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1889-90.

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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-THIRD SESSION, 1889-90.

Introductory Address.

By Mr EBENEZER KEMP, President.

Read 22nd October, 1889.

GENTLEMEN,

In taking the chair at the opening of the Thirty-third Session of the Institution of Engineers and Shipbuilders in Scotland, my first duty is to thank the Members for the great honour they have done me, in selecting me to such an honourable position.

My first impulse, when your decision came to my knowledge, was to refuse the honour, not feeling myself at all qualified for the post; but, on reconsidering the matter, I decided to accept your decision, and do my best, trusting to your forbearance for any shortcomings on my part, and to your assistance, and the support of the Members of Council, to enable the business to be conducted in a satisfactory manner, and thereby keep up the good feeling that has always characterised the proceedings of this Institution.

I have great pleasure in being able to congratulate you on the continued prosperity of the Institution, both as regards membership and the excellence of the papers read during the past Session, and I would like to impress on the Members the great advantage of a liberal supply of papers; and considering that this Institution is in the centre of such a great variety of industries, there should be no want of papers, and I hope the Members will do their duty in this respect, and keep up a plentiful supply.

The membership of the Institution now stands as follows:—

Honorary Members, - - -	7
Life „ - - -	15
Ordinary „ - - -	403
Associates, - - - - - -	37
Graduates, - - - - -	197
Total, - - -	659

It is a good thing to see the Graduate Section keeping up so well; it must be a great advantage to young men engaged in engineering business. The Graduate subscription is only 10s, and entitles to the attendance at the general meetings as well as to the sectional meetings of the Graduate Section; also to use of Library, which is being kept up to date by new books being added yearly.

This section should be one of the principal feeders of the membership proper, as after the period of apprenticeship is over and appointments are secured, those who are Graduates should naturally become Members of the Institution and take part in its management.

The funds are satisfactory, as during last Session there has been added to the bank balance £106 4s 8d. The new rooms in which we now meet, built jointly by the Institute and the Philosophical Society, have also not only satisfactorily served for the purpose of the general and sectional meetings of the Societies, but are now a recognised centre of scientific and literary meetings, the rents last Session drawn from the letting of the rooms amounting to £60.

Amongst our tenants we have the Geological Society, Natural History Society, Archæological Society, Educational Institute Teachers' Guild, Society of Chemical Industry, and other kindred bodies.

The social life of the Institution does not make much show, unless when we have a visit from other bodies, such as that of the Naval Architects last year. With a view to encourage this, however, the James Watt Anniversary Dinner having been held for the last two years under the auspices of this Institution and the Philosophical Society, and as this year, in January next, it falls to be held under our auspices, it is to be hoped that the Members will ably support the Executive in making it a success.

During the past Session we have lost a large number of very influential Members, and amongst them two Past-Presidents. You will find a pretty comprehensive notice of all the deceased Members at the end of the Transactions of the Institution just published; and it is not in my province to say anything more than to express our great regret for the loss, and our heartfelt sympathy with their friends in their bereavement. But since the Transactions were published we have had recorded the death of one of our Honorary Members, who has been on the roll for the last 30 years—Dr James Prescott Joule, of Manchester, one of the greatest philosophers of our time.

He is said to have written no less than ninety-seven papers on a great variety of subjects for the Royal Society; and his numerous papers to the British Association, and other kindred bodies, must make up a vast amount of work performed for the good of his fellows. His discovery of the mechanical equivalent of heat alone was sufficient to stamp his name on the roll of enduring fame.

In your late President's address for the Jubilee year of our good Queen Victoria, Dr Kirk gave you a very interesting history of the progress of electricity, railways, and steam navigation during the last 50 years, and the various subjects treated of by Past Presidents have been so numerous that I had a difficulty in selecting a subject

The present time is pre-eminently the age of great undertakings all over the world, and I therefore propose to draw your attention to some of them in a very general way.

And first I shall speak of the two great engineering achievements of the Paris Exhibition, viz., the Machinery Hall and the Eiffel Tower. The Paris Exhibition of this year gave a splendid opportunity to the engineers and architects of France to display to the world their artistic and constructive ability. The task of making a building large enough under one roof to contain all the machinery that was to be exhibited was intrusted to Mr Dutert, the eminent architect, and Messrs Contamin, Charton, & Pierron, engineers. The Machinery Hall is certainly the most magnificent building of the kind that has ever been produced. Looked at either from its architectural features, including its artistic details, or from the engineering point of view, it surpasses anything that has ever been done before; and the opinion of engineers of all countries who have visited it is, that in proportion to its vast dimensions it is a wondrous combination of solidity, lightness, and grace.

Looking from the floor of the building along the roof, or from the travelling cranes, which were used as passenger elevated railways, the roof did not look so very high; but when you went to the outside of the building and looked up at the end elevation, you could then realise its great size; and if we compare the roof of St. Enoch Station with it, we will in that way get an idea of the immense size of the building.

The span over the principals in the roof of St. Enoch Station is 209 feet, and in the Machinery Hall 374 feet 6 inches; and the height from the platform to the top of the principals in St. Enoch Station is 85 feet, and from the floor to the top of the principals in the Machinery Hall the height is 153 feet, thus making both the breadth and the height of the Hall about 1⅞ times the size of St. Enoch's. And taking the length of each into account, the superficial area covered by the roof of St. Enoch Station is 103,950 feet, and the space covered by the roof of the Machinery Hall 515,372 feet, which is equal to 4·95, or nearly 5 times the area covered by the roof of St. Enoch Station; and outside the principals in the Machinery

Hall there is an aisle, with a gallery overhead, running the whole length of the building on each side: taking this in, the building has a total area of 6½ times that covered by St. Enoch's.

I will not attempt to go into the details of the constructions, &c., as that has been gone into in various papers and journals very fully already. It is a good thing such an artistic and substantial building is not to be cleared away when the Exhibition closes, and that it is to remain permanently, along with the grand central dome and the buildings set apart to the fine and liberal arts.

The Eiffel Tower is perhaps the most unique building, and there is no doubt the highest building, in the world.

When I first heard of the tower I thought of the two high chimneys we have in Glasgow—viz., Tennant's and Townsend's--but either of these is considerably under one-half of the height of the tower. The height of Townsend's chimney, which is the higher of the two, is 445 feet, the total height of the tower being 984 feet; and the height of the top platform for ordinary visitors is 896 feet, which is just exactly double the height of Townsend's chimney.

Having the exceedingly plain-looking structures of the chimneys in my mind, I wondered what possible form Mr Eiffel could give such a very high building that would have any appearance of elegance or beauty about it; and, besides, I thought it was quite beneath the dignity of an engineer of his reputation to propose to construct a tower for mere show, without some substantial prospect of its being applied to any useful purpose; but after seeing it, and ascending to the various platforms, and enjoying the panoramic views from the various heights, each one different from the other, and realising the immense amount of pleasure it is destined to give to hundreds of thousands of people, I came away with a very different feeling regarding the tower, and a great deal higher appreciation of the utility of the whole conception.

It certainly is a thing of great beauty and elegance of form, and when seen on ordinary evenings illuminated with electric and other lights, it was exceedingly pretty; but when it was illuminated, as I saw it on the 4th of July, in a blaze of red light from top to bottom, giving it the appearance of being red hot in all its members, it was perfectly enchanting.

And looking at the structure from an engineering point of view, it appears to be designed with great ability and care through the entire structure.

I walked up to the first platform by the stairs, so that I might examine the structure and observe the quality of the work, and I must say that I have never seen neater or better executed work in any structure; and it is a matter for gratification, that the owners of the tower and the authorities of the City of Paris, have arranged between them to let the tower remain as a permanent building, and no doubt it will be utilised for some of the scientific or other purposes that have been proposed from time to time.

The first platform, which is 187 feet above the ground, has an area of 38,000 feet, on which is erected restaurants and other offices and a large covered gallery all round, from which to enjoy the surrounding scenery. Access to this platform is attained either by two wide staircases constructed in the east and west piers, or by one or other of the lifts which are constructed in each of the four piers. The second platform, which is 377 feet above the ground, has an area of 15,000 feet, and is surrounded by a covered gallery 8 feet 6 inches wide, access to this platform being attained by a small winding staircase in each of the four columns, or by lifts which are constructed in the north and south piers. The third platform, which is 896 feet high, is 53 feet square, covered in all round with glass, and from it on a clear day a most magnificent panoramic view is obtained. Access to this third platform is by a spiral staircase from the second floor, or by a single vertical lift in two stages.

The lifts to the first and second platforms travel on an inclined path, on which the angle of inclination is constantly changing as the lifts ascend, and great ingenuity has been displayed in overcoming this difficulty. However, all of them appear to work smoothly and safely, and answer the purpose well. 2400 persons per hour can be taken from the ground level to the first platform by two of the four lifts, and 800 per hour to the second platform by the other two lifts, which also start from the ground, and 800 more can be taken to the top platform by the lift which starts from the middle platform, so that altogether 3200 persons per hour can be taken to the first platform by the four lifts, and in addition to these a great many people walk up the staircases.

The honour that the French have at present, of taking people so easily and quickly to such a great height, may not remain long with them, for if rumour comes true, as it sometimes does, the Eiffel Tower is to be put quite in the shade by the tower which is spoken of for the great American Exhibition of 1892. It appears to be with this as with other great achievements, which are usually no sooner accomplished than the desire or rivalry of nations or individuals produces something greater still.

The two canals of great interest to this country at present are the Manchester Canal, now under construction, and the Forth and Clyde Canal, which is again being talked and written about.

The former will be of great importance to Manchester and surrounding towns ; and the latter, if it should be constructed, will not only be of great local interest and importance, but will have quite a national, and to a considerable extent an international, character.

The Manchester Ship Canal, which will be fully 35 miles long, is the most gigantic undertaking of the kind ever attempted in this country, and is estimated to cost over eight millions (£8,000,000) of money.

An idea may be formed of the great extent of this canal by comparing the navigable channel which has been cut in the Clyde from Greenock to Glasgow—a distance of 22 miles—and has taken the Clyde Trustees about half a century of cutting and dredging to bring to its present depth, which is barely sufficient for the passage of the large ocean steamers now frequenting the port of Glasgow. And although the Manchester Ship Canal is fully one and a half times longer than the channel cut in the Clyde, it is on the fair way to be completed to a depth suitable for the passage of ocean steamers in about six years from the cutting of the first sod, which was in November, 1887. The work is being pushed on with great vigour, and in all likelihood will be completed in the time named. I might mention one item in connection with the plant employed to show the great extent of the work being carried on—viz., that there are about 200 miles of rails laid for running the earth to bank, and otherwise providing for the traffic about the works.

The various projects that are being put forward for a ship canal between the Forth and Clyde are all more or less interesting, but there is no doubt the best would be one without locks, although any plan of canal crossing the central manufacturing districts of Scotland would be of very great commercial value to the country, and from a national point of view it would be difficult to overestimate its importance. The facility it would give of transporting a fleet from one side of the country to the other, would be almost equal to the creation of an additional fleet; for in the possible event of a portion of our fleet being blockaded by a superior force, either in the Firth of Forth or the Firth of Clyde, assistance could come from either side to disperse the enemy. In that way a great additional source of security would be obtained from a given number of vessels.

For these reasons it would be well for the Government to consider how much it would be their duty to support such an undertaking in the interests of the nation, and it would at the same time give an enormous impetus to the general trade of the country.

The great canal, however, of the present time, and the one which, if completed, would have an influence of world-wide importance, and which would most likely be of more commercial importance to this country than any other, is, of course, the Panama Canal. The great difficulties, both engineering and financial, encountered by M. de Lesseps, in carrying the Suez Canal to a successful termination, naturally gave his countrymen an extraordinary amount of confidence in his opinion as to the practicability of constructing the Panama Canal.

The difficulties encountered in carrying on the work of the Panama Canal have been enormous, both in their material and physical nature, and in their financial nature. They have been quite unprecedented both as regards their nature and extent, and it must be a source of great disappointment to M. de Lesseps, after spending about £46,000,000 of money on the works of the canal, which are estimated to be at least two thirds completed, to find the whole undertaking come to a deadlock. M. de Lesseps is, however, a man of great resource, and I have no doubt that some way will be found to raise sufficient money, and give the grand old engineer the satisfaction of seeing his last great work carried to a successful termination.

A correspondent of the London *Daily News* some months ago described the Forth Bridge as the "eighth wonder of the world." He said there had been many claimants for the title, but it may be doubted if any work ever had a right to it equal to that of the great bridge which is now nearing its completion on the Firth of Forth at Queensferry; but however it may be as to the title, we are all proud of having such a splendid monument of engineering skill and enterprise brought almost to a finish. It has been a great source of pleasure to engineers and all ranks and classes of people, from all parts of the world, to examine the Forth Bridge from time to time during its construction; and it has always been somewhat difficult which to admire most, the engineers who designed the bridge, or the contractors who displayed so much skill and ingenuity in carrying on the details of the work in such a novel and systematic manner.

During the last few months the Eiffel Tower, owing to its great height and the mass of work it represents, has been enjoying a distinguished celebrity; but if we compare the weight of material in it with that in the bridge, which is in the proportion of 7500 tons in the tower to 50,000 tons in the bridge, it will at once be seen how small an undertaking the one is as compared to the other; and when we think of the difficulties to be encountered in erecting a given weight of material in a horizontal position overhanging water, as compared with erecting less than a sixth part of the weight in a vertical position on the solid ground, the relative merits of the two undertakings become at once apparent.

The Forth Bridge, like all other great achievements of modern times, is likely to be soon superseded by larger and grander bridges before long. There is a proposal by Mr Lindenthal to bridge the North river at New York by a single span of 2850 feet, or fully one and a half times one of the spans of the Forth Bridge; but the proposal to bridge the English Channel is a scheme of such gigantic proportion as compared with the Forth Bridge, that the latter sinks into comparative insignificance.

The scheme as proposed last month at the Iron and Steel Institute appears to have been well considered, and the possibility of building a bridge in such an exposed position, and the mode of proceeding with the erection of the bridge in all its details, have been carefully gone into by gentlemen of the very highest standing; and the fact that Sir John Fowler told the president that he would guarantee the bridge, and also that a great financier told him that he would find the money, makes the project of a bridge across the Channel somewhat like a possibility.

The projectors, like most clever men who have put forward great schemes, have most probably underestimated both the difficulties to be encountered and the cost of the undertaking. Taking the Forth Bridge as the only one having spans somewhat like the one proposed, and supposiug it would cost as much per mile as the former has done, the price would run up to a much larger sum than that proposed.

No doubt a considerable portion of the Channel Bridge would have shorter spans than the Forth Bridge; but, on the other hand, the water is deeper, and the piers would be in proportion more expensive, which in all likelihood would more than make up for the difference in the short spans.

The Forth Bridge is just about a mile long, and there is 50,000 tons of steel in it, and the total cost is said to be £2,000,000.

The proposed Channel Bridge is 24½ miles long, and at the same weight per mile would require 1,225,000 tons of steel, and at £2,000,000 per mile, the cost of the Forth Bridge, the Channel

Bridge would run up to £49,000,000, whereas the estimated cost by the promoters is only £34,000,000.

However, whether we are to have a railway across the Channel above the sea, or a tunnel under the sea, remains to be decided; but there is no doubt a growing public opinion that a more direct means of communication with the Continent is desirable than can be had by a steamboat service, no matter how efficient it may be, and no doubt it has been much improved in recent years, both in speed and superior accommodation.

The machinery which is coming into use for electric lighting is getting very much increased in dimensions, and more especially that which is being made for the Deptford Central Station. It is of such extreme dimensions that new machine tools have had to be made to grapple with it, and mechanical engineers will, in the future, require to get into a very different mode of comparing electrical plant with other styles of machinery which they have been accustomed with.

It is not so very long ago since we were accustomed to think of a dynamo for producing electricity as the production of the tools such as are in use in an optician's workshop, and later on we became used to those of a size which required portable engines to drive them, and more recently at the various exhibitions which have been held there have been pretty large engines employed to drive the dynamos for producing the electric light required; but all of these were still of moderate dimensions, from a mechanical engineer's point of view, or as compared to machines in use for many other purposes; but the dynamos that are being made for the installation at Deptford are not only much larger than any dynamos that have been made in the past, but they are very much larger than any other kind of machine in use for any other purpose whatever, and the same may almost be be said of the engines for driving them.

Even marine engineers, who have been accustomed to consider the machinery they had to deal with the largest required for any purpose, will now have to take a back seat.

I have only to mention the size of the shaft required for these dynamos, which are the largest shafts ever made for any purpose, and I am glad to say that they are being made in our own neighbourhood, viz., at Parkhead Forge; they require an ingot of about 80 tons from which to forge them, and have a diameter of 36 inches on the middle portion where the dynamos are fitted. The indicated horse power which is being provided to drive these dynamos is quite unprecedented. The amount required for the buildings being erected at present is 43,000, and space is acquired for the erection of buildings for an additional 80,000, making a total of 123,000 indicated horse power. In view of these facts it is difficult to imagine what will be the future of electricity, but if electric lighting becomes to any extent general, in the near future a great prosperity is in store for the engineering trades of the country.

I will close my address by noticing very briefly the advance which has recently been made in shipbuilding, although nothing of a very startling nature has recently been done in steam navigation, still a steady advance has been going on, both in hull and machinery, and we have had during the year some of the most exciting ocean racing that has ever taken place, with the result that more than one record has been made, and a six-day passage to New York quite established. When at the Paris Exhibition, I went to see the panorama of the fleet of the Transatlantic steamers, and was told by a French sailor in attendance that the steamer we were looking at could steam from Havre to New York in five days, and when I laughed at the joke, he insisted it was quite true, so of course I let him have his way, but I imagine the French have a considerable advance to make before they possess a steamer that will make the passage from Havre to New York in six days.

Of all the magnificent steamers we had running this year on the New York trade, only one of them has as yet made the passage within the six days, and it appears to take very close watching and very hard running to accomplish that. The "City of Paris" has proved herself the fastest liner afloat, and her passage of 5 days 19 hours and 22 minutes will be very difficult to beat.

None of the other four new twin-screw racers that have been running, during the year, have made the run in six days as yet.

An important improvement in regard to safety has been carried out in these new twin-screw Atlantic liners, viz., that they are practically unsinkable by being divided into a sufficient number of water-tight compartments, and by having two complete sets of engines and boilers quite independent of each other, so that they are not liable to be stopped altogether at sea; for in the event of one engine breaking down or being disabled in any other way, the steamer would still be able to go on at three-quarters speed with the remaining engine, which is a great source of additional safety where there is such an important passenger traffic. As to the prospect of improvement in the future, there is no doubt that the next step forward will result in larger and faster express boats, most likely of the twin-screw type; and as to the improvement in the engines and economy of coal, they are to be looked for by the adoption of higher pressures, and by working the steam through another stage of temperature in the engine; and by some method of raising the steam by stages of temperature, and utilising the fire gases also in stages of temperature in the boiler, so as to reduce the escaping gases to a minimum, we should be able to produce an indicated horse-power for less than 1 lb. of coal in regular work at sea. A few years ago triple expansion engines came into general use with a standard steam pressure of 150 lbs., and already we hear of pressures of 180 and 200 lbs. coming into use, and we may expect a much higher pressure when the quadruple expansion system gets fairly established; probably pressures of 250 and 300 lbs. will prevail with a corresponding increase in the economy.

We are at present on a wave of great commercial prosperity, which, it is to be hoped, will long continue; and now, I shall close by wishing that we may have a very prosperous session before us.

On a University Faculty of Engineering.

By Mr HENRY DYER, C.E., M.A.,

Life Governor of the Glasgow and West of Scotland Technical College.

Received and Read 22nd October, 1889.

A LITTLE over two years ago, I had the honour of reading a paper before this Institution on "The Education of Engineers," in which I sketched the arrangements which I considered necessary to be carried out in Glasgow so that Engineers might have something like the same opportunities for gaining a theoretical and practical knowledge of their profession as was afforded to the members of the older professions of the Church, Law, and Medicine. I pointed out that advantage should be taken, not only of the classes at present being carried on in the University, but also of those of other Institutions which gave instruction in the required subjects, if these were conducted under proper conditions. My proposals received a considerable amount of support from the Members, but there seemed to be a very prevalent feeling that however good they might be, they were not likely to be carried out for a considerable period. At the time the paper was read, the Glasgow and West of Scotland Technical College was being organised, by the amalgamation and re-arrangement of Anderson's College, the Young Chair of Chemistry, the College of Science and Arts, and Allan Glen's School; and, as one of the Governors of the College, I have been able to have my proposals largely carried out. Taking advantage of certain classes held in other Institutions which were needed to complete the various courses of study, arrangements have been made for granting the diploma of the College in the following departments :—

1. Civil Engineering.
2. Mechanical Engineering.
3. Naval Architecture.
4. Electrical Engineering.
5. Architecture.
6. Chemical Engineering.
7. Metallurgy.
8. Mining Engineering.

There is also a course in Agriculture, but the consideration of that subject does not fall within the objects of this Institution. Certificates are also given to those who complete courses of study and pass the necessary examinations in the following departments of the evening classes :—

1. Mechanical Engineering.
2. Naval Architecture.
3. Electrical Engineering.
4. Architecture.
5. Building Construction.
6. Mining.
7. Metallurgy.
8. Agriculture.
9. Chemical Industries.
10. Textile Industries.
11. Art Industries.
12. Commerce.

