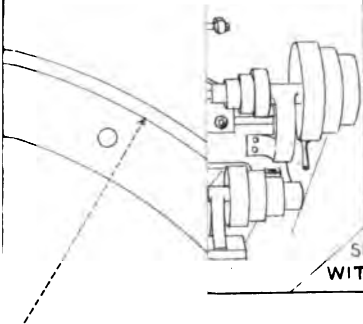
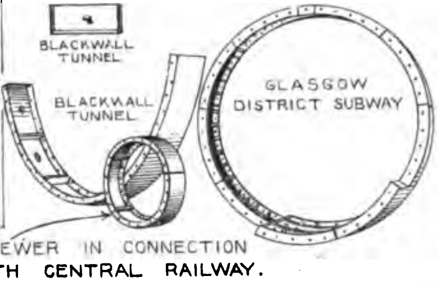
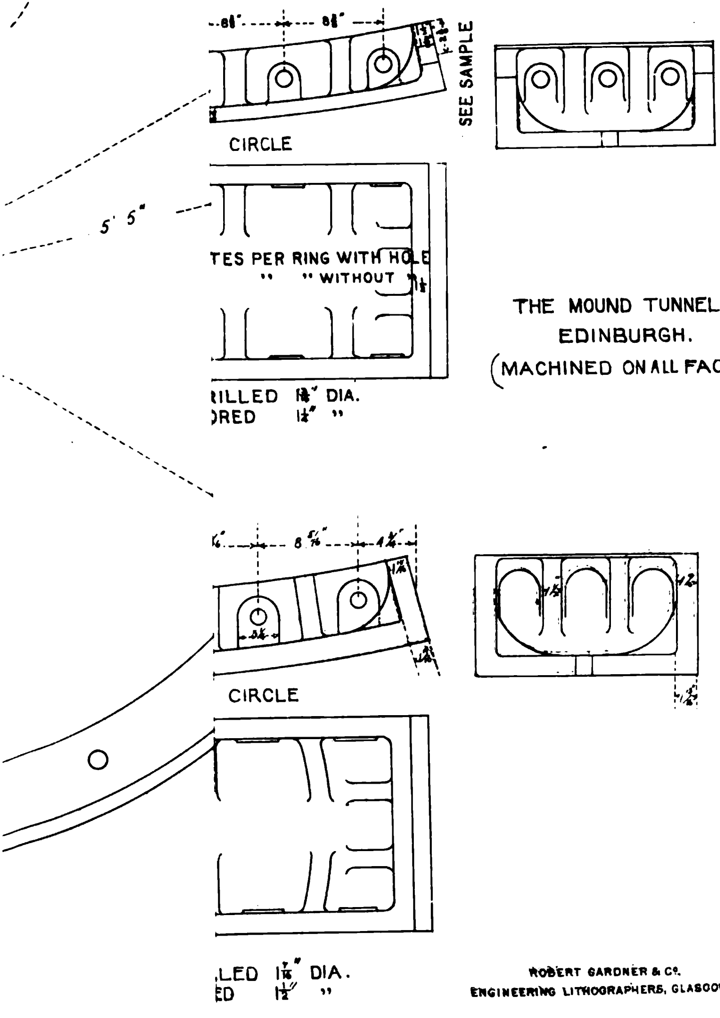


Fig. 13.





THE MOUND TUNNEL
EDINBURGH.
(MACHINED ON ALL FACES)