These are not merely lists which indicate what may be advisable, but with two exceptions arrangements have been made for giving very complete courses of instruction, by means of lectures, and drawing office and laboratory work in the subjects which are required by those who intend to follow any of the departments which have been enumerated. These two exceptions are day classes in Architecture and Mining, as it is found that the evening classes are sufficient to meet the present demands. It is hoped, however, that before long arrangements will be made for the institution of day classes in these subjects, so that the list of curricula above enumerated may be made complete. These curricula represent fairly well the requirements of the chief departments of modern industrial enterprise, and if properly developed would supply the scientific training for the different technical professions, especially those of importance in Glasgow and the West of Scotland.

Now that the Universities Bill has become an Act of Parliament, and that the Commissioners appointed under that Act are about to proceed to take evidence on the subject of University Education, and to make ordinances for carrying it out, it seems to me that it is the duty of the Institution of Engineers and Shipbuilders in Scotland to make its views known as to what is required for the profession of Engineering. In this paper I propose to put forward a plea for a University Faculty of Engineering, not simply for the purpose of expressing my own views on the subject, but also for giving the Members an opportunity of expressing theirs.

To prevent misunderstanding, it will be well if I explain what I mean by the different parts of the title of my paper. By University I understand an organisation which includes all the higher education of a given district, the details of which may be managed by local bodies, subject to the general superintendence of the University Court in all matters which affect the examinations for degrees. I do not, therefore, propose to speak of any special institution. My object is to indicate what, in my opinion, is necessary for Glasgow and the West of Scotland, the exact position of the various parts of the organisation being of comparatively small importance so long as they are convenient to the majority of the students who are likely to take advantage of them. It will, of course, however, be understood that in making my proposals I have kept in view the resources of the present University, and the Glasgow and West of Scotland Technical College, the two chief scientific educational institutions in the district. By Faculty I understand a department or division of that organisation, which is devoted to a special object or group of objects. A University Faculty of Engineering, therefore, means that part of the organisation of a modern University which is intended to give an adequate preparatory scientific training to those who intend to devote themselves to the practice of the modern professions and trades which have arisen through the development of the arts and manufactures.

It might be supposed that before an Institution of Engineers it would be unnecessary to explain what I mean by "engineering," but the discussion which took place on the paper to which I have alluded, showed that there was a want of definiteness about the ideas of some of the members. Time will not allow me to trace the etymological and historical uses of the term "engineer." That, however, has been done by Dr Pole in the opening chapters of his biography of Sir William Fairbairn, and he distinctly proves two things. First, that "an engineer is, according to the strict derivation of the term, not necessarily a person who has to do with engines, but any one who seeks in his mind, who sets his mental powers in action, in order to discover or devise some means of succeeding, in any difficult task he may have to perform." "Engineering" is therefore capable of a very wide application, and it is in fact often applied to other than what are usually considered engineering matters. For instance, Professor Meiklejohn in his inaugural address at St. Andrews, spoke of the "engineering" of the subjects of education. The second thing shown by Dr Pole is that down to a recent period, the title "engineer" was unknown in any application except its military one, that is to say that Civil Engineering is a term applied to all engineering other than military. This was the view taken by the Council of the Institution of Civil Engineers, a few years ago, when that body finding that some misunderstanding existed as to the precise nature and extent of the occupations legitimately constituting their profession, enumerated the following classes of works as examples of what the members might be called upon to do :—

1. Works for facilitating and improving internal communications — as roads, railways, tramways, navigation by canals and rivers, bridges and telegraphs of various kinds.
2. Works connected with the sea-coast, and for facilitating communication between the sea and the land, such as harbours, docks, piers, breakwaters, sea-walls, and lighthouses.
3. Works for facilitating communication across the seas, including naval architecture, iron shipbuilding, and the construction and keeping of submarine cables.
4. Works for the reclamation, irrigation, or drainage of land ; and for the prevention and repellation of floods, including the improvement of rivers as arterial drains.
5. Works for cities and towns, such as sewerage, water supply, lighting and street improvements.
6. Large and massive buildings generally, in their scientific and mechanical arrangements.
7. The operations of mining and of metallurgy, so far as they involve the application of mechanical science.
8. The design and construction of mechanical prime movers, such as steam engines, water-wheels, and other hydraulic motors, windmills, electric and other engines.
9. The design, construction, and adaptation to practical use of machinery and mechanical appliances of all kinds.
10. The design and manufacture generally of all large and important metallic structures, including artillery and other large munitions of war.

This is a very comprehensive list, and it shows how utterly impossible it is for one man to teach, or to practise, all the departments included in it. There is another term, "Applied Mechanics," which is used in a very indefinite manner. It was introduced before the science of engineering was developed, and was taken to mean the application of dynamical principles to engineering problems, and treatises on the subject attempt to give an introduction to the different departments of engineering. The name is too wide to have any definite meaning, and therefore should not be used. The term "mechanics" was taken by Newton to mean the science of machines, or what is now called the theory of mechanical engineering, and which is included in the list of departments of Civil Engineering, as defined by the Institution of Civil Engineers. The term "Civil Engineering" has come to be used in the restricted and illogical, although somewhat convenient sense, as applying to such works as roads, railways, and hydraulic works, and it is in this sense it is to be understood in the list of departments in the Technical College which I have enumerated. The French name of *ingénieur des ponts et chaussées* is more nearly descriptive of the actual work done, although it also is somewhat too restricted. These considerations show how absurd it is to call a man Professor of Engineering, rather than a Professor in the Faculty or Department of Engineering. The different parts of the subject should be divided among the professors or other teachers, according to their special studies or inclinations, or the requirements and convenience of the students, and not by the artificial limits of an antiquated commission, or even of a modern one, if these are found to be inconvenient in the arrangement of the work. In the Universities hitherto it has been possible to give special names to the work of the different men, on account of the rigid nature of the examination regulations, but in scientific subjects, and especially in those of an engineering faculty, such a division is impossible, as we cannot draw strict lines between the different departments. Pure mathematics runs into applied mathematics and physics, physics into chemistry, and all of these into the different departments of engineering. It is equally impossible to separate these departments. Every one of them is mixed up, for instance, with mechanical engineering. The civil engineer requires a good knowledge of machines, and of mechanical construction; the electrical engineer without mechanical engineering is confined to the least important parts of his subject; the naval architect should be well acquainted with at least the connecting lines of mechanical engineering and his own department; while the chemical engineer, the mining engineer, and the metallurgist all require a very considerable knowledge of machinery; and the field is so wide in each case that it is absurd to expect one man to cover it. It is therefore advisable to take advantage of the varied experience of the different members of the staff, and not confine their work by artificial limits.

But while this be so, it is highly necessary for the sake of the students that the whole field of engineering should be fairly covered by different courses of study, bearing chiefly on the departments in which they are likely to be engaged. All the subjects are of about equal educational value, and as it is utterly impossible for any student, in the time usually devoted to a college course, to attempt them all, it becomes necessary to draw out courses of study, from which the majority are able fairly well to have their requirements met. The courses I have mentioned as having been arranged in the Technical College (see p. 16) are designed to meet these requirements, and they cover fairly well modern practice. University education has hitherto erred in forcing all the students through the same groove. In organising engineering education we must avoid this mistake, and recognise that engineering is not a single profession, but a group of allied professions, each of which is capable of division into various parts.

I claim for all of the departments I have named a place amongst University studies, not merely because of their immense importance in our present state of civilisation, and therefore deserving the highest culture and training the Universities can afford, but also because of the good general education, and of the preliminary training in pure science which they require of those who would successfully pursue them. If the different subjects were properly taught, and their connection with the lives of the people clearly shown by the effects of their development on the state of civilisation, I further claim for them a high position as instruments in a liberal education. It is highly necessary that engineers should receive such an education. Mere technical skill and knowledge in themselves are of little use unless they are accompanied by manly spirit and enthusiasm, and even these will not lead to the greatest good unless combined with depth of social spirit. An engineer's general education should therefore include, in addition to the ordinary subjects, a knowledge of existing political institutions in Britain, both local and central, and this should be obtained by a historical study of their development, and of the political ideas therein involved. The relations of Britain to other countries, and to her colonies, should also be studied. But above all, attention should be paid to the history of economics, and of industrial and commercial institutions, and to the development of social ideas and their influence on the lives of the people.

In the same way the historical development of the different departments of engineering could be made a most valuable means for developing the minds of the students, by showing the influence they have had on the advancing civilisation of the world. The most instructive and interesting, and ultimately the most useful method of studying any subject whatever, is the historical, and in none could it be made more interesting and instructive than in Engineering. It would not be a mere case of collecting facts, figures, and formulæ all in a cut-and-dry form, ready to be poured on an examination paper, but would give the students a living interest in the subject. In what, for convenience, I have called Civil Engineering, for instance, the development of roads, railways, canals, harbours, lighthouses, &c., might be traced from the earliest periods to the present time with the side lights they threw on the lives of the people and their social habits. The history of Mechanical Engineering is bound up with that of the great industrial revolution which has changed the face of the globe, and the methods of carrying on almost every department of work. The study of the effects of these on economic and social conditions should be an essential part of the education of all mechanical engineers. In Naval Architecture the development of ships of all kinds, and the effects of improved navigation on the trade and customs of the world, would afford a similarly interesting field for historical, economic and social studies. Electrical Engineering, which has shrunk the globe to insignificance and has levelled the inequalities of commerce, and which promises to again revolutionise our industrial system, opens up many fields both for economic inquiry and speculation. Architecture, from a historical point of view, is simply the manners and customs, and ideas of the people, built up in wood, brick, or stone, and is directly connected with their social economy. The applications of chemistry and metallurgy, which have been the means of utilising substances formerly thought useless, and have afforded work and subsistence to large bodies of the people, have all had an immense effect on social conditions, while mining in all its departments has afforded the raw materials for many of the arts and manufactures. This brief sketch is sufficient to show that Engineering is not necessarily the dry-as-dust, matter-of-fact study which it is often supposed to be, and which, unfortunately, it too often is.

Not only is Engineering entitled to a place among liberal branches of education on account of the training which might be given with it, but also because of the knowledge of pure science required of those who intend to practice it. All engineers should have a fair knowledge of mathematics and physics. Not necessarily such a knowledge as would secure them a high position in such things, or phantoms, as mathematical triposes, or other university honour lists, but a real knowledge which would not only train their intellectual powers, but also fit them to solve the problems which they met in everyday life. They should also have a fair knowledge of French or German, or if possible of both, and at least of one general subject, such as literature, history, or political economy, so that they may be able to rise out of the narrow groove of scientific and professional interests. The subjects I have mentioned are the only ones which should be compulsory on *all* engineering students. The other sciences should, however, be included in the courses when they are wanted in their applications to engineering or manufactures.

It is not necessary to enter into details of the courses required in the different departments of Engineering. Those who wish to have an idea of the extent to which they may be enlarged may consult the programme of a German Polytechnic School. The following outline, however, indicates the nature of the work to be done in addition to the subjects which have been mentioned as common to all the departments.

Civil Engineering.

- Higher Mathematics.
- Higher Natural Philosophy.
- Applied Mechanics (as usually defined).
- Geology.
- General Course on Surveying and Civil Engineering.
- During the last year a special section should be thoroughly studied, *e.g.*, Roads, Railways, Tramways, and Bridges, Drainage and Water Supply, Canals, Rivers, Harbours, and Docks, Sanitary Engineering, &c.

Mechanical Engineering.

- Higher Mathematics.
- Higher Natural Philosophy.
- Applied Mechanics.
- General Course in Mechanical Engineering.
- During the last year a special subject should be chosen, *e.g.*, Stationary Engines, Locomotive Engines, Marine Engines, Gas Engines, Machine Tools, Textile Machinery, &c.

Naval Architecture.

- Higher Mathematics.
- Applied Mechanics.
- Naval Architecture.

This department is not so subdivided as the others, but the work of the last year might be specialised somewhat according to the probable requirements of the students.

Electrical Engineering.

Higher Mathematics.

Higher Natural Philosophy.

Applied Mechanics.

General Course in Electrical Engineering.

During the last year special attention should be paid to one department, *e.g.*, Telegraphy and Telephony, Electric Lighting, Transmission of Power, Electric Instrument Making.

Architecture.

Drawing.

Applied Mechanics.

Architecture, both as a Fine Art and as a branch of Construction.

Chemical Engineering.

Chemistry and Chemical Physics.

Applied Mechanics.

Technical Chemistry and Chemical Engineering.

With special reference during the last year to the branch in which the student was to be employed.

Metallurgy.

Chemistry and Chemical Physics.

Applied Mechanics.

Mineralogy.

Metallurgy.

With special reference during the last year to the branch in which the student was to be employed.

Mining Engineering.

Applied Mechanics.
Mineralogy.
Geology.
Surveying.
Mining Engineering.
With special reference during the last year to the branch in which the student was to be employed.

The work in the main subjects of each of those departments should be divided between the lecture room, the drawing office, and the laboratory. In engineering subjects especially, the pumping and cramming processes are largely a waste of time. The professor should be able, in two or at most three lectures a week, to give his students sufficient to think about for the remainder of the time, while the drawing office and the laboratory would be powerful helps in making their thoughts of some use, and not mere metaphysical speculations or mathematical puzzles. In the courses I have named I have, therefore, not given drawing and laboratory work as separate subjects, as I consider them essential parts of the class work. In some departments, however, and especially with advanced students, lectures by themselves, if of the right kind, may be of great service. They should be, as Max Müller put it recently, teaching lectures, and not mere preaching lectures. They should be free and easy conversations between the teacher and the students, and not mere formal prelections which may excite wonder and awe, or possibly only irritation, but which do nothing to educate those who listen to them. In the drawing offices every part of the work should be illustrated graphically, and the principles taught in the lectures applied to such problems as occur in every day practice. It would thus not only be a most useful part of educational training, but it would afford an introduction to the work of the actual drawing offices of engineers and manufacturers. Even in mathematics and physics it is of the greatest importance that the students should become acquainted with drawing and experimental work. In mathematics especially they should be required to delineate almost all the problems they studied, so that it might be evident that they had a real, and not merely a formal knowledge of their meaning. It cannot be doubted but that the requirements of engineers have been the direct cause of a great improvement in the methods of the mathematicians. Professor Osborne Reynolds has well said: "All the more useful branches of science are now within the reach of the student of engineering, and in the forms most suitable for him. So that, as a step towards understanding the theory of machines, it is not now necessary for him to begin with the theory of astronomy or the doctrine of chances. The miserable form in which the only mathematics to be obtained was wrapped, has compelled engineers to work out methods for themselves; and now that the demand for such knowledge has increased, we find that the first mathematicians in the land have, so to speak, patronised our system."

In Glasgow, where Sir William Thomson has done so much for experimental science, it is not necessary that I should dwell on the importance of laboratory and drawing office work for students of natural philosophy. During recent years, however, the domain of physics has increased to a very great extent, and to make the department what it ought to be, we require not only a considerable addition to the staff, but also to the accommodation and appliances. In addition to the purely physical sections, there ought to be one which would be a connecting link between the natural philosophy and the engineering departments of the University, and would take the form of what is sometimes called a mechanical laboratory, in which the students would have opportunities of illustrating the work done in the lecture room, and of verifying the principles which they have been taught. No attempt should be made to draw a strict line of division between what are usually called theoretical and applied mechanics, as it is only by illustrations drawn from practice that the students ever clearly realise the meaning of the theory. The work would include the testing of the strength and elastic properties of the materials used in construction, and the laboratory would be supplied with a selection of the ordinary hand and machine tools, which would be used not only in the preparation of experiments, and in the making of the simpler pieces of apparatus, but also for illustrating the lectures. The chemical laboratories also should be extended, so that opportunities might be given for research in every department of the science of chemistry, which in recent years has also developed to a very great extent.

The Scientific Department of the University with its sections of mathematics, mechanics, physics, and chemistry, arranged as I have indicated, should be connected with the Engineering Department or Faculty by means of a corresponding series of laboratories and drawing offices in which the applications to the different departments of engineering, I have enumerated, would be carefully studied. The Civil and the Mechanical Engineering Laboratories might be combined, as many of the appliances would be common to both sections, and the students could select the special work which was likely to be most useful to them, and they would be prepared to take up others more directly connected with practical work. In Civil Engineering the testing of cements and mortars, and their methods of application to structures under different conditions would require attention, and the theory of structures might be tested by means of models of girders, arches, trusses, and other constructions, while many interesting and instructive experiments in hydraulics could easily be arranged. The lecture work would be continually suggesting corresponding work either in the laboratory or the drawing office. In the latter, every problem would be worked out both by analytic and graphic methods, and the drawings done under as nearly as possible the conditions which exist in an engineer's office. The students would receive sketches and data, and from these they would after a study of standard examples be expected to make out their designs, and all mere copying would be discouraged.

In the department of Mechanical Engineering there is opportunity for a much greater variety of experimental work than in that of

Civil Engineering. The testing of the efficiency of steam engines and machines under different conditions, the proportioning of their parts in accordance with the results of experiments, the measurement of the work done by them, the methods of testing springs, indicators, dynamometers, gauges of various kinds, the lubricating power of unguents, the efficiency of cutting tools, and of pumps, and valves are examples of the class of work which might be taken up. The drawing office work would be closely associated with the lectures and experiments, in fact would be their graphic representation. Moreover, while attention would be paid to the more theoretical aspects of the questions involved, designs would be made, as nearly as possible, under the conditions which exist in practice.

The department of Naval Architecture should be supplied with a tank for experimenting with ships' models, or for testing the resistance of bodies generally to passage through water. The utility of such a tank has been fully shown, and no Chair of Naval Architecture should be without such a useful auxiliary to its teaching. The work in the drawing room or office of the department would be chiefly the calculations required in the designs of ships, their graphic representation, and an introduction to actual design.

Electrical engineering is almost the only department of engineering in Glasgow which is fairly well supplied with laboratory appliances. Between the University and the Technical College, students are now able to get a good introduction to the experimental parts of the subject, but these have been so much extended during recent years, that there is now room for a more systematic arrangement of apparatus, and co-ordination with other allied subjects, such as some parts of mechanical engineering.

The students of Architecture have not the same need for direct experimental work as those in other departments, although they would find short courses of instruction in the physical and engineering laboratories of the greatest assistance in dealing with the problems connected with the lighting, heating, ventilation, and acoustic properties of buildings, and the properties of the materials of construction. A good studio or drawing office, however, is most essential to the architectural section. In that the students would practice drawing in its application to their profession, would work out examples of design, of measuring, of graphic methods of investigating the action of loads on structures, and of specifications for buildings of different kinds. The studio would, of course, be under the management of the Professor of Architecture, but the leading architects of the district should be invited to become visitors, so that the practice might be prevented from running into a groove, or settling into antiquated methods.

The laboratories for Chemistry, Mining, and Metallurgy should be arranged in a convenient group, so that the students might pass easily from one to the other, and the professors be able to illustrate the different parts of their subjects. Analysis, assaying experiments with materials of all kinds, which it is not necessary, even if it were possible, to particularise, open up a very wide field for laboratory work in connection with chemistry, mining, and metallurgy. I am told that nothing strikes foreign mining engineers and metallurgists when they visit Glasgow and the West of Scotland more than the fact that there is no School of Mining in the district, and they soon discover that although many modern methods had their origin in this country, they are worked on more scientific aud economical principles on the Continent and in America. The fact of the matter is that our mine owners and metallurgists have not yet recognised, at least as much as they ought to have done, that during the past twenty years a great change has come over the conditions under which they do their work. Formerly they had abundance of raw materials and practically no competition; now the materials are scarcer than they were, and they have competition in all parts of the world. They require to supplement the practical methods learned from costly experience by a knowledge of the principles which underlie their work, and the sooner they realise this the better it will be for themselves.

In all the departments of laboratory and drawing office work which I have mentioned, the educational aspect should always be kept more prominently in view than the instructional. They might, however, be also utilised for commercial purposes, that is to say that experiments might be made in them to the orders of engineers in the different departments, especially in the way of testing the constituents of materials used in chemical or metallurgical manufactures, or the properties of those used in construction. This would have a double advantage. It would add to the funds at the disposal of the department, and it would tend to keep the instruction within practical lines, as the experiments would be chiefly designed to meet some immediately useful purpose. Such an arrangement would by no means confine the teachers to directly utilitarian ends, as some of the most important discoveries have been made in endeavouring to solve practical problems, which prevented the investigators from losing themselves in mist, and enabled their students to obtain a solid grasp of their subjects, by giving them a great deal of practical information which they could not obtain in an ordinary workshop. Having pointed out the advantages of laboratory training to engineering students, I must now say plainly that I do not consider it at all satisfactory that Glasgow, the greatest engineering centre in the world, should, in respect to many of these advantages, be behind some of the provincial towns of England and Scotland, and I trust that this only requires to be pointed out in order that an effort may be made to improve matters.

On the subject of examinations a great deal might be said, but time will only allow me to remark that in the Faculty of Engineering a competent examiner should have no difficulty in distinguishing between cram and real knowledge. Class examinations should be carried on for testing the progress made by the students in their work. If that work be done faithfully by the teachers and the students, the diplomas or degrees might almost be awarded on the results of these examinations, as the real value of the student's knowledge could thus be ascertained more exactly than by any special examination, if that were conducted by men who had nothing to do with their teaching. In the German Universities the degrees are awarded entirely on the results of the examinations conducted by the professors, and I believe that on the whole they are fairly given. In this country it is usual to appoint assessors in addition to the professors, as somewhat of a guarantee to the public that no partiality is shown to any particular set of students. The circumstances of the Scotch Universities are such as to render it advisable to continue this method, although not for the reasons usually assigned, but simply that greater variety may be given to the examinations, for even the best examiners are apt to get into a rut. The final examinations should be of such a nature as to test not only the knowledge of the students in the theory of their work, but also their ability to apply it in practice to such problems as arise in the every day work of the department which they have selected. They should be placed under very nearly the same conditions as they would be in an engineer's office. A piece of work should be given them to do, with such data, sketches, and figures as are necessary to make designs and calculations, they should be required to explain the theories of the different parts of their work, make all the necessary drawings and specifications, and write a thesis on a subject connected with it. This may seem a very complicated arrangement, and difficult to carry out, but I know from my experience in the Imperial College of Engineering, Japan, that it can be carried out in a most satisfactory manner. How much of it should be at once attempted in Glasgow will depend largely on the opportunities the students have had. At the recent meeting of the British Association, Sir Benjamin Browne, of the well-known engineering firm of Hawthorne, Leslie, & Co., expressed the opinion that the universities had done harm by giving degrees in engineering, and that if such degrees are given at all they should be bestowed exclusively and solely by engineers. This opinion reflects that of many men who are well qualified to judge of the matter, and it has been produced by the style of teaching and examination which unfortunately has been too common in colleges and universities.

The arrangements made by the students for obtaining a knowledge of the practical parts of their profession will to a large extent depend on their private circumstances and opportunities. Some may enter the University or Technical College on leaving the secondary school, and take what practical work they can during the summer recess, and complete their apprenticeship at the end of their university or college course; some on leaving school may go direct to the workshops, and attend classes in the evenings, and when they have finished their apprenticeship they may go to the day classes for a session or two; while others may try a combination of the two systems. Sir Benjamin Browne, in the paper which I have already mentioned, strongly advocated the retention of the system of apprenticeship in workshops, supplemented by theoretical training according to the abilities and opportunities of the students. He thinks that ordinary apprentices will get nearly all they require in well conducted evening classes, supplemented in some cases by a session at the day classes. His firm is in the habit of paying the fees of every apprentice who attends approved evening classes, a practice which might be much more extensively adopted than it is. As regards the class known as premium apprentices or pupils, or in general those who can afford to pay for exceptional training, he would allow no substitute for the manufactory as a place for practical training, but they may advantageously spend one or two years at college or at a technical school before or after apprenticeship. He believes that the college workshop is the least useful part of a college, and often does more harm than good, and that many of our most scientific engineers would like them shut up altogether. With these opinions I thoroughly agree, and in advocating the extension of laboratory work in connection with the teaching of engineering, I wish it to be restricted to its educational bearings, and not allowed to drift into attempts to replace apprenticeship in workshops.

To carry out all I have suggested, no doubt it will be said, would require a very large staff of teachers, extensive buildings, and consequently a heavy expenditure of money. This may be admitted, although not to the extent which might, at first sight, be supposed. In a German or Swiss Polytechnic School we find each of the main departments, I have enumerated, represented by three or four professors, and a considerable number of fully qualified assistants, and supplied with splendid buildings, and all the latest apparatus. We may come to that, but by taking advantage of the classes of existing institutions, and making a few additions as may be possible, we may, without any great expenditure of money, or causing any great change in the methods which have hitherto been adopted in the training of engineers, be able to carry out the greater part of the programme which I have suggested. In educational, as in social affairs generally, we should try to improve matters by the slow and sure methods of evolution, and not by the destructive and wasteful methods of revolution.

In America, I find that in the most important Technical Schools special courses of lectures are given by the men who are most distinguished in the different departments of practical work, and surely there is sufficient public spirit among our most distinguished engineers and manufacturers to induce them to give the results of their experience to the rising generation. If there is not, then society is in a bad way. There should be room in a University, or in connection with it, for every man who is able to render it effective service. I am optimist enough to believe that it is possible so to organise the University that it will be able to render the maximum social good, and at the same time that the interests of all concerned should be duly considered. The welfare of the University, however, demands that there should be about it a considerable number of men who are freed from the necessity of having to fight for bread and butter, so that they may devote themselves to the advancement of their different departments of learning, or to their organisation, which is quite as important. Competition to a certain extent we ought to have, but it ought to tend upwards, not downwards, and it should be regulated by a body able to weigh the best interests of the University and of the individuals concerned Competition simply for fees and students, will inevitably lead to the degradation of the University, and the destruction of all true study. We do want, however, in addition, buildings which are better adapted to the present requirements of scientific teaching than those we possess, and a supply of the most improved apparatus, and the latest books. If we had these, and if they were available to those who had proved themselves qualified, I do not doubt for one moment, but we would find a sufficient supply of good teachers.

A great deal could, however, be done by systematic reading, not only of books but also of scientific periodical literature. Universities have not yet learnt the lesson which Carlyle tried to teach them nearly fifty years ago. "Once invent Printing," said he, "you metamorphised all Universities, or superseded them: The teacher needed not now to gather men personally round him, that he might *speak* to them what he knew: print it in a Book, and all learners far and wide, for a trifle, had it each at his own fireside, much more effectually to learn it:—Doubtless there is still peculiar virtue in Speech: . . . There is, one would say, and must ever remain while man has a tongue, a distinct province for Speech as well as for Writing and Printing. In regard to all things this must remain: to Universities among others. But the limits of the two have nowhere yet been pointed out, ascertained: much less put in practice: the University which would completely take in that great new fact, of the existence of Printed Books, and stand on a clear footing for the Nineteenth Century as the Paris one did for the Thirteenth, has not yet come into existence." Carlyle in this, as in almost all other things, carries his arguments to an extreme when he says that "the true University of these days is a Collection of Books." I would rather put it in this way, that one of the most important duties of a University Professor is to guide the reading of his students. This is true not only of the scientific parts of engineering study, but also of the more general aspects of the subjects to which I have alluded.

Glasgow is the centre of the most important engineering works in the world, and if such arrangements as I have indicated were carried out, it might have the most complete school of engineering. The present time, when the Universities Act has been passed, is a crisis in the history of the University, and if advantage be not taken of the opportunities which have now arisen, they may be lost for ever. The inventions of James Watt revolutionised our industrial and social life, and were the direct cause of many of the problems with which we are now confronted. If it had not been for the assistance of the University of Glasgow these inventions might have been delayed for an indefinite period. To that University, therefore, the world has a right to look for the training of men who are not only thoroughly qualified to follow the scientific results of Watt's inventions, but also to assist in the solution of the social and political problems which have flowed directly from them. Every social improvement must have for its foundation an improvement in education, and I trust that along with the Faculty of Engineering in Glasgow University will be developed another Faculty or Guild, which will have for its object the good of all who are in any way connected with the great industries which have made Glasgow what it is. The welfare of the producers, be they employers or employed, and not simply the cheapness of the products, the organisation of capital and labour, and the arrangement of all disputes by reason, and not by force, are the great problems of the future, and their solution will demand the best efforts of our noblest men. Surely for such a cause one might be content to devote his life, and to feel that the success of his efforts was his best reward.

The discussion of this paper took place on the 19th November, 1889.

Professor JENKINS said that the subject for discussion that evening was one which Mr Dyer had given a great deal of attention to; and therefore everything that fell from his lips on such a theme was worthy of their best and most careful attention. With a great deal of the paper Mr Dyer had written he was in full accord; but at the same time there were a few points to which he desired to call attention. Mainly he would draw their attention to that part of the paper on page 16, where Mr Dyer enumerated twelve subjects which he considered worthy of being taught separately in the University, and he (Professor Jenkins) understood that Mr Dyer considered it necessary that Professorships should be founded for the purpose of teaching them. When he first saw this very long list, two questions came into his mind. The first was—where was the money to come from to pay the Professors? and the second—where were the students to come from? There was another list previously given, on the same page, of eight departments, which Mr Dyer told them were being treated at the Glasgow and West of Scotland Technical College, with the aid of other institutions, and for which the diploma of that college was granted. But had they students for all these classes? He had looked at the Calendar, and found that last year they had in all 153 students in the day classes, and this number would include men who attended those classes that they might gain a general education, without specialising in the way suggested. If, they supposed two-thirds of the number in attendance were taking the course indicated by Mr Dyer, that would give 100 students; but that number would not pay for a staff of Professors, and if the classes were to be carried on, the Professors must be paid from some other source. Indeed, he had heard that the attendance this year was not so good as last. If that be so, how were they able to carry those classes on at the Technical College? He believed it was done to a great extent with the assistance of the money got from the fees for the evening classes, and the pecuniary aid which the evening classes received from the Science and Art Department. Now, if Chairs for teaching those subjects at the University were to be established, funds must be got, as the attendance at the Technical College was not sufficient even to pay the professors there. If they could get the public to give £100,000 to form an endowment, then by all means let them have these Chairs; but until that was done he did not think they could take so great a step in advance as was contemplated in the paper. He thought he heard the remark made at last meeting of the Institution—although he could not find it in the printed paper—that the Professors in the Technical College should be incorporated with the Glasgow University. There were objections to this, however. So long as the Technical College was connected with the Government Science and Art Department, their teaching had to be confined within certain rigid lines, and so long as that was the case, he did not think it possible for the College to become incorporated with the University. But there was another objection. He understood that at a recent meeting of the Governors of the Technical College, it was proposed that they should apply to the Universities Commission for that institution to be affiliated with the University, but the Governors almost unanimously agreed that they would not apply, which naturally suggests that they are not willing to connect the Technical College with the University, and thus lose the control they now exercise. On the question of the kind of teaching that should take place at the classes enumerated, Mr Dyer has said that it would be of great advantage if the Professors were to take up the history and development of their subjects. For his (Professor Jenkins) own part, he did not feel that he could follow that course. He would not consider that he was doing his duty to his students by treating them to the history of the subjects under notice. He was of opinion that the student could get the history of such subjects better in books, and that the time that the student devoted in that way to the prelections of any professor could be better employed. Of course he did not object to giving history in class for purposes of illustration. He had that day found it necessary to go back and point out to his students the pernicious effects of the old law of Builders' tonnage. That, however, was an exceptional case, and he did not often find it necessary to take up the time of students in that way. He was in hearty accord with Mr Dyer as to the necessity for laboratories. He felt that they were handicapped in Glasgow in this matter of laboratories, and he hoped that they would soon have one established at the University which they would all feel proud of. In his own class there would be men going out soon who would be dealing with iron and steel every day of their lives, and it was right that they should have the advantages gained by being taught in a class with the aid of experimental apparatus. It would be a great happiness to him to be permitted to demonstrate in the laboratory facts which his students had now to take on his dictum alone. With regard to the tank, he might say that he felt the want of one very much in teaching his class Naval Architecture. He believed the possession of such a tank at the University would be of great advantage, not only to the students, but to shipbuilders and engineers, as well as to shipowners; for any change of form suggested by experiments with models in the tank, leading to an increase in the rate of speed, would pay in the course of a year or two for the cost of its construction. He did not know whether they would ever get a tank at Gilmorehill, but he hoped they would, as the necessity for it was most apparent. And this was true not simply in the direction of ascertaining the resistance of ships. He had been working lately upon the stresses which vessels had to sustain at sea, and the first difficulty he met with was the want of data to enable him to prosecute his inquiry, and which a tank would have given him in a few days, so that until he had the use of a tank he was unable to advance any further in the matter.

Professor BARR being called upon by the President, said that the subject of the paper was one in which he took a very deep interest. It was one, however, in which—as in every matter connected with engineering—experience was the best guide; and in his present circumstances, when just renewing his acquaintance with Glasgow students and Glasgow engineers, he must postpone any expression of his opinions upon the special requirements of Glasgow in regard to the teaching of engineering science; especially as it was a matter which concerned not the University courses alone, but also the admirable classes held in other local institutions, of which he had, at present, only a somewhat distant and superficial knowledge. If he took experience as his guide, perhaps the best thing he could do would be to state the results of his experience during the five years he had conducted the work of the Chair of Civil and Mechanical Engineering in the Yorkshire College, Leeds. When he went to

Leeds he found that there was a movement among the engineers of the town to establish an engineering laboratory in the Yorkshire College at a cost of £3000. When the matter was fully gone into with the Engineering Committee, it was soon seen that to erect and equip a departmental building worthy of the importance of the engineering interests of the district would cost about £10,000 instead of £3000. The engineers not only sanctioned the increase, but insisted upon the equipment being thorough and complete, because they were convinced that it was necessary for the best interests of the local engineering trades. They felt, further, that little support would be given to any scheme which was not thoroughly satisfactory and complete. The laboratory and other necessary class-rooms were completed three years ago, and the whole of the £10,000 expended had been subscribed by the engineers connected with Leeds and its neighbourhood. In all the work which was done in the Yorkshire College, connected with Victoria University, one object was kept clearly in view—and he thought that it was the most important thing which could be kept in view in connection with the part of engineers' training to be got in the University—that the aim of a University course should be "education" rather than "instruction." He was glad to see that Mr Dyer had expressed the same view on page 30 and elsewhere in his paper. There is a great difference between "education" and "instruction," as Sir John Lubbock points out when he says*—"Herein lies the importance of education. I say education rather than instruction, because it is far more important to cultivate the mind than to store the memory. Studies are a means and not an end." It does not follow that the student must not be taught anything that will be of direct use to him. Quite the reverse. But keeping in view the main object of the University course—its educational value, though it be educational in special reference to the future work of the student—the course must not be too much specialised or it will fail in its principal aim. No attempt should be made to teach in detail every separate branch of

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* "The Pleasures of Life," p. 181.

engineering practice even were it possible to do so, but to teach what underlies all the branches. That cannot be learned in the ordinary course of apprenticeship or pupilship. In the workshop, or in the office and the field, one can learn the details of one or more branches of engineering practice, but the principles which underlie all branches alike and in common cannot be there mastered. Engineers are sometimes a little apt to forget that, whether they know those principles and laws or not, they must conform to them or suffer the consequences of fighting against the inevitable, for "Nature never overlooks mistakes or makes the smallest allowance for ignorance." Surely, then, it is better for the engineer to know, and to know thoroughly, those laws which will and must govern the results of his labours. The object of a University course is to give the engineer a knowledge of those laws, and the manner in which they may be applied in his daily work. With regard to the subject of degrees in engineering, he might say that he had always strongly objected to the granting of such degrees as "Bachelor of Engineering" or "Master of Engineering." In Glasgow University they had not a degree which carried with it any implication that the holder was entitled to be called a *Master* of Engineering or even a Bachelor of Engineering. They had a Bachelor of Science in the special department of engineering science, which was a very different thing. It was not the duty nor the aim of a University to turn out engineers ready made, and no mistake could be greater than to suppose or to suggest that a University should attempt to do so. He was glad to see that Mr Dyer had laid stress upon that view also. On page 34 Mr Dyer remarked, no doubt with good reason, upon the splendid buildings and equipment of the German and Swiss Polytechnic Schools. When, however, we look to the case of University education as distinct from purely technical or workshop instruction, he thought that it should not be lost sight of that it was not the Continent that had led the way and taught this country in that particular matter, but they had been largely taught by us. Engineering laboratories, in which the students undergo a systematic training in experimental work, were commenced by an engineer, whom all would be glad to know was a Scotchman—Professor Kennedy—who last session resigned his connection with University College, London. Professor Kennedy set the example, which has since been followed by many institutions. And not only had this country led the way in this matter, but he believed that in many particulars we had kept the lead. He had, on a recent occasion, shown two Belgian professors over the engineering laboratories which the engineers of Leeds had, with such liberality, provided for his work, and he might be pardoned for quoting in this connection their impressions of the institution. Professor Dwelshauvers-Dery, of Liège, writes—"On returning from my journey in Angleterre, I have, unfortunately without success, asked our Government to organise our institution upon the model of yours." And Professor Boulvin, of Gand, writes—"I daresay that your School of Engineering, with its laboratory, is the most complete and best arranged that I have seen among all the establishments that I have visited; nowhere in France, in Italy, at Zürich, in the United States, or in England, does there exist, to my knowledge, any establishment so well equipped; also, I have adopted much from you in the one that I have projected for Gand. . . . . If the Belgian Government are willing to grant me the necessary funds, as I hope they will, it is, without any doubt, your establishment in Leeds that will serve as model." The magnificent Walker Engineering Laboratories just erected at University College, Liverpool, at a cost of £20,000, are no doubt, in some respects, more complete again than the Yorkshire College Laboratory. I think, therefore, that we may fairly claim that, as a nation, we are not behind in this matter. With regard to the work to be done in an engineering laboratory, he might say that there were three principal subjects that should be dealt with. These were questions dealing with the strength and elasticity of materials and of elementary structural parts, such as beams and columns, questions relating to the economy of steam and gas engines, and questions in hydraulics. When Naval Architecture is included there was, of course, also questions of the resistance of ships. Now, it is impossible for one to get a grasp of these and other such subjects during an apprenticeship in the workshop or on civil engineering works. For instance, there was not one apprentice in a hundred who had the opportunity of seeing the properties of materials thoroughly demonstrated. And, again, opportunities could not be had in the works for experimenting on steam engine economy or even to learn the methods of ascertaining with anything like scientific accuracy the performance of steam engines, by indicator or brake tests, and complete measurements of the quantities of heat disposed of in all the various losses. So, again, in the subject of hydraulics, men in practise had constantly to make use of formulæ deduced from experiments; and it ought ever to be remembered that if they put a formula before a man who knew nothing of the assumptions involved in its construction, nor of the nature of the experiments upon which it is founded, he was far more likely to abuse it than to use it properly, and therefore it was of importance that the methods by which formulæ are deduced should be demonstrated to the students and not merely dictated to them. That could not be done in many cases without a laboratory. The training in an engineering class should, however, neither go over a great variety of subjects and give results merely, nor go into all the details of practice, which the student could learn in the works, and could only there learn well; but should aim at giving the student a firm grasp of the methods of Engineering Science and of the principles with which all his future work must necessarily conform if it is to be successful in practice. He was sure that all the members would thank Mr Dyer for having brought so important a subject so fully before them.

Mr Arthur W. Thomson said that Mr Dyer had referred in his paper to a former paper which he had read before the Institution, on the "Education of Engineers," remarking that although his proposals had "received a considerable amount of support from the members, there seemed to be a very prevalent feeling that, however good they might be, they were not likely to be carried out for a considerable period." He believed that if Mr Dyer had not energetically pushed the matter, his proposals would have been acted upon, as yet, only to a limited extent. He believed that to Mr Dyer, perhaps more than to any other gentleman, they were indebted for the present efficient state of the Glasgow and West of Scotland Technical College; and he hoped that the Governors of that College would be assisted by the liberality of the citizens of Glasgow to carry on their good work. On page 22 of the paper there occurred a passage which Professor Jenkins had referred to, where Mr Dyer recommended that the history of a subject should be treated in the class-room. He did not agree with Mr Dyer in that part of his paper. He had had some experience in this matter, and it had been his practice to ask his students to read the history for themselves. He held that it would be a waste of time on the part of a professor or teacher to occupy much of the time of the class-room with such matters. He remembered very well when in the Imperial College of Engineering, Japan, with Mr Dyer, that it was their constant practice to ask the students to read the history for themselves. There was a well-stocked library in connection with the College, so that they had no difficulty in finding the works necessary for this purpose. As a matter of fact, he believed the history could be better learned at home than in the class-room. On page 32 Mr Dyer speaks about final examinations for certificates of proficiency. He desired to state the manner in which these were carried out in the Engineering College, Japan. The students spent the first four years of their course in the College; and the following two years on works suitable for their future careers, *e.g.*, Civil Engineers went on to Railway Construction, Dock Construction, &c.; and at the end of the sixth year the students came back for their final examination. This was divided into two parts; in one part of the examination the student was required to work without books—that is to say, he had to depend upon his memory; in the other part, the student was allowed to use certain prescribed books; and in this way more important problems could be set, problems such as the students might be expected to deal with in actual practice. It was found that examinations with the aid of books were very successful, and that they were held in high esteem by the students themselves.

Mr **David Bell**, on being called upon by the President, said Mr Dyer's paper was very interesting, and well fitted to be of service in pointing out the essential requirements for the education of engineers. He would not attempt to go into the details of the paper, but he thought that the subject was one well worthy of being brought before their Institution, and he trusted the study of the paper would be productive of real and lasting good.

The **President** proposed a very hearty vote of thanks for the painstaking way in which Mr Dyer had treated the subject, especially for his advocacy of laboratories for engineers, and also for the necessity for a tank for the teaching of Naval Architecture. Undoubtedly it would be of great advantage to the whole district of the Clyde if there was a tank to facilitate the study of Naval Architecture, and the possession of a well filled laboratory would likewise be an advantage.

The vote was carried unanimously, and the discussion was adjourned till next general meeting, to give further opportunity for remarks, and reply by the author.

The discussion of this paper was resumed on the 17th December, 1889.