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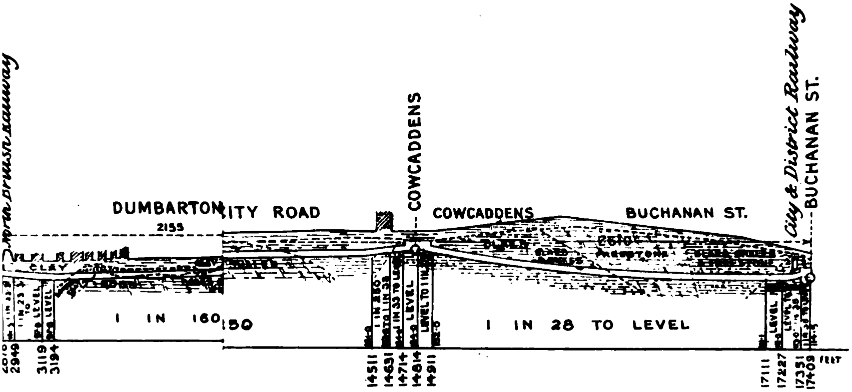
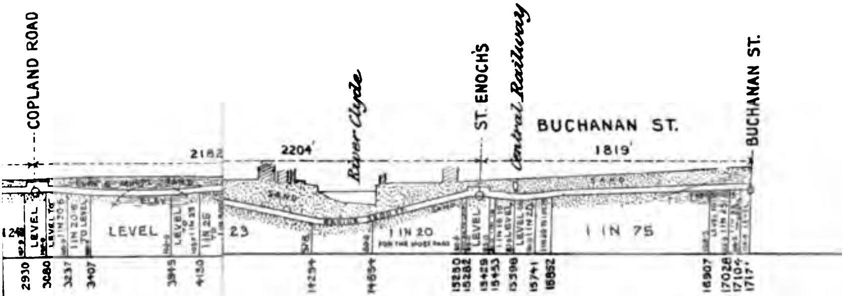
ENGINEERING LITHOGRAPHERS, GLASGOW.

PLATE VI





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ENGINEERING LITHOGRAPHERS, GLASGOW.

PLATE VII

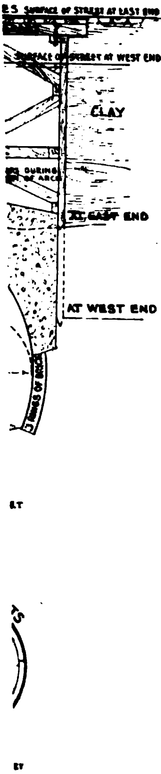
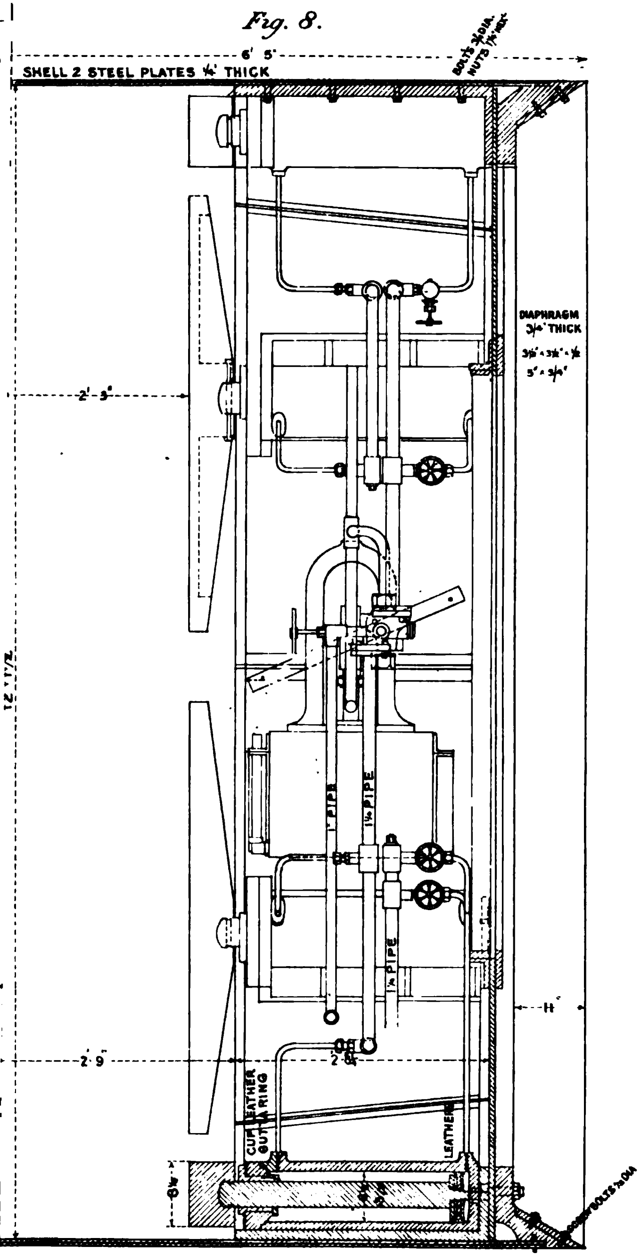