Mr **C. C. Lindsay** said that Mr Dyer in his paper spoke of the change that had taken place in the curricula when the different educational institutions in Glasgow had amalgamated and formed the Glasgow and West of Scotland Technical College, as the result of his proposals to a great extent. He (Mr Lindsay) regretted that this change had taken place. His sympathies were with the scheme under which diplomas were granted by the College of Science and Art, for he was a director of and secretary to that College when the scheme was initiated. His chief reason for objecting to the change of curricula was that it had become so difficult to meet the requirements that the success of the students and the College was greatly and injuriously affected. Past Calendars showed that fifteen diplomas were granted by the College of Science and Art, that there were a large number of candidates, and that the success of the students in gaining Whitworth scholarships and exhibitions was quite phenomenal. Since the amalgamation, he was sorry to say, no diplomas had been granted, and there had been but one or two entrances. No doubt each curriculum was good, but the standard was too high for students attending the Technical College. He was of opinion that one thing that had hindered the success of the Technical College was that the evening class students were practically excluded from the diploma scheme, so that diplomas could only be gained by students attending the day classes. Now, formerly all the classes participated in this scheme. Of course, it might be said that the former standard was too low. He did not think that would hold very well, and his reason for so thinking was that all the students that had taken the diplomas of the College of Science and Art occupied responsible appointments at the present time. He maintained that the evening class students, and even the day class students, were not able for the curricula which Mr Dyer had prescribed. The standard was so high that it was almost impossible for a student, in the few years at his disposal, to gain the diploma of the College.

Mr JAMES MURRAY said that Mr Dyer's paper was, in his opinion, one of the best papers that had come before the Institution since he joined in 1886. There were a few very pithy parts in the paper. One of these, on p. 23, he would like to draw attention to :—"Not only is Engineering entitled to a place among liberal branches of education on account of the training which might be given with it, but also because of the knowledge of pure science required of those who intend to practise it. All engineers should have a fair knowledge of mathematics and physics. Not necessarily such a knowledge as would secure them a high position in such things, or phantoms, as mathematical triposes, or other university honour lists, but a real knowledge which would not only train their intellectual powers, but also fit them to solve the problems which they met in everyday life. They should also have a fair knowledge of French or German, or if possible of both." This latter point reminded him very much of an incident related in a lecture he had heard last winter by a gentleman who had travelled through Germany, and who related how, in seeking his way through a small town to an old institution, he had accosted a little native girl and asked her where it was situated, and who, to his astonishment, answered him in good English, although neither she nor her parents had ever been out of Germany, she having stated to the gentleman that she was taught English in school every day. He thought that although they prided themselves in this country in being ahead in education, the incident he had mentioned showed the necessity for engineers having more than one language, more especially as now-a-days so many of them were in the habit of going to sea. He had heard the remarks made at last meeting by Professors Jenkins and Barr, and was satisfied that all the gentlemen who heard, or had since read the printed report, would agree with those gentlemen as to the necessity of getting without delay two very important things in Glasgow—the centre of the engineering profession—and these were, engineering laboratories and an experimental tank. Now, he did not know when those matters might again be brought so ably before them, as Mr Dyer had done; and, therefore, he put the question—Who are the proper parties to start the foundation of those two essentials for the proper education of engineers? He had no hesitation in answering that it was this Institution which should undertake the duty. The Institution included all the men of light and leading in engineering and shipbuilding circles in the Clyde district, and therefore he thought it would be a great pity if they did not take this matter up, seeing that it was admitted, by those best able to judge, that the very branches of trade—engineering and shipbuilding—which were the staple trades of the Clyde district, and which had contributed, and were contributing, so much to the prosperity and wealth of the nation, and to the civilisation of mankind, were really handicapped and hindered for want of what, one might say, were the proper and necessary tools for the grinding in of a thoroughly scientific education.

Mr **Edward J. Duff** said, as an old technical student, Whitworth scholar, and winner of the College of Science and Arts diploma, he wished to make a few remarks on Mr Dyer's paper. He thought that, however good an object the author might have in view, the scheme was somewhat premature. Mr Dyer claimed a principal part in the organisation of the Technical College. That organisation had now been practically tested, and had been found wanting. In the first place, the age of boys entering the College had been raised to sixteen years of age, and a difficult entrance examination imposed. Raising the age had been followed by reducing the day classes—a very undesirable object, but one which might have been anticipated, as the two years preceding sixteen were especially the two years when most boys wanted a special training to suit the trade in which they were going to serve a practical apprenticeship. The courses subscribed for the diploma were too ambitious. Supposing a boy to have passed his entrance and first year's examinations for the course in Civil Engineering, the second year's course was an impossible one. A lad would want an average of six or seven hours in class each day, and that allowing three hours for meals, and three hours for travelling from Anderson's College to College of Science and Arts, and from there to the University and back; he would want at least four hours to do his exercises at home; thus making sixteen or seventeen hours each day. After that he must read up his literature, history, or political economy in order to pass the examination. As might have been expected, this had proved a totally impracticable scheme, as proved by the fact that only one out of the 153 day students last year had attempted it. Now it is impossible for evening students to obtain a diploma. He failed to see the difference between knowledge obtained in the evening and knowledge obtained during the day—a fact discouraging to evening students. Mr Dyer's scheme did not encourage Whitworth scholarships. Two years ago six scholarships were obtained, value £850. Last year only three exhibitions were obtained, and no scholarship. He was sorry Mr Dyer did not encourage Whitworth scholarships, more so as he himself obtained one; but he was pleased to see a

Whitworth scholar who had done so well, and who took such a prominent interest in technical education. He regretted that the knowledge obtained at the Technical College was not recognised by the University. He could have easily passed the examinations for B.Sc., but objected to spend other three years or so at the University in order to be eligible to take that degree.

Professor **Barr** said, with reference to the last speaker's regret that the Technical College was not recognised by the University, that arrangements had now been made whereby the students of that College would be able to take the B.Sc. degree of Glasgow University with only one year's attendance at the University.

Mr **Dyer**, in replying to the discussion said, the chief objects he had in view in preparing the paper were (1) to show the arrangements which he considered necessary for a Faculty of Engineering, in order that engineers might have the same educational opportunities as the members of the older professions; (2) to point out the necessity for a certain amount of specialisation of study; (3) to emphasise the importance of all professional education being liberal in its tendency, and not simply scientific and technical. He would have preferred if those who had taken part in the discussion had confined themselves to those main points, instead of entering into details, which, however important to the special institution mentioned, did not affect the chief objects of the paper, which were intended to indicate what ought to be, and not to dwell on what is. The divisions of study in the Technical College were only mentioned for the purpose of showing that they covered fairly well the field drawn out by the Council of the Institution of Civil Engineers, and not with the intention of bringing the affairs of that institution under discussion. As, however, some observations had been made on these affairs, it was necessary that he should notice them shortly. In the first place, it would be well to direct attention to the definition of a University given in the paper, that is, "an organisation which includes all the higher education of a given district." The historical meaning of the term is simply an association of men for any purpose whatever. When they were associated for the purpose of learning they were a learned University. It ought to be remembered, then, that a University consists of persons, and stone and lime are merely accessories which, however important, should always be subsidiary. If it has the right men, these accessories will soon come. Professor Jenkins seemed to overlook the fact that the proposals of the paper were for the purpose of co-ordinating all the instruction in the district, and not for making any one institution self-contained. The twelve courses of study for the evening classes, mentioned at p. 16, are now completely carried out between the Technical College and the various other institutions affiliated or associated with it, while the eight divisions for the day classes are complete, with the exception of the two mentioned. Professor Jenkins' calculation about money therefore requires to be modified. He said that he believed that the day classes were carried on to a great extent with the assistance of the money got from the fees of the evening classes, and the pecuniary aid which the evening classes received from the Science and Art Department. Between £2000 and £3000 a year was received from that Department, but in addition the College had fully £5000 a year from endowments, and if it had proper buildings and appliances, a comparatively small extra endowment would be sufficient to carry out the greater part of what had been proposed in the paper. The statement that there were only 153 students in the College is apt to give an altogether wrong impression of the amount of work which is being done. It has in addition 2000 evening students, and in Allan Glen's School there are about 600 scholars, and in the upper classes of that school better work is being done than in some institutions which are called colleges. It is a simple matter to increase numbers at College classes if no restriction is made as regards qualifications. The comparatively simple entrance examination which is demanded keeps out school boys who are unfit for the freedom of a college, but it does not exclude any who are really worthy of entrance. The question of affiliation of the Technical College with the University is also one which should not have been introduced into the discussion beyond indicating that some connection was necessary. It will be sufficient to remark that since last meeting of the Institution the Senate of Glasgow University has agreed to recognise the possession of a diploma of the Technical College, as qualifying for two out of the three years' attendance at the University required for the degree of B.Sc. This *is* affiliation in the sense in which the term has hitherto been employed in any British College. In the case of the Technical College and Glasgow University it ought in his (Mr Dyer's) opinion to mean something more; but this is a point for discussion before the University Commissioners, and not before this Institution, and therefore need not be touched upon further. Professor Barr had given some interesting details of his work at Leeds, and it was to be hoped that he would be able to stir up the engineers of Glasgow to follow the example of the engineers in other parts of the country. He (Mr Dyer) was quite aware that in the matter of engineering laboratories this country had gone ahead of Continental countries, and he alluded to their general arrangements, not to their laboratory accommodation, when he spoke about them. In the paper which he read two years ago he selected an American College as being the most complete he knew (at that time) as regards engineering laboratories. He wished Professor Kennedy to receive all praise for the work he had done in connection with such laboratories in this country, but as a matter of history it might be stated that when he (Mr Dyer) went to Japan in 1873 one of the first buildings completed in connection with the Imperial College of Engineering was the engineering laboratory, and which was supplied with almost all the appliances which were required for teaching and experimental purposes. The very serviceable testing machine was designed and made in the works at Tokio under his superintendence. The remarks by Messrs Lindsay and Duff would have been more in place at a meeting of the Governors of the Technical College than at this Institution, but as they will appear in the Transactions they may be noticed shortly. In the first place, it may be explained that there are now four grades of study and examination in connection with the Technical

College and the University. In the evening classes the courses for the junior certificate of the College are well within the reach of all ordinary apprentices, while those for the senior certificate may be taken during apprenticeship by the students who have had better educational advantages or have greater abilities. The diploma of the College may be taken by attending three years at the day classes, *or* by those who hold the senior certificate above mentioned, and thereafter attend one year at the day classes. This arrangement of study and work was strongly recommended by Sir B. Browne at the last meeting of the British Association. Lastly, it has now been arranged that those who hold the diploma may after one session at the University proceed to the degree of B.Sc. The wants, capacities, and opportunities of all classes of students are thus met. The diploma of the College of Science and Art was given to students who had obtained a certain number of Science and Art Department certificates, and without special examination by the College. The name diploma ought never to have been applied to such a document. The junior certificate of the Technical College will be very similar in its nature and standard to the so-called diploma of the College of Science and Art. With regard to the standard for the diploma, it is not so high as that of an American Technical College, or even a Japanese one. The Calendars of the Massachusetts Institute of Technology, of Cornell University, and of the Imperial College of Engineering, Japan, may be consulted in the library, and it will be found that the courses in these Institutions are far more complete than has been proposed for the Glasgow Technical College. From the fact that some of the classes are held in the University, one or two of the courses are somewhat difficult in the second year, but this will be modified in the next edition of the calendar. Mr Duff said that he (Mr Dyer) did not encourage Whitworth Scholarships. If Whitworth Scholarships or any other examinations can be taken as the result of the ordinary work of the College, they ought to be encouraged, but both the students and the teachers would be better if none of those things existed, if they become the main object of the teaching. It is a comparatively simple thing for an Institution to obtain a reputation for its students passing examinations, but those who know most of such institutions are very much inclined to estimate their educational value inversely as the successes at such examinations. However, the discussion of this point lies beyond the scope of the present paper. Some objection has been taken to the recommendation that the historical method of teaching a subject should be adopted. He (Mr Dyer) did not mean that all the details of ancient history should be entered into, but only that the more general laws of development might be indicated so that the students might fill up the details by their reading. He had very often expressed his opinion about the uselessness of a great deal of lecturing on engineering subjects, and in the paper he emphasised this particularly. But as yet there were few or no books which treated the subject in this manner, he thought it well to point out the necessity for the professor laying out the main lines and guiding the reading of his students. From a scientific point of view, the historical method is most useful, but it was in order that engineering might be made a branch of liberal education that the recommendation was chiefly made, and with special reference to the economic and social bearings of the different departments of engineering. The greatest difficulties of the present day, and the greatest dangers of the future will arise, not so much from want of technical skill, as from the want of a clear realisation on the part of employers and employed of the conditions of economic and social welfare, and men whose heads have been simply crammed with facts and figures will not be the men who will aid in the solution of these difficulties. As was stated in the paper, "the welfare of the producers, be they employers or employed, and not simply the cheapness of the products, the organisation of capital and labour, and the arrangement of all disputes by reason, and not by force, are the problems of the future." Hence the necessity for engineers being men of broad and liberal minds, and with a clear grasp not only of scientific principles, and a practical knowledge of work, but also of the more general conditions necessary for human progress.

The PRESIDENT said that the matter recommended by Mr Murray might be considered along with the question of the Rankine Memorial, which might assume such a form.

Mr MURRAY said he would be quite pleased to leave this matter in the hands of the Council, and hoped that they would soon take ways and means for procuring laboratories and an experimental tank worthy of the City of Glasgow.

The discussion was then closed.

The Alexander-Thomson Moment Delineator, and its Application to Maximum Bending Moments due to Moving Loads.

By Professor THOMAS ALEXANDER, M.A.; and
Mr ARTHUR W. THOMSON, B.SC.

(SEE PLATE I.)

Received and Read 19th November, 1889.

I. THIS kinematic arrangement, for showing the bending moments due to the transit of a load over a span, consists of the following principal parts—Board, slot frame, compass bars, transverse bar, distance piece, Fig 1, Plate I; and distorting table, Fig 2, Plate I.

BOARD.

For the working model which the authors have constructed, the board is about 3′ 6″ × 2′ 6″ of well seasoned wood, and fitted with bars on back. On the face of the board a girder and supports, certain bending moment curves, and scales are drawn.

SLOT FRAME.

This frame consists of three slotted vertical bars, W_1, G, W_2, fixed at top and bottom to cross pieces. The middle vertical bar can be fixed in two positions—one midway between the two outer bars; the other as in Fig. 1, Plate I., nearer the left. The frame can move easily across the face of the board, this motion being facilitated by the use of friction rollers.

COMPASS BARS.

These bars LB, LC are hinged at L; and, by means of slots, pass over bolts B and C. Another bolt forms the hinge L, and slides in the slot of the middle bar of the slot frame.

TRANSVERSE BAR.

This bar HK is also slotted; and, near its centre, carries a handle for moving the whole arrangement into any desired position. The bar can rotate on a bolt, N, which passes through the slot in the middle vertical bar. The two bolts, H and K, pass through the slots of the compass bars, of the two outer vertical bars, and of the transverse bar.

DISTANCE PIECE.

The distance between the two points, L and N, is kept constant by means of the distance piece, LN, which slides in the middle vertical slot, and whose ends pass over the bolts, L and N.

BOLTS.

All the bolts used are of iron $\frac{1}{8}$-inch diameter, with flat heads, pins, and wooden washers. The heads of B and C are firmly secured to the back of the board; the sides of the heads of H and K are turned upwards so as to embrace the compass bars, and prevent their slots from gaping when the model is moved from one position to another.

DISTORTING TABLE.

This Table (see Fig. 2, Plate I.) is composed of about 90 wooden laths $9'' \times \frac{1}{2}'' \times \frac{1}{8}''$ thick. The middle and two outer laths are heavier, as they have to guide the others and keep them in position; their ends, H,K,L,N, are strengthened with pieces of sheet brass, and can slip over the corresponding bolts of the slot frame arranged so that the inner vertical bar is midway between the other two. On the under side of laths, H and K, guiding pieces are fastened, which slide in the slots of the slot frame. Wires hinged at m, m', n, n', pass through small holes in the middle lath, LN, and remain parallel to the centre line of slot HNK while the table is distorted ; on these wires the intermediate laths are threaded. On the face of the table when rectangular, a parabola, HAK, and two tangents, HL, KL are drawn.

LUBRICANT.

The rubbing surfaces should be well greased with vaseline or some other lubricant.

MATHEMATICAL INVESTIGATION OF THE MOMENT DELINEATOR AND THE DISTORTING TABLE.

II. *Rigidity of Model.*—When the slot frame is clamped in any position, Fig. 1, Plate I., the model is rigid. For suppose the compass bars lifted off the bolts, B and C, and the four points H,L,N,K, moved upwards in the slots any short distance, and so as to keep the bars, BL, LC, parallel to their original directions ; that the points, L and N, are fixed in their new positions ; and that the compass bars are again put over the bolts, B and C ; then the two points, H and K, must move downwards in the slots, and the line, HNK, will be no longer straight ; but in the model, HNK, is a rigid bar, and therefore for any given position of the slot frame, there can be only one triangle, HLK, and it can have only one position. In other words, for any position of the slot frame, the model is rigid.

III. *As the slot frame moves across the face of the board, the points* H,L,K, *and* N, *describe portions of the same parabola in different positions.* Figs. 1 and 3, Plate I.

In Fig. 3, Plate I., one position of the bars of the delineator is shown. Let O, the origin for rectangular co-ordinates, be at the centre of the base, BC ; let $2c$ denote the length of this base ; let the co-ordinates of the points, L, H, and K, be denoted by $\bar{x}$, $\bar{y}$; x_1, y_1 ; and x_2, y_2 ; let the length of NL, the distance piece, be denoted by d ; the distance between the two outer vertical bars of the slot frame by $2\,k$, and the distances from each to the middle bar by $2\,h_1$ and $2\,h_2$ respectively ; that is, $2\,k = 2\,h_1 + 2\,h_2$.

The ordinate of N, TN $= \frac{h_1 y_2 + h_2 y_1}{h_1 + h_2}$ is always shorter than $\bar{y}$ by the constant d; therefore

$$\bar{y} - d = \frac{h_1 y_2 + h_2 y_1}{h_1 + h_2}. \qquad (1)$$

Also

$$x_1 - \bar{x} = 2\,h_1, \qquad (2)$$

and

$$\bar{x} - x_2 = 2\,h_2, \qquad (3)$$

From similar triangles,

$$\frac{y_1}{c - x_1} = \frac{\bar{y}}{c - \bar{x}}; \qquad (4)$$

and

$$\frac{y_2}{c + x_2} = \frac{\bar{y}}{c + \bar{x}}; \qquad (5)$$

hence

$$y_1 = \frac{\bar{y}}{c - \bar{x}}\,(c - \bar{x} - 2\,h_1), \qquad (6)$$

and

$$y_2 = \frac{\bar{y}}{c + \bar{x}}\,(c + \bar{x} - 2\,h_2). \qquad (7)$$

Substituting into equation (1),

$$k\,(\bar{y} - d) = \frac{h_1 \bar{y}}{c + \bar{x}}\,(c + \bar{x} - 2\,h_2) + \frac{h_2 \bar{y}}{c - \bar{x}}\,(c - \bar{x} - 2\,h_1),$$

$$k.d = 2\,h_1 h_2\,\bar{y}\,\frac{2\,c}{c^2 - \bar{x}^2},$$

$$\bar{y} = \frac{k.d}{2\,h_1 h_2}\,\frac{1}{2\,c}\,(c^2 - \bar{x}^2). \qquad (8)$$

Therefore the path of L is a parabola, with axis vertical, and vertex over the centre of the base, B C; and whose principal equation is—

$$\begin{aligned} \mathrm{Y} &= \frac{k.d}{2\,h_1 h_2}\,\frac{1}{2\,c}\,\mathrm{X}^2 \\ &= \lambda\,\mathrm{X}^2, \end{aligned} \qquad (9)$$

where λ is the modulus of the parabola, and represents the constant $\frac{k.d}{4\,h_1 h_2\,c}$. From equations (4), (8), and (2),

$$\begin{aligned} y_1 &= \frac{\bar{y}}{c - \bar{x}}\,(c - x_1) = \lambda\,(c + \bar{x})\,(c - x_1) \\ &= \lambda\,(c + x_1 - 2\,h_1)\,(c - x_1), \end{aligned} \qquad (10)$$

is the equation to the path of K; it is the *same* parabola as for the path of L, since the principal equations are identical; the axis is vertical, and at a certain distance to the left of the centre of the base, B C. In order to find this distance, find that value of x_1, which makes the product $(c + x_1 - 2h_1)\ (c - x_1)$ greatest; since the sum of the factors is constant, this occurs when they are equal; thus,

$$c + x_1 - 2\,h_1 = c - x_1,$$

or

$$x_1 = h_1 \tag{11}$$

gives the abscissa of the vertex A_1 measured from O towards the left.

Similarly the path of K is given by the equation

$$\begin{aligned} y_2 &= \lambda\ (c - \bar{x})\ (c + x_2) \\ &= \lambda\ (c - x_2 - 2\,h_2)\ (c + x_2), \end{aligned} \tag{12}$$

it is therefore the same parabola as before; and the abscissa of its vertex A_2, to right of centre of base, is

$$x_2 = h_2. \tag{13}$$

The path of N is evidently the same as L, only lower in position by the constant quantity d, the length of the distance piece.

Q. E. D.

IV. *The paths of the moving points* H *and* K *intersect at* D; *to find the co-ordinates of this point.* Figs. 1 and 4, Plate I.

Let x', y' be the co-ordinates of the point D. When the delineator is moved into position such that H is at D, then, equation (10)—

$$y' = \lambda\ (c + x' - 2\,h_1)\ (c - x');$$

Similarly when K is at D, then, equation (12)—

$$y' = \lambda\ (c - x' - 2\,h_2)\ (c + x');$$

equating these values of y' gives

$$x' = \frac{c}{k}\ (h_1 - h_2), \tag{14}$$

the distance from origin to the point F, positive to left. Fig. 1, Plate I.

In either of the above values for y', substitute this value for x' and

$$y' = \frac{cd}{k} - d, \tag{15}$$

the height of the point D above the base, BC.

V. *For every position of the delineator, the centre line of the transverse bar, produced if necessary, passes through the point* D. Figs. 1 and 4, Plate I.

Let x, y be the co-ordinates of any point in the line HK; the equation to the line HK is

$$y = y_1 + (y_2 - y_1)\frac{x_1 - x}{2\,k}. \tag{16}$$

From equations (10) and (12)

$$y = \lambda\left[\{c\,(c - 2\,h_1) + 2\,h_1x_1 - x_1^2\} + \{c\,(c - 2\,h_2) - 2\,h_2x_2 - x_2^2 - c\,(c - 2\,h_1) - 2h_1x_1 + x_1^2\}\,\frac{x_1 - x}{2\,k}\right];$$

substitute $x_1 - 2\,k$ for x_2, and

$$y = \lambda\,\{c\,(c - 2\,h_1) - x\,(x_1 - 2\,h_1) + \frac{c}{k}(h_1 - h_2)\,(x_1 - x)\}; \tag{17}$$

into this equation substitute for x the value given in equation (14),

$$y' = \lambda\,\{c\,(c - 2\,h_1) + \frac{2\,h_1c}{k}(h_1 - h_2) - \frac{c^2}{k^2}(h_1 - h_2)^2\},$$

and writing for λ its value, this becomes

$$y' = \frac{cd}{k} - d,$$

the same result as given in equation (15); this shows that the line of transverse bar, HK, always passes through the point D.

Q. E. D.

Taking advantage of the fact that the direction of the transverse bar always passes through the point D, the authors have devised a *modified form of the moment delineator.* In this modified form the distance piece, LN, is no longer necessary and may be removed; a pin is fixed into the board at the point D, and projects slightly from its face; and the transverse bar is placed next the board with its slot passing over this pin.

In the same way a delineator for a load on three wheels would consist of a slot frame of three bars, one at each wheel; compass bars; and two transverse bars sliding on pins fixed at $D_{1,2}$ and $D_{2,3}$ the intersection points of parabola No. 2 with Nos. 1 and 3. Such an arrangement would be complicated by the friction of its parts.

DISTORTING TABLE.

VI. When the table (see Figs. 5 and 6, Plate I.) is rectangular (Fig. 5), there is painted on it an isosceles triangle, HLK, standing on the base, HK $= 2k$, and of height, LN $= d$, the length of the distance piece. The height, LN, is bisected at A, and the parabolic right segment, HAK, is painted on; HL and KL are tangents to this parabola. Suppose now that the table is distorted as shown in Fig. 6; HK is a sloping base; all vertical heights measured from this sloping base to the curve, HAK, are the same as before; and it is a well-known fact that HAVK is the *same* parabola as in Fig. 5, with axis vertical, and vertex in a new position; and that HL, KL are still tangents to the curve. Let V be the vertex of the curve in this new position, and draw FW a tangent to the curve and passing through V.

Let the slot frame be arranged with the inner vertical bar *midway* between the other two, and let it be clamped in any position, as in Fig. 4. Apply the distorting table to the points HKLN, and the agreement of these points of Figs. 4 and 6 will be at once apparent. From a well-known property of the parabola, VM = MW, and VZ = ZF; thus ZM $= \frac{1}{2}$ FW = EW $= k$, ZE = VM, and ME = VZ. From similar triangles (Fig. 4),

$$\mathrm{ME} : \mathrm{ZE} :: \mathrm{CT} : \mathrm{BT} :: c + \bar{x} : c - \bar{x},$$

therefore

$$\frac{\mathrm{ME} - \mathrm{ZE}}{\mathrm{ME} + \mathrm{ZE}} = \frac{\mathrm{ME} - \mathrm{VM}}{\mathrm{ZM}} = \frac{\mathrm{TS}}{k} = \frac{\bar{x}}{c},$$

and if v represent the abscissa of the vertex V, positive to left of origin, then for any position of the slot frame

$$v = \bar{x}\left(1 - \frac{k}{c}\right). \tag{18}$$

The greatest ordinate to the figure BHAVKC, Fig. 4, is SV; its amount is found thus: The equation to the line HK is given in equation (17); putting $x = \bar{x}\left(1 - \frac{k}{c}\right)$, $\lambda = \frac{d}{kc}$, and $h_1 = h_2$, gives

$$y' = \frac{d}{kc}\left\{c^2 - ck - \bar{x}^2 + \frac{\bar{x}^2 k}{c}\right\};$$

taking N as origin, and HK as axis for abscissæ, the equation to the parabola HAK (Fig. 5), is

$$y = \frac{d}{2} - \frac{x^2}{k^2}\frac{d}{2}, \qquad (19)$$

and putting $\frac{\bar{x}k}{c}$, for x, the height of V above sloping base HK is

$$y'' = \frac{d}{2} - \frac{\bar{x}^2}{c^2}\frac{d}{2};$$

adding y' and y'', the height of V above base BC is

$$\mathrm{SV} = \frac{d}{2\,ck}\left\{\left(2 - \frac{k}{c}\right)\,(c^2 - \bar{x}^2)\right\} \qquad (20)$$

This maximum ordinate occurs at the point S of the base BC; but it is to be observed that for some other position of the slot frame, the ordinate at S may exceed SV.

VII. *To find* I, *the point of the base*, BC, *at which* IU, *the ordinate to the figure*, BHAVKC, *for a given position of the delineator with distorting table attached, is greater than the ordinate at* I *for any other position of the delineator.* (Fig. 4.)

Let a represent the horizontal distance from the middle bar of the slot frame to the point I; let J be the point in HK intersected by IU, and γ the angle which HK makes with the horizontal.

Consider the effect on the ordinate IU of moving the delineator a small distance Δx towards the left:—1st. The bar, HK, rotates about D in the left-handed direction, and cuts the ordinate, IU, at a point a little lower than J. 2nd. The ordinate, JU, of the parabolic segment is replaced by another, J′U′ (Fig. 5), a little longer than JU, since it is nearer the middle of the segment. For the first reason the ordinate at I is diminished, and for the second it is increased; while for some particular position of I as defined by a, these two effects will neutralise each other, and for a small motion of the delineator, the length of the ordinate, IU, will remain unchanged.

At such a point, I, in the base, BC, the ordinate, IU, is greater when the delineator is in the given position, than when it is in any other.

For the slot frame as now arranged, $2\,h_1 = 2\,h_2 = k$, and $\lambda = \frac{d}{kc}$;

the point D, equations (14) and (15), is above the centre of base, BC, and at a height

$$y' = \frac{cd}{k} - d;$$

The height of H, equation (10), is

$$y_1 = \frac{d}{kc}(c + \bar{x})\ (c - \bar{x} - k);$$

and

$$\tan\gamma = \frac{y' - y_1}{\bar{x} + k} = \bar{x}\,\frac{d}{kc}. \tag{21}$$

When the slot frame moves Δx towards the left, let γ become γ'; then

$$\tan\gamma' = (\bar{x} + \Delta x)\,\frac{d}{kc};$$

hence the transverse bar cuts the ordinate, IU, at a distance below J equal to

$$(\bar{x} + a)\,(\tan\gamma' - \tan\gamma) = (\bar{x} + a)\,\frac{d}{kc}\,\Delta x.$$

The difference between the ordinates JU and J'U' (Figs. 4 and 5), measuring from the base, HK, is the same as the difference of the depths of U and U' below the tangent at A (Fig. 5); and since the principal equation to the parabola, HAK, is

$$Y = \frac{d}{2k^2}\,X^2,$$

$$\begin{aligned} J'U' - JU &= \frac{d}{2\,k^2}\,a^2 - \frac{d}{2\,k^2}\,(a - \Delta x)^2 \\ &= \frac{d}{k^2}\,a\,.\,\Delta x, \end{aligned}$$

leaving out the term containing Δx^2 since Δx is small. Equating these two results gives

$$\frac{d}{k^2}\,a.\Delta x = (\bar{x} + a)\,\frac{d}{kc}\,\Delta x;$$

$$\frac{a}{k} = \frac{\bar{x} + a}{c}$$

$$\frac{k - a}{k + a} = \frac{c - \bar{x} - a}{c + \bar{x} + a} \tag{22}$$

$$\frac{W_1I'}{I'W_2} = \frac{BI}{IC} \tag{22a}$$

a proportion which gives the following

RULE.—To find the position of the slot frame which gives for I any point of base, BC, the greatest ordinate to the figure BHAVKC while the slot frame with distorting table attached moves into every possible position:—Divide the distance between the vertical bars, W_1W_2, at the point I′ in the same proportion that I divides the base, BC; and move the slot frame until the point I′ is directly over I.

VIII. *The locus of the tops of these maximum ordinates,* IU, *is a parabola,* BE A_3 C. (Fig. 4, Plate I.)

In equation (17) the equation to the line HK has been given; putting $h_1 = h_2$, $\lambda = \frac{d}{kc}$, and $\bar{x} = x - a$;

$$IJ = \frac{d}{kc}\{c^2 - ck - x^2 + ax\};$$

the equation to the parabolic segment, HAK (Fig. 5), gives

$$JU = \frac{d}{2} - \frac{a^2 d}{2\,k^2};$$

adding these quantities, and substituting for a its value $\frac{kx}{c}$,

$$IU = \frac{d}{2\,ck}\left(2 - \frac{k}{c}\right)(c^2 - x^2). \qquad (23)$$

The locus of the points U is therefore a parabola with axis vertical and vertex over centre of base, BC; and the vertex A_3 is lower than A_0 by half the length of the distance piece. Comparing equations (20) and (23) shows that the ordinates, TE and SV, are equal to each other. (Fig. 4.)

APPLICATION OF THE MOMENT DELINEATOR TO BENDING MOMENTS FOR MOVING LOADS.

IX. The base BC of the delineator is now to be taken as representing a span of length $2\,c = l$. The scales chosen for the actual model are: one foot to an inch for horizontals and dimensions, and six foot-tons to an inch for verticals of bending moment curves. The numerical example represented by the model is—span 36 feet; load 18 tons (*a*) rolling on one wheel; (*b*) rolling on two wheels 12 feet apart, the load being borne by the two wheels in equal portions, or in the ratio 2 : 1; or (*c*) uniformly distributed over a length of 12 feet, rolling over span, and resting directly on the girder, and corresponding to the simple method often adopted in practice, of taking the rolling load at so much per foot run, and of a given length. In the case (*b*) $W_1 = W_2 = 9$ tons, or $W_1 = 12$ and $W_2 = 6$ tons; and the vertical bar G, under the centre of gravity, is placed midway between the other two, or (as in Fig 1, Plate I.) divides the distance between them in the ratio 1 : 2. In the case (*c*) a uniform load 1½ tons per foot run, and of length 12 feet rests along its entire length, upon the girder, and moves on the span. In order to make one vertical scale applicable to the bending moment diagrams for the two positions of G, the centre of gravity of load in case (*b*), two distance pieces LN are required. For the model, the lengths are 9 inches for the case $W_1 = W_2 = 9$ tons; and 8 inches for the case $W_1 = 12$, $W_2 = 6$ tons. See equation (26).

X. *Beam under a Rolling Load* (Fig. 1).—Let R be the amount of the load concentrated at a point and rolling over the span; and suppose it over a point at a distance $\bar{x}$ from centre of span. In such circumstances the bending moment at the point is proportional to the product of the two segments into which the given point divides the span; the equation being

$$M_{\bar{x}} = \frac{R}{2c}(c + \bar{x})(c - \bar{x}) = \frac{R}{2c}(c^2 - \bar{x}^2). \qquad (24)$$

Move the slot frame of the delineator so as to have its middle bar, G, over the point $\bar{x}$; the height of the point L has been shown (equation 8) to be proportional to $(c^2 - \bar{x}^2)$; and therefore the path described by L gives, to a scale yet to be determined, the bending moment for each point of span as the load passes over that point. The bending moment diagram for whole span for the load in any given position is the corresponding triangle BLC, as shown by the delineator; and since the bars LB, LC, fall within BA_0C the path of L, the diagram of maximum bending moments for every point of span, while the concentrated load R rolls over the span, is the parabolic right segment BA_0C. When the load is at the centre of span

$$_{\max.}M_0 = \frac{R}{2}c, \qquad (25)$$

from which the vertical scale of the parabola is at once determined.

Graphical Solution (Fig. 1).—Draw a horizontal line, BC, to represent the span; apply a pair of parallel rollers to BC; on the rollers place the base of a right segment of *any* parabola cut in wood or cardboard; move the rollers until the edge of the segment passes through B and C, which it will do simultaneously; and draw a parabolic arc, BA_0C. This is the maximum bending moment diagram; and the vertical scale is obtained by taking the height of A_0 equal to $\frac{Rc}{2}$, which in the above example is 162 foot tons.

Numerical Example.—Given—Span = 36 feet, and load R = 18 tons rolling over span. Find the maximum bending moment at centre of span, and at a point 10 feet to left of centre; and draw a diagram of maximum bending moments. Fig. 1.

The maximum bending moment at centre occurs when the load is at the centre, and it amounts to

$$_{\max.}M_0 = \tfrac{18}{2} \times 18 = 162 \text{ foot tons.}$$

The maximum bending moment at 10 feet to left of centre of span occurs when the load is there; and (equation 24)

$$_{\max.}M_{10} = \frac{18}{2 \times 18}(18^2 - 10^2) = 112 \text{ foot tons.}$$

This result may be scaled off the graphical solution.

XI. *Beam under a Travelling Load System of two weights at a fixed interval apart* (Fig. 1).—Let R be the total load; W_1 and W_2 the weights numbered from left end; G the centre of gravity of the two weights, distant $2\,h_1$ and $2\,h_2$ from W_1 and W_2 respectively; and the distance between W_1 and W_2, $2\,h_1 + 2\,h_2 = 2\,k$. Figs. 1 and 3.

In what follows, the words "Bending Moment" and "Bending Moment Diagram" are, on account of the frequency with which they occur, abbreviated to B.M. and B.M.D.

Let the centre of gravity, G, be over a point distant x from centre of span. If the whole load $R = W_1 + W_2$ were concentrated at G, the triangle BLC would be the B.M.D. If the load be composed of W_1 and W_2 in the given positions, the portions of the B.M.D. outwards from the loads will be the same as before; that is BH, KC unaltered will form parts of the B.M.D. Since the B.M. between the loads varies uniformly, HK the portion of the B.M.D. between the loads is a straight line. The B.M.D. for whole span supporting the loads W_1, W_2 in the given position is therefore the polygon BHKC, Fig. 3; and it is evident that this corresponds to an instantaneous position of the bars of the moment delineator.

The path of H (or K), Fig. 1, gives, to a vertical scale yet to be determined, the B.M. at each point of span as W_1 (or W_2) comes over it; these paths are portions of the same parabola as for the rolling load R of the previous case, and they intersect at a point D. The maximum B.M. at any point of span to the left (or right) of F occurs when W_1 (or W_2) is over the point.

Let the load R, concentrated at G, be placed over $\bar{x}$, any point of span; then, as given by the delineator, the height of L represents the quantity $\frac{R}{2c}(c^2 - \bar{x}^2)$ to some vertical scale; to this same vertical scale, the distance LN represents the quantity $W_1 \, 2 \, h_1$; but $W_1 = \frac{R}{2k} \, 2 \, h_2$, and therefore the value of the length of the distance piece LN is

$$d = R \, \frac{2 \, h_1 h_2}{k}; \qquad (26)$$

this determines the vertical scale for bending moments as represented by the delineator. It may be observed that this quantity is the bending moment at the load, due to a concentrated load R on a span equal to the wheel base $2 \, k$, when $2 \, h_1$ and $2 \, h_2$ are the segments into which the load divides that base.

The distance to the point F (Fig. 1) is derived from equation (14) thus,

$$\frac{x'}{c} = \frac{h_1 - h_2}{h_1 + h_2}; \quad \frac{c - x'}{c + x'} = \frac{2 \, h_2}{2 \, h_1} = \frac{W_1}{W_2};$$

or the point F divides the span into two segments proportional to the loads; that is,

$$\mathrm{BF} : \mathrm{FC} : 2\,c :: \mathrm{W}_1 : \mathrm{W}_2 : \mathrm{R}. \qquad (27)$$

In order to determine for each point of span, the maximum B.M., while the loads W_1, W_2 move into every possible position, the following is a

Graphical Solution (Fig 1).—Draw BC to represent the span; mark the middle point O, and the point F as derived from the proportion (27) just given; mark S_1 and S_2, equations (11) and (13), at distances h_1 to left and h_2 to right of O, and draw vertical lines through these points. Apply a pair of parallel rollers to the span BC; place *any* parabolic right segment with its base on the rollers, and vertex on the line passing through S_1; move the rollers till the edge of the parabola passes through B, and draw BA_1D; with the vertex of the segment on the line through S_2, and its edge passing through C *and* D, which it will do if the construction be accurately made, draw CD. With the same parabolic segment draw BA_0C. The figure BA_1DC thus obtained is the maximum B.M.D. required; and the vertical scale is derived by taking

$$OA_0 = \frac{R}{2}\,c,$$

as in the previous case, equation (25),

Numerical Example (Figs. 1 and 3).—Given—Span 36 feet; two loads, numbered from left, $W_1 = 12$ tons, $W_2 = 6$ tons, at an interval of 12 feet. Find the equations to the maximum B.M. for each point of span, while the load rolls into every possible position; find its maximum value for whole span, and its value at the points 14 feet to left and 12 feet to right of centre of span.

The position of the point F, Fig. 1, is derived from equation (27);

$$BF = \frac{W_1}{R}\,2\,c = 24 \text{ feet; or}$$

$$OF = -\,6 \text{ feet.}$$

Between $x = 18$ and $x = -\,6$, the equation to the maximum B.M.D. is given by equation (10).

$$_{\max.}M_x = \frac{R}{2\,c}\,(c + x - 2\,h_1)\,(c - x)$$

$$= 126 + 2\,x - \tfrac{1}{4}\,x^2.$$

Between $x = -6$ and $x = -18$ it is given by equation (12).

$$_{\text{max}}M_x = 90 - 4x - \tfrac{1}{2}x^2.$$

The maximum B.M. for whole span occurs at the point $x = h_1 = 2$; see equation (11).

$$_{\text{max}}M_2 = 126 + 4 - 2 = 128 \text{ foot tons.}$$

For $x = 14$ and $x = -12$,

$$_{\text{max}}M_{14} = 56 \text{ foot tons.}$$

$$_{\text{max}}M_{-12} = 66 \text{ foot tons.}$$

These results may be scaled off the graphical solution.

XII. *Beam under a Travelling Load System, consisting of a Uniform Load of given length* (Fig. 4).—Let R be the total amount of the load; $2k$ its length; $w = \frac{R}{2k}$ its intensity.

Suppose that the load R is concentrated at the centre of the short beam $\beta\beta$ of span $2k$, HLK (Fig. 5) is a *normal* B.M.D.; if the base HK be now inclined as in Fig. 6, vertical heights remaining exactly as before, HLK the corresponding *distorted* B.M.D. is obtained. If now the load R be spread uniformly over the short beam $\beta\beta$, the two triangles, HLK (Figs. 5 and 6), are respectively replaced by the parabolas, HAK; these two parabolas give, for the uniformly distributed load, two B.M.D.'s one normal (Fig 5), the other distorted (Fig. 6).

If the two ends of the short beam, $\beta\beta$, be supported on the main beam as in Fig. 4, BHKC is the B.M.D for main beam. If now the uniformly distributed load of length $2k$ comes directly on the main girder without the intervention of the short beam, the parabola HAK (Fig. 6) added to the polygon BHKC, gives BHAVKC (Fig. 4) the complete B.M.D. for main girder for the uniform load under consideration.

If the delineator with distorting table attached be brought into position, it is evident that Fig. 4 represents the result. The B.M.D. consists of the parabolic arc HAVK, and the two tangents, HB, KC.

When the uniform load is in any given position on span, the maximum B.M. occurs at S, a point of span under the vertex of the parabola HAK; the distance from O the centre of span to S is given by equation (18),

$$r = x\left(1 - \frac{k}{c}\right),$$

or its position may be fixed by the proportion,

$$GS' : GO :: 2\,k : 2\,c,$$

as shown in Fig. 4.

The greatest B.M. at any point of span occurs when there is directly over it, that point in the load which is situated in the extent of the load in a position similar to that in which the point is situated in the extent of the span; see equation (22), Let I be any point of span (Fig. 4); then when I' a point situated in the length of the load in a position such that

$$W_1I' : BI :: 2\,k : 2\,c,$$

e.g., centre of load over centre of span, quarter point of load over quarter point of span, &c., the B.M. at I is greater than for any other position of the load.