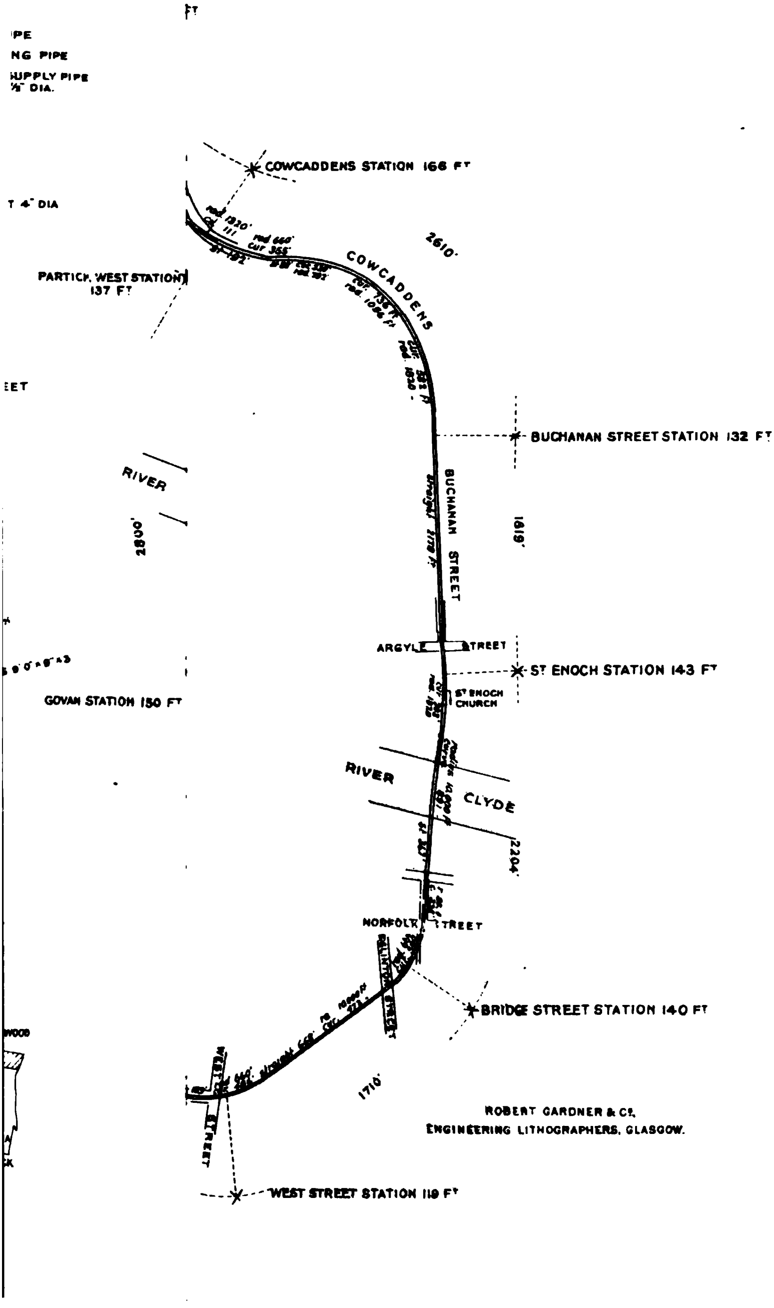
Fig. 8.



ROBERT GARDNER & Co.
ENGINEERING LITHOGRAPHERS, GLASGOW.

(Mr ROBER

PLATE VIII.