The equation for maximum B.M.'s for whole span is derived from equation (23) by substituting for d its value $\frac{Rk}{2}$,

$$_{\max.}M_x = \frac{R}{4\,c}\left(2 - \frac{k}{c}\right)(c^2 - x^2). \qquad (28)$$

When the length of the load becomes zero, in other words, when the moving load is concentrated at a point, $k = 0$, and equation (28) becomes

$$_{\max.}M_x = \frac{R}{2\,c}(c^2 - x^2), \qquad (29)$$

a result which corresponds with equation (24).

When the length of the load becomes $2\,c$, in other words when the uniform load covers the whole span, $k = c$, and equation (28) becomes

$$_{\max.}M_x = \frac{R}{4\,c}(c^2 - x^2), \qquad (30)$$

one-half of the quantity given by equation (29).

Graphical Solution, Fig. 4.—As in previous cases, draw *any* parabolic right segment BA_2C, with vertex over centre of span, and sides passing through B and C the ends of span. This will give the maximum B.M.D. for R uniformly distributed over its length $2\,k$, and moving on span. The vertical scale for bending moments is found by making

$$OA_3 = \frac{R}{2}\left(c - \frac{k}{2}\right).$$

Numerical Example, Fig. 4.—Given—Span 36 feet; load 18 tons, 12 feet long, uniformly distributed over its length, and moving into every possible position on span. Find the equation for maximum B.M.'s on whole span. Find the amount of this maximum at a point 13·5 feet to left of centre of span; and show how the load is situated when this maximum value occurs. While the load is thus situated, find the maximum value for whole span, and the point at which it occurs.

$$\begin{aligned} {}_{\text{max.}}M_x &= \tfrac{18}{72}\left(2 - \tfrac{6}{18}\right)\left(18^2 - x^2\right) \\ &= 135 - \tfrac{5}{12}\,x^2. \\ {}_{\text{max.}}M_{13\cdot 5} &= 59\cdot 06 \text{ foot tons.} \end{aligned}$$

This point divides the span into two parts in the ratio 1 : 7; divide the length of the load in this ratio, and bring the point 1·5 feet from left end of load over the given point of span. While the load is thus situated, the position of the point S at which the maximum B.M. occurs is given by equation (18), and the amount of this maximum value by equation (20).

$$\begin{aligned} OS &= 9\left(1 - \tfrac{6}{18}\right) = 6 \text{ feet.} \\ SV &= 135 - \tfrac{5}{12}\,\bar{x}^2 \\ &= 101\tfrac{1}{4} \text{ foot tons.} \end{aligned}$$

XIII. In conclusion, the authors desire to draw attention to the exact agreement of the results now obtained by means of their moment delineator with those given in their "Applied Mechanics," Part II., published by Macmillan & Co., 1882; and to express their belief that, for teaching the subject of bending moments for moving loads, their new kinematic arrangement will prove most useful. By the mechanism, some new properties of the parabola have been pointed out in the paper, and it is hoped that several others may yet be discovered.

The present model in wood has been made partly by Mr James Hamilton and partly by the authors in the workshop connected with

The Glasgow and West of Scotland Technical College; and the authors intend using it for class purposes in the College. Another model in brass, and of half the linear dimensions, is being constructed for Dublin University by Messrs White & Co., opticians.

The discussion of this paper took place on the 21st January, 1890.

Mr C. P. HOGG said he had read this paper with great interest, and it described what seemed to be a very excellent apparatus for ascertaining the bending moments due to the transit of a load over a span, and also for making a diagram thereof. He had not worked through the mathematical formulæ given in the paper; but he was quite willing to take on trust anything that Mr Arthur Thomson and Professor Alexander put their names to. He would like to draw their attention to the fact that the apparatus which they had designed was scarcely that which engineers could apply in actual practice. That was not due to any fault in the principle of the apparatus, but as they explained at page 60:—"In the same way a delineator for a load on three wheels would consist of a slot frame of three bars, one at each wheel; compass bars; and two transverse bars sliding on pins fixed at $D_{1,2}$ and $D_{2,3}$ the intersection points of parabola No. 2 with Nos. 1 and 3. Such an arrangement would be complicated by the friction of its parts." As a matter of fact, if they took a girder of 36 feet span, they might have five wheels on it; and those were the cases which an engineer met in practice. In making that criticism he did not undervalue the work of the authors of the paper, but he merely wished to point out that the delineator did not reach the actual cases the engineer had to deal with in his daily practice.

Professor BARR looked on the delineator as a most interesting piece of apparatus, and he could only say that if he had an engineering laboratory he would put one of them into it as one of its first appliances.

The **Secretary** (Mr W. J. Millar) said that the moment delineator was interesting from showing graphically the relation which obtained between the bending moments due to a load placed at different parts of a beam, or to a load rolling along that beam. It could be shown if the bending moments due to the action of the load at different parts of the beam were calculated, and these values set up as verticals to any suitable scale, commencing say at one of the points of support where the bending moment is equal to nothing, and going onwards to the centre of the span where the bending moment attained a maximum value, that the curve drawn round the upper ends of these verticals was a parabola having its vertex above the centre of span. Taking the equation of the parabala as $\frac{y^2}{x} =$ a constant quantity, then, by substituting the values for half span, load, and distance from centre at which the load acts, as Mr Thomson gave in his paper for the y and x, as shown, we had y represented by the distance $\bar{x}$ at which the load is supposed to act from the centre of the span and x represented by $\frac{W\bar{x}^2}{2c}$, and therefore $\frac{y^2}{x} = \frac{\bar{x}^2}{\frac{W\bar{x}^2}{2c}} = \frac{2c}{W}$ a constant quantity, showing that the curve was a parabola.

Mr **Arthur W. Thomson**, in reply, said he had to thank the members for the way in which they had received the paper by Professor Alexander and himself. The only point to which he might be expected to reply was as to the remark which Mr Hogg had made, that the delineator could not be applied to cases which engineers met with in actual practice. Now, the delineator was intended, as he had told the meeting two months ago, for the purpose of teaching students the way in which the greatest bending moment at any and every point of span could be determined while a load rolling on one wheel, a load rolling on two wheels one after the other, or a load distributed over a length shorter than the span, passed over the span. The application of the principle of the delineator to the cases which were met with in daily practice was very simple, and he would refer Mr Hogg to the mathematical results for practical cases which were given in the work—" Applied

Mechanics," Part II., by Professor Alexander and himself. Within the last few weeks he had been engaged in applying this very principle to the case of the heaviest engines in use at the present day on the Caledonian Railway system, and he expected to give the results of his investigations, on Monday next, at the meeting of the students of the Institution of Civil Engineers. The general case which he had taken was that of two of the heaviest locomotives running front to front, and passing over spans up to 100 feet; this brought out the greatest bending moment on each point of span which was likely to be met with in practice. The application of the principle of the delineator to such cases was very simple, but it would be difficult and perhaps useless to construct a delineator for a case where four or five wheels were running over the span. He again thanked them for the way in which they had received the paper, and for the friendly criticism which Mr Hogg, Professor Barr, and the Secretary had given it.

The PRESIDENT said that the graphic way in which the delineator showed the bending moments of moving loads must be very interesting and instructive to young men, and it might be, perhaps, better applied in practice than it seemed capable of being at the present time. He proposed a very hearty vote of thanks to the authors for their paper.

On the Utilisation of the Water of Condensation from Steam Pipes and Cylinders.

By Mr PETER FYFE.

(SEE PLATE II.)

Received and Read 19th November, 1889.

THE subject of the utilisation of the water of condensation in its practical aspect came before me towards the end of 1886, in connection with the treatment and washing of the city's infected clothing at the wash-house, Belvidere.

For the years 1885 and 1886, I observed that each article of clothing under treatment took in the former 3·9 lbs. of coal, and in the latter 4·3 lbs. of coal, which for 325,128 articles in the one and 281,456 articles in the other, meant a consumption of 481 and 454 waggons of coal respectively.

I got the drying stove reconstituted and divided, and, for the purpose of saving all the hot water of condensation, designed a "return steam trap," which I will have the honour of explaining to the Institute.

The improvements instituted at Belvidere effected in the following year a saving of 1·33 lbs. of coal per article over the year 1885, 1·73 lbs. of coal per article over the year 1886, and last year this rate of saving per article was very slightly increased.

When our Secretary, therefore, asked me about a month ago if I would undertake to submit a short paper to this Society, I thought it would not be time altogether wasted if I ventured to lay before you a few considerations on steam raising and the utilisation of its heat when spent as steam, and also introduce to your notice a new apparatus, which I designed, in order to stop the waste which was being caused by the hot condensed water continually passing away into the drains and sewers.

I am afraid, from what I have seen in several of our manufactories and workshops, that not only is an enormous amount of the practical thermal value of the steam raised in them lost when it finds its way skyward through the exhaust pipe, but that a serious loss is also experienced daily, through the water of condensation from the various pipes and cylinders finding its way earthward by way of the drains.

In the earlier days of steam, the products of manufacture under steam treatment commanded such prices as handsomely repaid the manufacturer for his outlays, and he could afford for a long time to ignore the constant drain upon his oncost through such losses as were caused by *direct exhaust*, *imperfect combustion*, and *hot water waste.*

But now, except where the manufacturer has the good luck to possess a monopoly, none of these items of waste must be lost sight of.

Competition is the mother of improvement in applied mechanics, and real improvement is the mother of economy.

To have any chance now in making the sale of his products pay, the average manufacturer has to guard well every outlet in his factory which may be a useless drain upon his resources.

It is well enough known that the steam engine cannot produce in work one-fourth of the practical thermal value of the coal burned in his furnace. So also when the steam is applied for heating and drying purposes, a waste is caused if the condensed water is permitted to flow away through cocks or atmospheric traps.

Before considering the amount of this waste, I would like to take you through the old story for a few minutes of the quantity of fuel which must be consumed in order to obtain the heat necessary to evaporate water to a pressure of one atmosphere.

One pound of water at 32° Fahr. requires 180·9 units of heat to raise its temperature to 212° = the boiling point. As you are aware, however, a much larger increment of heat must be taken up by the water before steam can be formed from it. This amounts to 966 units of heat which, entering into the steam, is not sensible to the thermometer, and has therefore been termed latent. The total heat units therefore taken up by steam from water at 32° = 1146·9. I will, however, put the ordinary temperature of unheated feed-water at 40°, so that 8 units of heat less will suffice.

A cubic foot of water, therefore, will absorb 10,730 heat units from 40° to 212°, and 60,267 heat units more to evaporate it to steam of 1 atmosphere. Thus a total of 70,997 heat units passes from the fuel into the steam formed from this quantity of water at 40°.

Now let us put the theoretical calorific value of 1 lb. of coal at 12,000 heat units. In an average boiler, 1 lb. of coal, it is allowed, will communicate 7000 of its heat units to the water, so that 70,997 ÷ 7000 = 10 lbs. of coal to evaporate 1 cubic foot of water at 40°. This is equivalent to 6·23 lbs. of water per lb. of fuel.

To convert steam at the absolute pressure of 15 lbs. per square inch to steam at any moderate pressure, requires a further small increment of heat. Regnault's formula is, $h = 1082 + (\cdot 305 \times t)$ in which h is the units of heat necessary per lb. of steam of any pressure, the water being 32° Fahr., and t is the temperature of the steam required.

Working this out we find that the units of heat required for water at 40° to steam at 40 lbs. pressure above the atmosphere are 1161·5, so that for all practical purposes we may at present disregard the difference from the units required for steam of 15 lbs., absolute pressure.

Having now got the expenditure of coal to evaporate 1 cubic foot of water into steam, let us see how it may be expended in turn through radiation from steam pipes and cylinder.

The amount of heat which radiates from hot surfaces into the surrounding atmosphere is directly as the difference between the hot surfaces and the temperature of the atmosphere. From small pipes under 12″ diameter, the radiation per square foot of surface exposed is not constant. It varies in an arithmetical ratio inversely as the square of the diameter.

So that we see small pipes radiate more per superficial unit of surface than larger ones up to 12″ diameter. Above this diameter it has been found that radiation is directly as the surface exposed.

In investigating the amount of condensation in cubic feet of steam, which takes place in steam pipes, there are two facts which must be discovered—

1.—The units of heat radiated per hour.
2.—The latent heat per cubic foot of the steam in the pipes.

When these are found, the former divided by the latter gives the condensation per hour of steam in cubic feet. All large drying stoves when heated by steam have to be brought up to a required temperature *gradually*, so that for the first 40 or 60 minutes the same formula which applies to uncovered steam pipes in a factory, exposed to the surrounding atmosphere, applies during the first hour or so to them, so far as their power of condensing steam is concerned.

So for the first hour, let us see what our drying stove at Belvidere is capable of condensing—

Let L = The length of piping in feet, = 4401 feet.
„ l = The diameter of pipes in inches, = 2·25 inches.
„ T = The temperature of steam in pipes, = 269° (25 lbs. pres.).
„ t = The temperature of air, = 40° at start.
„ h = No. of heat units radiated per hour.
„ c = Cubic feet of steam at T condensed per hour.
„ H = Latent heat per cubic foot of steam, = 88·14.
„ x = Exponent for draught of air in stove, = 1·2 (calm).

h will be found by the formula.

$$\text{I. } h = \frac{Ll}{3404{\cdot}8}\left[450 + (12 - l)^2\right](\tau - t)^x. \quad \text{Or, in figures,}$$

$$h = \frac{4401 \times 2{\cdot}25}{3404{\cdot}8}\left[450 + (12 - 2{\cdot}25)^2\right](269 - 40)^{1{\cdot}2}.$$

II. Then $C = \frac{h}{H}$.

The working out of this formula is as follows:—

269 — 40 = 229 = log. 2·3598355
Multiply by exponent x = 1·2 - 1·2
47196710
2·3598355
(269 — 40) 1·2 = + 2·83180260
(12 — 2·25) + 450 = 545 = + 2·7363965
2·25 × 4401 = 9902 = + 3·9957229
9·5639220
Coefficient 3404·8 - - = — 3·5320916
Total units of heat lost = h = 1,076,090 = 6·0318304
The latent heat of steam = H = 88·14 log. — 1·9451730
4·0866574

and 4·0866574 being the logarithm of 12,284 c = 12,284 cubic feet of steam at 25 lbs. pressure above the atmosphere, condensed during the first hour; or, 1 yard of 2¼″ pipe condenses 8·37 cubic feet of steam per hour.

This is equal to 19·4 cubic feet of water at 212° or 18·6 cubic feet at 40°.

So that if all this water of condensation passes away from this system of pipes into the drains, 12 per cent. of 18·6 × 10 = 186 lbs. of coal are lost in the first hour of each day, = 22·68 lbs., or over 3 tons per annum. For the other eight hours of the day, I take the following to be a fair estimate of the work of the steam when 3000 articles of clothing are being treated. I found by the anemometer that about 4000 cubic feet of air at 130° Fahr. escapes from the stove per minute. Now the steam has to do two duties in the stove after the first hour. First, it has to evaporate about 5 grains of moisture from the damp clothes per cubic foot of air discharged; and, second, it has to heat to 130° 4000 cubic feet of air per minute, drawn from the underground passages where it was found to be 85° of temperature.

So I find in eight hours 224 lbs. of coal are consumed for the first, and 1800 lbs. of coal for the second duty. In all, 2024 lbs. of coal per day to do this work, supposing the stove is kept full of clothes.

Now, as 2024 lbs. of coal will evaporate 202 cubic feet of water from 40° Fahr., 202 cubic feet may be taken as the daily flow of condensed water from the whole of the stove.

If this all passes into the drains (which it used to do at Belvidere) instead of being returned to the boiler at 180°, 140 heat units are lost for each lb. of water so wasted, which is equivalent to 251 lbs. of coal daily thrown away by such a proceeding, or about 34 tons per annum. To this add the 3 tons which are lost during the first hours of the days, and a grand total on this stove of 37 tons of fuel are cast away yearly into the common sewer.

Now, 37 tons at 7s = £16 19s, which does not look much, but when it is remembered that at a cost of something like twice that sum, a set of suitable traps and pipes to put the hot water back into the boiler can be erected in ordinary circumstances, the saving is seen to yield 50 per cent. on the outlay, which may be reckoned a first-class investment.

In the case of steam cylinders and pipes which do not carry their steam for heating purposes, but in order to produce force or obtain horse-power from it, a much greater waste is experienced than what I have recorded above, by letting the water of condensation *under considerable pressure* escape, the cause of this being that the water under such pressure in the pipes is almost of the same temperature as the steam, and only wants a place to expand, in order to fly into steam. Say we have water in the steam pipes or cylinders under a pressure of 40 lbs. above the atmosphere, and it finds its way to any atmospheric steam trap, and gets vent from it in the usual way, what would we see? We would just see what is to be seen daily in such traps, viz., a constant fizzle of steam and water coming from it—not, mark you, because the traps are really passing any live steam out of the pipes, but because the water they are passing into a tank, or into the drains from high pressure pipes, at once expands into steam on being set free from the pressure inside.

Now the sensible temperature of steam at 40 lbs. above atmosphere is 287°, and water compressed in a pipe, and in contact with such steam, will be of the same temperature. Let this water away through a trap or cock into the drain and you at once lose 1161·5 heat units per lb. of water so let off, or 10·34 lbs. of coal for every cubic foot of such water lost.

When one comes to consider the number of cubic feet of such high temperature water which yearly must flow away in a large factory, it does seem surprising that manufacturers and engineers do not pay more attention to the matter.

Percentage of Fuel gained by Feeding the Boiler with Hot Water.

Temp. of Feed.	32°	40°	50°	60°	70°	80°	100°	120°	140°	160°	180°	200°
32°	0	— 1	— 1·5	— 2	— 3·4	— 4·4	— 6·5	— 9	— 11	— 13	— 16	— 19
40°	+ 1	0	— 0·5	— 1	— 2·4	— 3·4	— 5·5	— 8	— 10	— 12	— 15	— 18
50°	+ 1·5	+ 0·5	00	— 0·5	— 2	— 3	— 4	— 7	— 9	— 11	— 14	— 17
60°	+ 2	+ 1	+ 0·5	00	— 1·4	— 2·4	— 3·5	— 6	— 8	— 10	— 14	— 16
70°	+ 3·4	+ 2·4	+ 2	+ 1·4	00	— 1	— 3	— 5	— 7	— 9	— 13	— 15
80°	+ 4·4	+ 3·4	+ 3	+ 2·4	+ 1	00	— 2	— 4	— 6	— 8	— 12	— 14
90°	+ 5·4	+ 4·4	+ 4	+ 3·4	+ 2	+ 1	— 1	— 3	— 5	— 7	— 13	— 15
100°	+ 6·5	+ 5·5	+ 5	+ 4·4	+ 3	+ 2	00	— 2	— 4	— 6	— 9·5	— 12
110°	+ 7·6	+ 6·6	+ 6	+ 5·6	+ 4·2	+ 3·2	+ 1	— 1	— 3	— 5	— 8	— 11
120°	+ 8·7	+ 7·7	+ 7	+ 6·7	+ 5·3	+ 4·3	+ 2·2	00	— 2	— 4	— 7	— 10
130°	+ 9·8	+ 8·8	+ 8·3	+ 7·8	+ 6·4	+ 5·4	+ 3·3	+ 1	— 1	— 3	— 6	— 9
140°	+ 11	+ 10	+ 9	+ 9	+ 8	+ 7	+ 4·5	+ 2	00	— 2	— 5	— 8
150°	+ 12	+ 11	+ 10	+ 10	+ 9	+ 8	+ 5·5	+ 3	+ 1	— 1	— 3	— 7
160°	+ 13	+ 12	+ 11	+ 11	+ 10	+ 9	+ 6·5	+ 4	+ 2	00	— 2	— 6
170°	+ 15	+ 14	+ 12	+ 12	+ 12	+ 11	+ 8	+ 6	+ 4	+ 2	— 1	— 4
180°	+ 16	+ 15	+ 14	+ 14	+ 13	+ 12	+ 9	+ 7	+ 5	+ 3	00	— 3
190°	+ 17	+ 16	+ 15	+ 15	+ 14	+ 13	+ 10	+ 8	+ 6	+ 4	+ 1	— 2
200°	+ 19	+ 18	+ 17	+ 17	+ 16	+ 15	+ 12	+ 10	+ 8	+ 6	+ 3	00
212°	+ 20	+ 19	+ 18	+ 18	+ 17	+ 16	+ 14	+ 11	+ 9	+ 7	+ 4	+ 1

The principle involved in the "return steam trap" (see Plate II.) is, so far as I know, a new one. It consists in utilising the steam pressure in the trap, both for stopping the discharge of the condensed water, and for starting its flow. The operation of valve closing and valve opening in this apparatus is not therefore obtained as in ordinary "float" traps and "pot" traps by the difference of weight caused by the float or pot being immersed in water or otherwise. In the well-known "pot" trap the floating power of the pan when emptied of its water is all that can be depended upon for closing the valve; and its excess of weight when full over its floating potentiality when empty, must open the valve. This being the case, the outlet valve must be necessarily of the smallest dimensions, something like in ordinary sizes ¼ inch diameter. Hence a very small quantity of sedimental matter coming into the trap from the steam pipe or cylinder is sufficient to render it inoperative.