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RATES OF SP

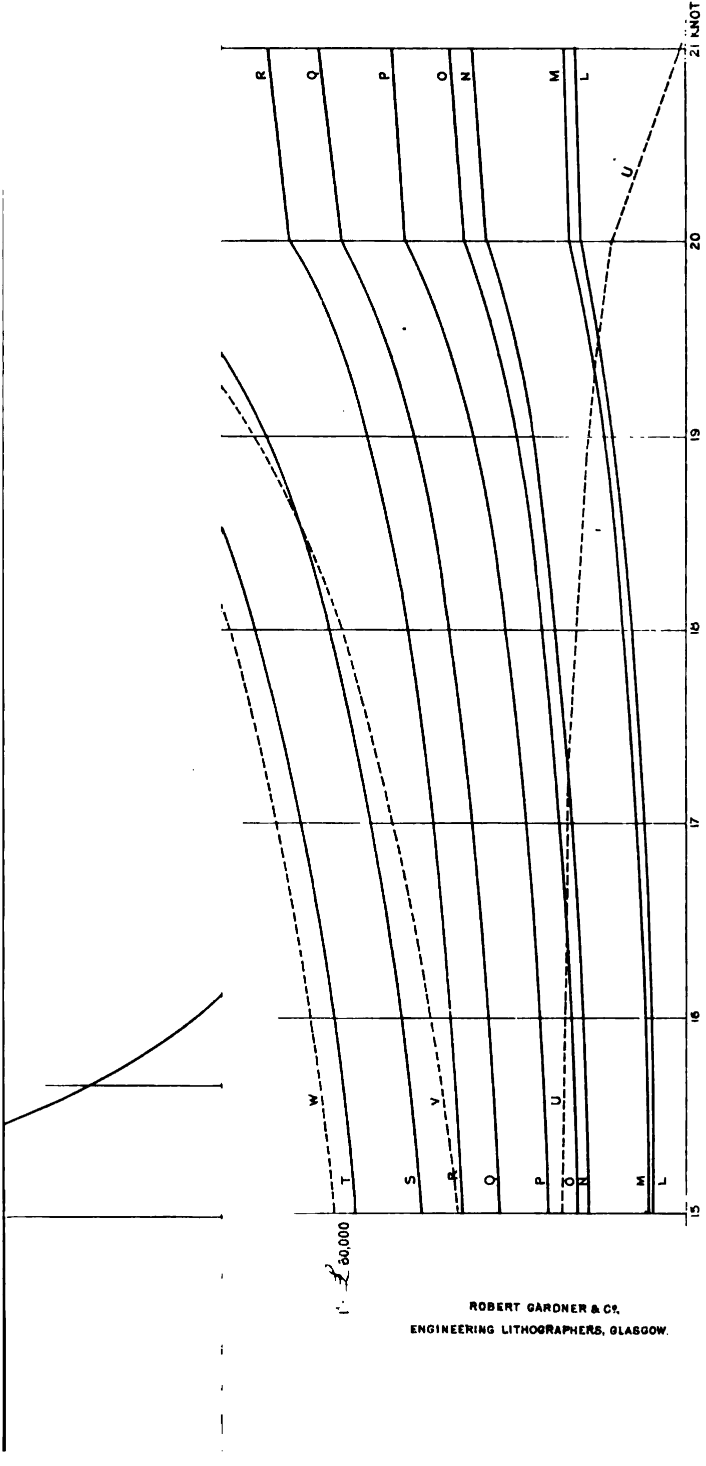

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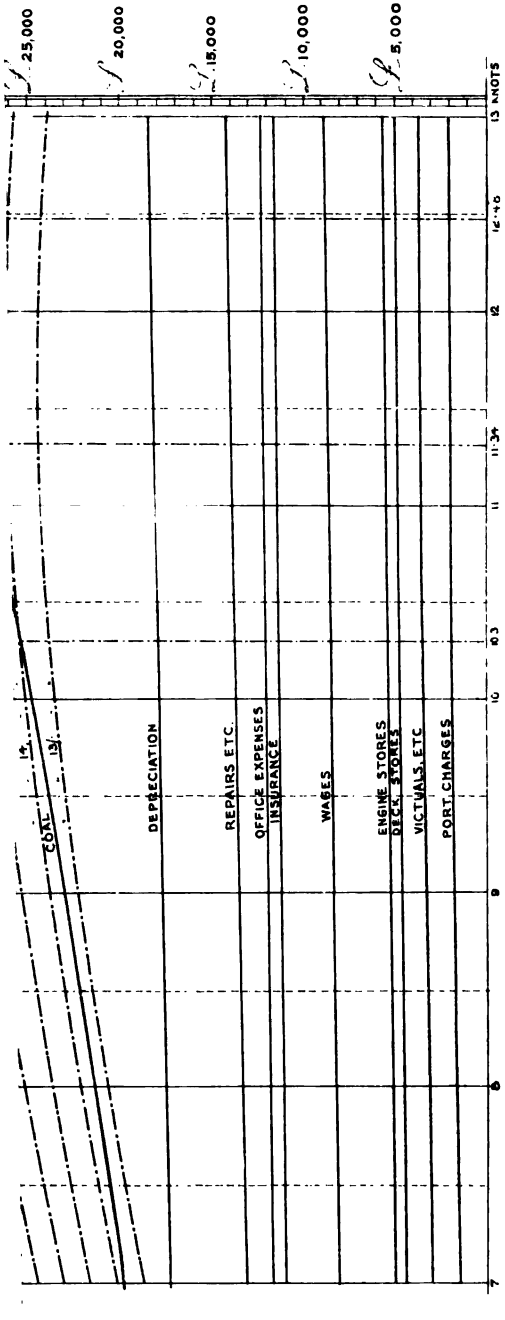