All traps also which depend upon the difference of expansion in the metals of which they are composed, under variation of temperature, or through the movement got on a flexible disc of metal, being acted upon by the expansion of highly volatile liquids, such as ether or alcohol, are open to the same objection. These latter are also open to the objection that an equilibrium becomes established, and water and steam flow through them in constant driblets. They may also at any time, when the condensed water comes to them in any great volume, allow it to back into the pipes and be carried away with the steam.

In the trap which is illustrated in the figure (see Plate II.) the water and steam enter E at the bottom into a small chamber distinct from the trap chamber proper, which is shown at A, B. This serves the double purpose of retaining pieces of solid matter and sediment which invariably find their way into all traps, and also prevents the ball or float being vibrated by the ebullition caused when the steam has immediate access to the main chamber.

The water rises in this chamber and flows over the top of the partition at X into A, B. At this time the balanced strong copper float, L, is lying at the bottom. In this position it admits, through the three-way cock, I, steam into the small chamber, D, which is fitted at the bottom with a flexible disc, H. This disc bears on the top of the outlet valve, G, and so long as the steam is kept in the chamber, D, the valve is kept closed so that no water can escape.

This action continues until the water reaches the top of chamber, D. At this point the steam is cut off from D, and a communication is opened between D and the outer air through the small pipe, Y. This relieves the pressure in D, and the steam at once forces the accumulated water almost full bore up through the valve seat, F, into the chamber, C, and out through W to a distance or height corresponding to the pressure of the steam in the trap.

As the float falls in the trap, the communication is closed between D and the open air, and opened between D and the chamber, A, B, when the steam pressing on the flexible disc closes the valve until the water accumulates again, when the action described is repeated.

It might be thought that the pressure of the steam in D would simply counteract the pressure on the under side of the valve, G, but this has from experience been found not to be the case.

So long as no obstruction exists in the valve, no water nor steam escapes until the ball has risen cutting off the connection.

When the valve is, from any small obstruction, leaking water continuously, a small rod having an eccentric motion, which passes through the hole, Z, in the head of the valve, is turned by a handle situated at the side of the trap; this lifts the valve and permits a full blow through, which at once relieves the valve.

M is a small air valve to let the air off which always accumulates in steam pipes and cylinders. Here, then, we have a steam trap actuated mainly by the steam itself, discharging its water at any temperature desired, to any place consistent with the pressure behind it.

In order to have the *full* benefit from such traps, it is necessary to conduct their water back to a similar apparatus of somewhat larger dimensions, placed 10 or 12 feet above the boilers. This apparatus is shown in Plate II., Fig. 2. It consists of a chest arranged in a similar manner. The steam cock communicating with the chamber, D, is placed on the outside of the apparatus, and the float lever, K, which works on a pin, P, inside the trap communicates its motion to the lever, which is forked so as to allow a considerable play on the float. Before it begins to operate on the cock, I, when the float, L, is at the bottom of the apparatus, the outside lever, S, with the back balance weight on it has tilted the lever of the valve, so that the steam from the boiler is admitted to D, thus keeping the valve, G, closed. As the water rises in the trap, the outside lever, S, is gradually brought over the vertical position by the pins, PP, on the lever, L, and falls to the right (see Fig 3, Plate II.), opening the communication between the boiler and the chamber of the trap, and closing it between the boiler and the chamber, D.

The water is then forced out through the valve, G, and by force of gravity runs into the boiler through a small check valve placed on the delivery pipe.

Thus the alternating action is kept up, and all the water accumulating in the various traps, by being connected to this apparatus, is fed into the boilers at whatever temperature and pressure it may have on arriving at this second trap.

Considering that much waste of fuel attends our present system, I have been tempted to lay before you this paper, and the apparatus I have designed. I have been for some years so dissociated from engineering proper, and so engrossed in matters relating to the public health, that I may have overlooked some better designs for the same purpose.

The discussion of this paper was set down for the 21st January, 1890, but no one responding to the President's invitation, he said that Mr Fyfe had brought forward a very good paper with respect to an important matter—the utilisation of condensed water from steam pipes and cylinders, which was usually allowed to go to waste. Mr Fyfe had carried out this in a very efficient manner; and had clearly described it in the paper he had read, and therefore, he deserved a hearty vote of thanks from the meeting for bringing the subject before them.

On the Economic Value of Ship Railways.

By Mr William Smith, M.Inst. C.E.

Received 16th and Read 17th December, 1889.

(SEE PLATE III.)

I.—ECONOMIC CONDITIONS.

The main economic principle involved in the transport of goods is that the larger the unit of load transported the lower will be the rate of cost. The final test of efficiency is cost; the expenditure in time, plant, rolling stock, space, power, labour, management, insurance, and interest are summed up in the rate per ton per mile at which goods may be transported. All these items are affected by the bulk and weight of the unit load transported, the rate of cost of transport varying inversely as the mass of the unit load.

The question of economy of transport begins when large quantities of goods have to be transported over well defined routes. In a sparsely inhabited country, carriage is dear, goods are distributed over a wide area in small quantities by many routes, but even here the country town serves to aggregate the routes to a radiating centre, keeping the mass together in a large unit to the latest possible stage in its distribution. A densely populated country presents many centres of distribution, which also serve as interchanging centres, a constant circulation of goods in large masses being kept up on the trade routes between manufacturing and trading cities. (See Map, Plate III.) Geographical or physical features define in some cases trade routes between centres of population, countries, or even continents, as the Isthmuses of Panama and Suez, the great Continental rivers, the Bosphorus, the Straits of Gibraltar, and the English Channel. The introduction of railways multiplied trade routes indefinitely, until they came to depend solely upon the magnitude and resources of the towns and countries united by them for purposes of commerce. The practical recognition in modern times of the natural law that distribution (delivery to consumers) is an important element of production, makes the opening of trade routes the most important factor in the civilisation or settlement of new countries, and their improvement and multiplication the most essential element of progress in old.

Civilisation has invariably followed the great trade routes, and water carriage presenting ready means for the transit of goods in great bulk—or, in other words, for economical carriage—population, industry, and trade have been primarily developed along the coasts of inland seas, and lakes, and on the banks of the great rivers. The importance of the means of transport for goods in large bulk to the progress of civilisation and increase of population cannot be over estimated. The cities of the Nile Delta, the Euphrates and Tigris valleys, the Thames, the Po, the Scheldt, the Maas, the Seine, in the Old World; and the rapid growth of the river and lake cities of America in modern times, point to the main cause of their existence as cheap water carriage in large bulk. Canal and river carriage are absolutely essential still to the existence of all large eastern cities, and in ancient oriental civilisations it was even more so. From the area of the ruins of Babylon, George Smith computed its population to have been as high at one time as eight millions; from the invariable density of Asiatic urban populations it must have exceeded sixteen millions. Only by a system of canals as close as in Venice, and far more extensive, was it possible to supply the daily wants of a population so enormous. Decreasing freight rates are as essential to the growth of population as increasing capabilities of transport are. Canals must have been improved in depth and width to admit of larger vessels for the transport of goods to allow of the extension of a city so vast as ancient Babylon, and labour must have been as highly organised and as skilfully combined as in the most modern organisation. For the aggregation of large and dense masses of population cheap carriage of goods in large bottoms is always essential.

II.—COMPARATIVE RATES OF CARRIAGE.

Water carriage is notoriously cheaper than carriage by land. The competition of railways with steamers, notwithstanding higher rates, is rendered practicable by their higher speed and readier distributing facilities. People live on the land, and land carriage by rail follows them to any site open for reclamation from wilderness. But an examination of land and water carriage shows that the same law of unit bulk holds equally on both. During the last fifteen years the average tonnage of ships has risen 50 per cent., while freights have diminished 33 per cent. The reduction in freights is partly due to the economy of fuel gained by compounding engines, but largely to the increase of average tonnage, the reduction of freight being due to greater efficiency of "shipping, one British seaman now carrying as much as two in 1870, three in 1860, or four in 1850." (Mulhall's "History of Prices," page 46.)

Speed and bulk are the two factors which tell on the sea as on land. Twenty years ago freights for Australia by sailing liners ranged as high as $\frac{1}{2}$d per ton per mile; by steam it is now as low as $\frac{1}{32}$d per ton per mile. Freights between British and American ports average $\frac{1}{12}$d per ton mile; freights by canal barges average $\frac{3}{8}$d per ton mile. In countries possessing railways and macadamised roads, land carriage may be said to vary from 8d to 1d per ton per mile. The introduction of railways has reduced the average cost of land carriage in Europe to one-sixth (Mulhall) in thirty years. The smallest unit of bulk or weight is practically a ton, and the largest ten tons of paying freight. The cartage of 1 ton over a macadamised road costs about 8d per mile, and the average rate by rail in 6 to 10 ton waggons is $1\frac{3}{8}$d per ton mile in Great Britain.

In the United States of America the average freight charge is at the rate of 0·63d per ton mile, and for grain trains of 30-ton bogie waggons ¼d per ton mile. While terminal charges and short mileage tend to raise the rate in Britain, relatively to America, the larger goods trucks and labour saving contrivances for loading and unloading freight trains in the latter country are the chief economical factors in the competition. The curiously persistent resistance of railway managers and engineers in this country, to the gradual introduction of trussed or tubular 30-ton bogie trucks, is a very important factor in the maintenance of high railway rates.

Our national system of penny postage works out to the highest ton mileage rate in existence, about a pound sterling per ton per mile, or £150 per ton. Our Australian and Eastern mails at £1500 per ton, average 3s per ton mile, which shows even at the high rates for foreign and colonial postage from this country that ocean freights are far lower than land carriage. Comparing the ordinary rates of freight with land carriage, the average rate per ton mile by sea from America to England is one-seventeenth of the average rate per rail in England, and one-ninety-sixth of the average rate by road.

The main source of economy in ocean freights is the large unit of bulk In addition to this source of economy, however, allowance must be made for the interest charges upon capital expenditure on construction of roads and railways as against the permanent way of the trackless ocean, only partially accounted for by the dues required to meet expenditure on the formation of harbours. This second source of economy is absent, however, in canals and artificially improved inland navigations. The economic principle of the rate of transport varying inversely as the unit of bulk, is nearly counter-balanced in canals by the rapidity of the increase of cost of formation per foot draft of water. The average cost of barge canals in England was £6000 per mile, while the average cost of the three great ship canals is about £200,000 per mile. That is, the proportionate increase of cost per foot draft between the limits of 4 feet and 26 feet, is as 6 is to 200; while the depth advances arithmetically, the cost increases in geometrical progression at the rate of 20 per cent. per foot draft. A similar calculation on the basis of the cost of American and Colonial railways, constructed through settled districts (which give a fair rate of cost of construction per mile of single line at £10,000), the geometrical rate of increase of cost of ship railways, in comparison with the arithmetical increase of draft of vessel transported, is 5 per cent. per foot. The rapid rate of progression of the cost per foot depth of canals makes it impossible to increase the depth of ship canals beyond moderate limits, and at the depth required for ocean going vessels, it is only on one or two of the most populous or frequented highways of commerce that they are practicable in competition with ordinary railway transport.

The Suez Canal rates are as high as it is possible to levy, a penny per ton mile, with additional charges for every service rendered by the Company or their officials, the only savings by its use are the cost of two transfers of goods, from ship to train and from train to ship, and the simplification of the service by allowing the ships, each, to go through the whole voyage. For passenger service alone there is no saving, the P. & O. Company having kept up their Eastern fleet and transferred their passengers overland, long after the canal was opened. As a dividend earning concern, the Suez Canal is eminently satisfactory, but it is evident that the rates will continue only just below the margin of railway competition until the introduction of a rival canal or ship railway. The Company has a monopoly of the right to make a canal across the Isthmus, during ninety years after the construction of the first canal, so that the only means of lowering the rates is by the construction of a ship railway. On the opening of the Suez Canal, and for several years afterwards, the Company were not in a very flourishing condition. The enormous cost of a ship canal gives it the narrowest margin of financial security, the tonnage passing through it must exceed the capabilities of a single railway, before it can pay a dividend at railway rates.

III.—LIMIT OF TRAFFIC CAPACITY.

Another element affecting the value of a canal is its capacity for traffic. The limit of the traffic capacity is not far to seek, and may, in the case of a ship canal with locks, be much lower than the estimated tonnage passing over the route. If we examine the estimates for the proposed Forth and Clyde Canal, it appears the traffic capacity of the canal in the meantime is far below the estimated tonnage. Although the canal is constructed for the passage of vessels drawing 26 feet or more, the average tonnage of vessels passing through it will probably not exceed those entering and leaving the first-class ports of the Tyne, the Clyde, and the Forth, that is 500 tons register, or 1200 tons cargo carrying capacity—1200 tons × 300 days × 12 hours, allowing each vessel an hour to climb 100 feet of locks or lifts, gives a total tonnage capable of passing through the canal of 4,320,000. The expedients required to increase the capacity, namely night transport by electric light, the increase of the average capacity of vessels using the canal, and locking two or more vessels together would not bring the capacity up to the 9,500,000 tons estimated as available for the first year's traffic, while it would require a constant succession of vessels never realised in practice to make the full capacity of the canal available.

The element of speed seriously affects the economic value of canals. In competition with ordinary railways, canals of insufficient draft for ocean vessels are falling into disuse. Notwithstanding the low rates at which goods are carried on English canals, averaging nearly one-fourth of the average railway rate, the increase of traffic on canals is slight compared with that on competing railways. The description of traffic suited for slow canal transport is comparatively restricted, while there is practically no limit to the range of suitability of railways. All kinds of goods will bear a high speed, while few bear a slow rate of transit. The great advantage of ordinary railway transit over canal traffic, both as respects capacity and attractiveness, is speed. The barge canal speed of 3 miles an hour, or the ship canal speed of 5 miles an hour, with stoppages at night, and for locking, reducing both figures to less than half as the average, contrast in a sorry fashion with the day and night speed of a goods train, 15 to 24 miles an hour. Over the comparatively short mileage of English runs, the cost of transfer to barges being equal to the terminals by rail, the difference in mileage rates is not sufficient to counterbalance the greater speed, and wider range of distributing power with prompt delivery, by rail.

The limit of the goods traffic capacity of a single line of railway worked on the block system, together with the ordinary passenger traffic, appears, from the experience of the leading railway companies, not to exceed 50 trains per 24 hours. The train capacity is 300 tons, and for 300 days this gives the limit of capacity of a single line railway for goods traffic (in conjunction with passenger trains) as 4,500,000 tons per annum. On the same basis as the average tonnage of vessels estimated to pass through the Forth and Clyde Canal—1200 tons of cargo—the ship railway worked on the block system, at the speed of 15 miles an hour, day and night, for 300 days, would carry 36,000,000 tons without passenger traffic. The restriction to the average size of vessel makes the limit of capacity of the ship railway lines collectively appear rather less than the limit of capacity of the same lines taken singly, with goods and passenger trains running continuously. The average size of vessel and car occupies, on the ship railway, only half the number of lines of rails, leaving the other lines, during the greater portion of the time, free for ordinary railway traffic. The comparison of the limit of capacity applies more correctly to ship canals as against ship railways; in the calculation the ordinary railway train is always loaded to its full capacity of 300 tons, while the ship railway is subject to a temporary restriction by the average size of ships to one-fourth of its maximum capabilities. To compare the limit of traffic capacity of a ship railway with that of a single line railway, is actually as 9,000,000 tons is to 144,000,000 tons, or as 1 is to 16. A six-line ship railway, worked on the block system, will carry 144,000,000 tons in a maximum size of vessel carrying 4800 tons dead weight of cargo, while the same number of railway lines worked separately with 300 ton trains on the block system, without passenger traffic, yields a maximum traffic capacity of only 54,000,000 tons.

IV.—PROPORTION OF TRAFFIC TO POPULATION.

How does it happen that values are the only statements of traffic returns available in this country ? The systematic disregard of the volume or weight of traffic in all returns except those of shipping, makes it extremely difficult to obtain reliable data for the adaptation of public works to the necessities of commerce. The railway companies are required by Act of Parliament to furnish annually to the Board of Trade statements of the receipts from goods and passenger traffic; but no statement of the tonnage or nature of goods, number of passengers, or ton mileage is asked for. If the railways were the property of a Government Board, or if the same returns as are made by any public department or harbour board were required of the companies, a reasonable acquaintance might be obtained with the volume of the internal trade of the country.

Before the present boom in trade commenced in 1887, the tonnage of England and Wales, including railway, harbour, and canal traffic, approximated to 350 millions per annum, or 12 tons per head of population. Of this average, the urban populations take 15 tons, and the rural 9 tons per head. The place of a country in the scale of material civilisation can have no better index than the tonnage of internal trade per head. The combined railway and shipping trade of the so-called civilised world in 1883 showed an average of 3 tons per head of population. The large average in England may be accounted for by the immense accession of manufacturing power from the application of machinery and steam, and the enormous relative production of manufactures and minerals for foreign use. At the same time the average tonnage per head is kept down by the density of population, which constantly increases with the improvement of the means of transit.

With the growth of population in what may be called urban districts, such as occur in the black country, the means of transit by road and rail are in many cases essentially insufficient. It is quite possible that the capabilities of railway traffic accommodation may not meet the wants of neighbouring manufacturing and trading cities. It has become already essential to differentiate the traffic according to speed, the goods traffic being carried on separate lines from passenger trains, and even minerals carried over lines apart from general goods traffic. Notwithstanding these regulations, however, a permanent block of traffic appears to exist on several lines, as between Manchester and Bolton; and city railways are reserved exclusively for passenger traffic during the day. At enormous expense for right of way, urban and suburban railway lines have been laid in large cities, these in turn have been supplemented for passenger traffic by tramway lines along the streets, and the routes of traffic stereotyped by the extension of the cities in relation to these routes. As suburban districts of neighbouring townships join, and the cities run together into one huge urban area, the traffic routes become hemmed in and inexpansible, while the traffic increases beyond their limit of capacity. It thus becomes essential to the supply of the growing urban districts of the modern world, that on the existing lines of goods traffic some means of increasing the limit of carrying capacity should be introduced. On maritime routes and inland navigations the means are readily arrived at by the increase of the tonnage of ships. On favourable sites the extension and deepening of canals admits goods in large bulk, but without the early introduction of ship railways, the limit of population or extension must be reached at no distant date in towns only accessible for goods traffic by land.

Ship railways are thus more essential to the growth of inland towns, and to the supply of dense inland populations, than for any other purpose. While the shortening of trade routes appears to be their primary function, like ship canals, the main purpose to which they must in time be applied is that of supplying the wants of the huge city areas of the future.

V.—REDUCTION OF EXISTING RATES.

The ultimate object of all improvements in the means of transit for goods is to lower the rate of cost. But the reduction generally stops short of the consumer, the benefit being naturally reaped in the first place by the investor in the improved appliance. The limiting influence on rates where they are under the maximum allowed by the Act of Parliament, or the concession of the right of way, is only that imposed by competition. The competition may be indirect; it may be impossible to carry grain, for instance, from St. Paul eastwards to Baltimore, by any other means than railroad, at anything nearly so low as a farthing per ton mile, but if in America a higher rate prevailed, India, Russia, and Egypt would supply the European market. The problem of the reduction of existing rates simply consists in the introduction of competition, by means yielding a profitable return for equal service at lower rates. The competition need not be on parallel lines, nor in the same country, the lower price of transport in one country, or over one route, must rule that of all competing lines. If the introduction of a ship railway direct from Chicago to New York lowers the rates of carriage on wheat in the United States to one-twelfth of a penny per ton mile, the only means of placing Indian wheat on the English market will be by the construction of an Indus and Ganges valley ship railway. The flexible car system of ship railways proposed for England will lower the railway rates, not only upon the lines of the proposed ship railways, but upon all the lines carrying traffic in similar and competing goods. This is the natural law of competition, which regulates the railway rates all over the country, and in fact all countries, to an approximate uniformity for the same articles. If the railways raise the rates where there is no local carrying competition, they either kill the trade or impoverish the producer.

The sources of economy in transport by ship railway are: 1, cost of construction as compared with ship canals; 2, cost of transfer of goods as compared with barge canals and railways; 3, cost of haulage and service in large unit of mass as compared with railways; 4, demurrage on sailing distances and time as compared with sea and canal traffic. In order to realise these advantages, however, the traffic must be of sufficient volume to keep the ship railway fairly employed. About half the volume of traffic moved at present over the proposed routes through England and Scotland will be sufficient to make ship railways prove remunerative, at rates of one-ninth of a penny per ton mile, or one-twelfth of the existing rates. It is very improbable, however, that the users of the ship railway will reap anything like this advantage from the construction of lines in Britain alone. Similar facilities must be given for traffic in competing countries, before any great reduction of rates may be looked for in England; and in the meantime the ample margin of economy may be safely predicted to induce what might be characterised popularly as a "boom in ship railways."

The average cost of construction of the three great ship canals—the Suez Canal, the North Sea Canal, and the Manchester Ship Canal—including terminal works, is £200,000 per mile. The contract price of the rigid car ship railway now under construction at Chignecto, Nova Scotia, averages £80,000 per mile; and the flexible car ship railway over similar country would cost about £60,000 per mile. The contractors' service rails on the Manchester Ship Canal works (134 miles of temporary railway) are sufficient to form a ship railway the same as the Chignecto line. The estimates for a ship railway may be more clearly approximated to actual cost than those for ship canal works, the ship railway being the more superficial work, and involving less expenditure for plant, temporary works, and compensatory works for water supply and roadways.