PLATE X



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THE

PLATE XI.

g. 2.

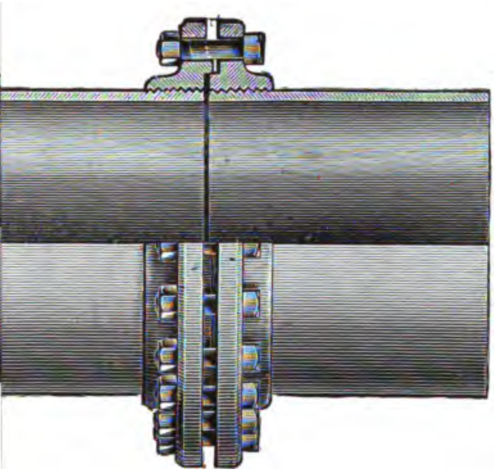
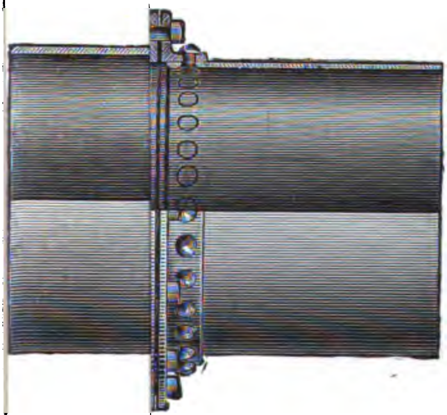


Fig. 5.

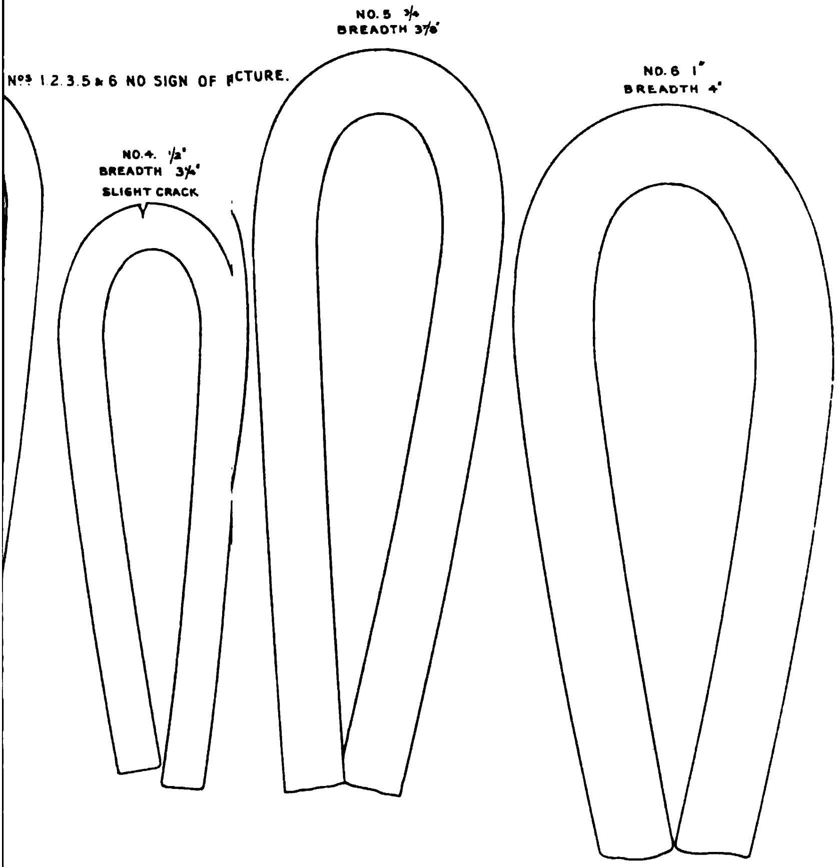


g. 9.

NICKEL STEE

PLATE XII

Fig. 3.



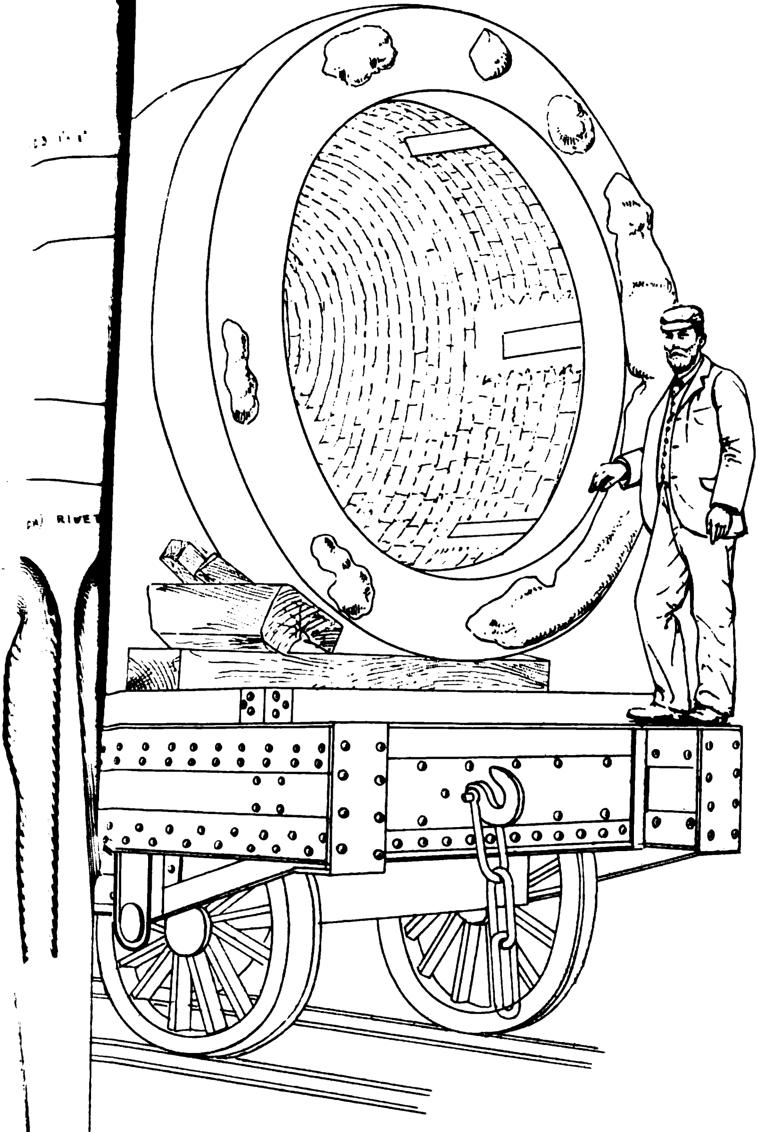
NICKEL STEEL TEMPER BENDS.
CHARGE D. 300.

ROBERT GARDNER & CO.
ENGINEERING LITHOGRAPHERS, GLASGOW.

PLATE XIII

WEIGHT. 72 INS. DIAMETER FOR 12,000 TON HYDRAULIC PRES

Fig. 6.



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