It is customary to compute the average cost per mile of British railways by dividing the total nominal capital invested by the total mileage constructed. For purposes of engineering proportion nothing could be more fallacious, as the classification of such works as the Severn Tunnel and the Forth Bridge—costing each about a million sterling per mile--with the railway mileage makes the average cost thus obtained unsuitable for purposes of comparison.

The £54,000 per mile average statement being worthless, the computation of the cost of a single line railway must be taken from the ordinary contract schedules, and amounts upon these generally to £10,000 per mile, and in America and the Colonies as low as £7000 per mile. Except on side lying ground and through cities, the cost should not increase at the same rate per parallel line, so that, apart from questions of land purchase and concession—

expenses which would be lighter for ship railways than ship canals—the cost of construction of a ship railway would probably never exceed one-third of that of a canal of equivalent draft and much less tonnage capacity.

The cost of the transfer of goods from one vehicle to another is more than the 6d or 1s per ton it actually costs for stevedoring. There are demurrage of both vehicles, damage to goods from handling, terminals for storage and covering, harbour and dock dues, customs, and petty local charges, varying with the port or country, all tending to raise the price of goods owing to transfer. A larger proportion of the factories have railway sidings than barge canal communication, so that the bulk of their goods are saved a transfer by railway communication. This, when taken in conjunction with quicker delivery by rail, is evidently worth an average of 1d per ton per mile on the carriage of goods in England, being the difference between the cost of canal barge carriage and railway trucking.

Besides raising the limit of traffic capacity, the increase of unit of mass cheapens the cost of haulage and service. The reduction of ocean freights 33 per cent. in fifteen years is chiefly due to the increase of the average tonnage of ships. The average proportion of the weight of the cars to paying freight in America is as 1 is to 2·13; in England as 1 is to 1·5. This is the chief factor in the lower freight rates of America as compared with England, the American cars carrying an average cargo of 50,000 lbs. each, while the English trucks average 18,000 lbs. capacity. On ship railways, the proportion would be reduced to $\frac{1}{4}$th, which would lower the cost of haulage per ton mile by $\frac{7}{10}$ths, while the cost of service would be reduced in a still greater ratio. For the convenience of conveying ocean-going vessels over land, a proportion of the saving by enlargement of the unit mass is sacrificed in carrying both ship and car, but this applies mainly to the dead weight, making little difference to the service. The cost for fuel of hauling a vessel containing 4000 tons of cargo would not exceed 2s per mile, with coal at 10s per ton; service would cost only three times that of an ordinary train, or 7s 6d per train mile; so that the haulage of the

4000 tons freight would cost $\frac{1}{33}$rd of a penny for working expenses —about the same as the cheapest ocean freight. Cost of general management and terminal expenses have to be added, with interest or dividends on capital, factors for which the total quantity of traffic must be known before the rate due to them per ton mile can be deduced.

The expenses of a sea going vessel are always running on, whether the ship is engaged in remunerative work or waiting to take the longest way round to her destination. The demurrage and cost for steam power of a steamer carrying 4000 tons of cargo is £75 per day. Where a saving can be made under this head by the construction of a ship canal, three times the amount can be saved by a ship railway, carrying on the traffic at three times the speed, irrespective of any delay for locking on the canal. The case for the formation of highways for ocean vessels across isthmuses has been amply worked out in favour of Suez, Panama, Tehuantepec, and several proposed routes across Britain. The saving of £525 for a week's steaming and demurrage of a 4000 tons vessel amounts to 2s 7d per ton, which may prove a considerable proportion of the vessel's charges for the voyage. Any diminution of the quantity of coal required to be carried by a steamer on a voyage, increases by so much her cargo capacity for paying freight. The numerous sea routes which may be shortened by transport over land at a moderate expense would be productive of an immense aggregate saving of demurrage and coal, with a valuable increase of cargo-carrying capacity.

VI.—SHORTENING TRADE ROUTES.

The shortening of the ocean trade routes by overland carriage or inland navigation of the Isthmuses of Panama and Suez are so obvious from a glance at the map of the world that it appears scarcely necessary to mention the matter. But the economic value of the shortening of the main trade routes of the world cannot be appreciated by a superficial glance. The opening of the Suez Canal "caused in its first decade, after deducting dues, a saving of 20 millions sterling to the commerce of the world—a sum in excess of the total cost of its construction." (Mulhall's "History of Prices," page 4.) This was the direct result of the canal; its indirect consequences were far greater and more lasting benefits, such as the consolidation of the British Empire and the advancement of the Australian Colonies by improved communications, the opening up of eastern commerce to unrestricted competition and consequent lowering of prices of commodities, and an enormous aggregate saving of valuable time, increasing the life power and influence of the human factor most essential to progress in civilised communities. The opening of the Panama, the Nicaragua, and the Tehuantepec routes between the Atlantic and Pacific Oceans must be fraught with still greater results to commerce and civilisation. The ocean trade of America depends mainly for its revival and successful prosecution upon the opening of those routes: a trade which will prove an entire gain to the world without necessarily diminishing the existing trade carried on by any other country. The annual saving to the commerce of the world gained by the execution of these works will be greater than that due to the opening of the Suez Canal.

VII.—DESCRIPTION OF SHIP RAILWAY.

The economic success of ship railways must depend in the first place upon mechanical appliances to insure—1, the safety of vessels; 2, the adaptation of the ship railway to follow curves and gradients; 3, the adaptation of the cars to fit any dimensions or lines of vessels; and 4, the attainment of a high speed with safety and thorough control. The rigid car system devised by the late Captain Eads met several of these conditions, and the application of this system in a practical form at the Isthmus of Chignecto, Nova Scotia, must be viewed with the greatest interest as a solution of both the economic and the engineering problems.

The leading principle upon which ship railways are based is the distribution of the weight of the laden ship and car over a great number of wheels on parallel lines of rails, so that the pressure on each wheel should be well within the resistance of the permanent way and the strength of the wheel and axle. This principle is common to the rigid car system and the flexible car system, but the latter system provides also for the uniform distribution of the pressure of the load over the skin of the ship, changes of direction by railway curves, and changes of level by railway gradients. The special objects of the flexible car system are: 1, to keep a ship of any dimensions constantly water-borne on the ship railway car upon a film of water forming a small percentage of its weight; 2, to make the car flexible vertically to admit of the usual railway gradients; 3, to make the wheel base flexible laterally to admit of curves, shunts, points, and crossings, and passing places on the multiple line ship railway. These results have been obtained by the contrivances of hydraulic cushions, sectional cars with adjustable sides, and the compound bogies. (See Figs. 1, 2, and 3, Plate III.)

The hydraulic cushions are a series of plain tubes of india-rubber and canvas, placed side by side athwart the ship from stem to stern, the ends of each tube on a level with the deck, and the middle of the tube bent underneath the ship's bottom, and resting on the car. One end of the cushion is left open; the other, which has to be lowered for the reception of the ship, being closed. When they are not supporting a vessel, the horizontal portion only of each cushion is filled with water. Thus the pressure outwards on the interior of any cushion, when not balanced by the weight of a ship, does not exceed a foot or two of head, or about one pound per square inch. On the ship settling on to the cushions, its weight compresses the horizontal portions of the cushions, and forces the water up the vertical portions until it reaches the level of the immersed depth of the ship. The internal pressure of the water is then counterbalanced by the weight of the ship and the resistance of the car and contiguous cushions. The internal pressure can in no circumstances be increased so as to become dangerous to the cushions. The weight of water required in the cushions to float a ship may be reduced in a well-fitting car to a small fraction—say 5 per cent. of the weight of the ship. The functions of the cushions are: 1, to keep the vessel afloat equally from stem to stern when the car is on a gradient; and, 2, to compensate by a slight rise and fall of the water in the vertical portions of the cushions for the inflexibility of the ship in passing over a change of gradient. If the film of water were contained in an open tank it would flow, when the car was on a gradient, to its lower end, leaving the upper end of the ship aground. The cushions divide the tank of water they represent into separate transverse bands independent of each other.

In passing over the change of gradient, the rise and fall of the water occurs successively in the vertical portions of the cushions, which form reservoirs to accommodate the water required for the varying space between the bottoms of the car and the ship; the changes of level or head running along the row of hydraulic cushions as the vessel travels over the change of gradient, like the passage of a ship across a smooth swell at sea. The movement of the ship, though perfectly free, is of very slight range vertically, and there is practically no horizontal movement on the cushions. The latter effect is the result of fluid friction inside the cushions, and surface friction outside them. The cushions have absolute immunity from damage by cutting or abrasion, by barnacles, stones, or any rough projection like the keel of the ship, owing to the absence of resistance in the water within the cushions.

The bottom of the car forms a flexible platform, consisting of tranverse sections hinged together, resting upon two trains of trucks on each railway line—*i.e.*, on seven lines there will be fourteen trains of trucks, called compound bogies. The peculiarity of these bogies is that, while each train of trucks is linked together, end to end, so as to allow of free lateral movement, guided only by the wheel flanges on the rails, the train has only a single centre pin connecting it through a swinging bolster on one of the constituent trucks to the bottom or platform of the car. The car links the trains of trucks together, while leaving them free to bend laterally round the railway curves, on which they are guided by the wheel flanges, the rails being pressed into the service as guides to keep the trains of trucks in position under the ship-car, which they support. A five-line ship railway will carry a flexible car containing a 270-foot ship, of 2000 tons burthen; but the addition of one or two parallel lines of railway will adapt it for larger and heavier ships, at a moderate additional expenditure, as compared with deepening or enlarging a canal. At the sea end of the ship railway a submerged slipway is built, consisting of the railway inclined to a gradient of about 1 in 20, resting upon a bed of masonry, leaving the rails in high relief, and enclosed within a small wet dock.

The car is made up of sections attached to each other by hinges at the bottom to suit the length of the ship to be carried, the sides are adjusted to the width by sliding them inwards towards the centre line, the hydraulic cushions set in position to form a bed for the ship, and the whole run down under water till the bottom of the car is deeper than the bottom of the ship. The segments forming one side of the car are hinged and temporarily lowered to admit the vessel sidewise. As the car is hauled up the slipway it carries the ship along in it, which gradually settles on the hydraulic cushions without further adjustment. The way of the vessel and car, which are towed by locomotives, need not stop, except at stations, for the delivery and reception of cargo.

The same provision applies to the control of the momentum by continuous brakes as to the distribution of the weight over a great number of wheels. The momentum being a function of the weight, continuous brakes applied to every wheel will possess the same control over the momentum of the ship railway car as they would over a railway train in proportion to the weight per wheel. The launching of the vessel at the end of its journey overland, is the converse of the operation of taking it on the car.

Ship railway docks in cities will be much more compact than either wet docks or railway goods termini, the quays consisting of lofty warehouses, affording economical storage for goods on several floors from the ground up to the level of the deck of the ship. (See Fig. 4, Plate III.)

In the event of the general use of ship railways for heavy inland traffic, there will be a strong motive for the introduction of uniformity of lines and dimensions of vessels. For a vessel of a certain tonnage and speed, it will be advisable to conform as closely as possible to certain standard lines to which a ship railway car may be more readily and economically adapted. Where traffic has no communication necessarily with the sea, ship railway traffic may be carried advantageously in hulks, with a minimum gross weight, including hydraulic cushions. On existing railway lines hydraulic cushioned cars, to carry 100 ton freights of grain, &c., may be adapted to run economically over a single track.

The PRESIDENT said they had heard Mr Smith's description of the ship railway, and he was sure they were all indebted to him for coming from Aberdeen to read the paper. At that late hour they could not discuss it, but if any gentleman had anything to say upon it they would be glad to hear him. If not, the discussion would stand adjourned till next meeting.

The discussion of this paper took place on the 21st January, 1890.

Mr R. DUNDAS had been struck by the very large proportions of the railway described by Mr Smith. That a ship railway could be constructed and vessels of the size stated by the author could be carried overland on railway, he thought no engineer would gainsay. The whole thing was a question of expense. This proposed railway was simply an elaboration of the principle of the patent slip, only that the vessels were proposed to be hauled by locomotives instead of stationary engines by means of ropes or chains. That vessels could be transported on land had also been proved; for not far from this place there was an incline where vessels had been hauled from a lower basin to an upper basin, and *vice versa.* But with regard to some of the statements made by the author he must say he looked on them as taking too rosy a view of the matter. He would take the author's assumption first, that the measure of the traffic on a single line of railway would be 50 goods trains in the 24 hours, and that there would be an equal number of passenger trains—

that is, 100 trains a day—at a speed of 15 miles an hour. The author further assumed that this same number of trains and speed would be attained on this gigantic railway of five or six lines of rails in breadth. He was of opinion that 15 miles an hour for moving such a mass, with 155 bogies under it, was far too great a speed to assume. A much more prudent assumption would be half of that speed, or 7½ miles an hour. Then there was another element which he did not think Mr Smith had taken into consideration in regard to those carriages travelling across the land on five parallel lines of railway, and only a single line after all—that was, the danger of a breakdown. On a single or double line of railway something did give way occasionally, and there was a breakdown. That took place at present sometimes by one truck giving way, which brought the whole train to a standstill, and sometimes the momentum of the other trucks following caused such disturbance that the trucks got piled one upon the other, and much time and labour had to be expended before the traffic could be resumed. Now, what would be the case supposing an axle of one of these numerous bogies were giving way in the centre or anywhere except at the outside of the train? It would bring the whole mass to a stop, and probably before it could be brought to a standstill great destruction would ensue. They would thus have a vessel stranded inland, and he thought it would be an enormous task to get all matters put right, probably after a delay of many days or weeks. He believed it would be as serious a matter to get one of those vessel trains on land started again as if she were sunk at sea in a moderately accessible depth of water. That was one of the difficulties that presented itself to him with regard to this ship railway. Another point worthy of consideration was as to its facility of distribution inland of materials carried by sea. He was of opinion there could be no doubt that it would not facilitate the distribution of cargo so much as if the ship had landed it at a port. Let them take the ports of Greenock or Glasgow. There a ship came alongside the quay, and the material with which the vessel was loaded, if it had to go by railway, was landed into the trucks at once and taken to the various points of destination. This would still occur although the ship was carried on rails inland. There must always be railway carriage and cartage of goods for actual distribution, so that he did not think it was much matter, as long as materials were to be distributed over this country, whether they were taken say five miles less by railway and ten miles more by ship, or whether it was to be ten miles less by ship and five miles more by railway. The railways had been found hitherto to be the best deliverers. Many works had their own sidings, with very sharp curves, into which waggons were run speedily, and that in quantities as required, some getting 5, 10, or sometimes 100 waggons a day, or it might be half a waggon load at a time. The ship railway could not go into them. The only other point that he would notice in reference to this ship railway was in regard to the cost. He thought the author was not very far wrong in what he assumed to be the ordinary cost of railways in the country—about £10,000 a mile; but when they went into the cities to construct a line there was much more expense. Well, Mr Smith assumed that his railway, which would be but a single line, would be five times the breadth of an ordinary railway; it, therefore, would cost nearly five times as much. Further, he did not think it was possible to carry on such a railway the number of vessels that Mr Smith assumed. If they took 100 trains per day, as the author assumed, that was something less than a quarter of an hour a ship. Whether it was possible or not to bring a ship, of even a smaller size than he said, safely from the port on to the railway in that short time, he would leave those who were used to docking ships to judge. He thought it would take much longer than a quarter of an hour to put a vessel on the slip and safely set it upon its landward journey, and especially so to send a continuous succession of them at such an interval. Then there was another point in regard to what had been said as to their construction in urban districts. There were very great difficulties of cost and otherwise experienced in extensions of railways around cities, or in widening the existing lines. He thought there would be greater difficulties experienced in making so wide a railway around cities in addition to those lines already there. That there were places which a ship railway would suit he had no doubt; but he did not know of any such place in this country where it would be suitable. In some foreign countries where land was cheap, and it did not matter very much where they went, if the levels were at all suitable, he believed that a ship railway might be more successful than a canal for crossing an isthmus, with the exception of any of the trains giving way, which might cause great detention; and this was a very serious matter.

Mr ROBERT SIMPSON agreed with Mr Dundas that ship railways would not do for a country like this: they might suit where land was not so precious as here, such as in the Isthmus of Panama.

Professor JENKINS remarked that Mr Dundas had discussed the proposed railway: he would like to say a word or two about the ship. Mr Smith's was a very brilliant idea, and he (Professor Jenkins) wished it were possible to carry it into effect without injury to the vessels carried. No doubt, if all vessels were of the same form and size, the plan proposed would succeed. But practically no two ships were alike in form, and it was this fact that led him to doubt the feasibility of Mr Smith's plan. Assume for the moment that the people who prepared the carriage knew nothing of the underwater form of the vessel for which it was to be used. It might be prepared for a vessel having a considerable rise of floor, whereas the vessel herself might have a very flat floor; or it might be prepared for a vessel having a very flat floor, and the vessel carried might have a sharp floor. What consequences would follow? The cushions were only capable of accommodating themselves to difference of form between the ship and the bed to a limited extent; and in the case where a flat floored vessel rested upon a carriage prepared for one having considerable rise of floor, she would bear hardly at the bilges, forcing the water away from the places of contact. The bottom would be unsupported, and severe straining would follow if the vessel were laden. In the other case, where the vessel had considerable rise of floor, and the carriage prepared for a vessel having a flat floor, she would bear hardly upon the carriage on each side of the keel, the bottom from near the keel to the side being practically unsupported. It might be said that cases of the kind mentioned could be remedied by the insertion of additional cushions after the vessel had been drawn ashore, but in the meantime the mischief would have been done. Moreover, as the vessel would be bearing heavily against the carriage near the middle line or at the bilge, as explained, it would be impossible to get the additional cushions round her. Similar difficulties would be met with forward and aft, where the variations in form were so very great as to make it impossible to arrange to adequately support a vessel without having her plans. But it might be said that a vessel's plans could be furnished a month before she required to use the railway, and in the meantime the carriage could be suitably prepared. If this were possible the difficulty would be overcome; but he asked them to consider for a moment the immense amount of plant that would be required, and the great labour involved in specially preparing a separate carriage for each ship. He would like to say one word on the subject of the water in the cushions. Some years ago he was inclining a vessel in the south West India dock. Her ballast tanks had been filled, and the water in the dock was so still that he could not observe a ripple. Notwithstanding this, the vessel had some small dipping motion, and although this could not be detected on board, it was sufficiently great to force water out of the tanks through the sounding pipes on to the deck every time the vessel dipped. In the same way, in the ship railway, he had no doubt that the jerking that would take place would speedily empty the cushions of a good part of their water. That was not a very important point, but it was one that would have to be attended to and provided against. With regard to the distribution of cargo, he agreed with Mr Dundas in saying that anything like a general distribution through the agency of the ship would not pay. Instead of going about from town to town discharging a few tons here and a few tons there, the owner would be anxious to get his ship unloaded, in order that she might load another cargo.

Dr T. F. **Macdonald** said two points struck him most forcibly upon hearing Mr Smith's excellent description of his ship railway—the originality of his hydraulic cushions, and the perfect manner in which they fulfilled their important functions of enabling a ship to be waterborne in transport across country. A natural question occurred to him as a student of physiology, viz., How did Nature perform the task of carrying great weight and delicate material, as she was frequently asked to do in animal economy? His attention was consequently directed towards a consideration of the brain, joints, and feet of animals in reference to the above question—more particularly to the mechanism found to obtain in the horse's foot. In the horse's foot there was a system of cushions subservient to hydraulic law by virtue of the blood vessels, &c., which were contained within them—blood cushions they might be termed—and they performed a function comparable to that of the cushions seen in Mr Smith's model. Dr Macdonald then showed by models and diagrams the action of the cushions whereby the weight coming down the bones of the leg is distributed over the foot.

Professor **Barr** said that no doubt Nature repaired her hydraulic cushions; but such self-restoration would be difficult to carry out in regard to the wheels and axles of the ship railway. He was very much struck by the ingenuity of the system proposed by Mr Smith, and he thought it might easily be carried out with regard to canal boats varying little in dimensions and lines. He thought that the difficulty which Professor Jenkins had stated might possibly be overcome, but not very easily.

Captain **Bain**, Nautical Assessor to the Board of Trade, said he was not going to say anything at all on the mechanical construction of the railway. He would leave that in the engineers' hands. But he looked somewhat anxiously to the safety of the vessel. He would like to know who was to be responsible for the vessel while on the railway? Was it to be the master, or the railway people who were to be in charge of the vessel? Now, with regard to the difficulty about the concussion in travelling, he thought that the cushions and chocks underneath them could be guided quite as well upon the railway as upon the ordinary slip. He thought that the ship could be set at rest, but he was not sure that a ship could be carried by railway at 15 miles an hour in safety. With regard to the cushions, and the illustration of their use by the description of the horse's foot in carrying the ship, it was a new revelation to him. He had learned something at every meeting of the Institution he had attended, and that night he admired the courage of the author, who, he supposed, only meant to carry small vessels on his railway, and not ships like the "City of New York" or the "City of Paris." He would like to know what it was proposed to do, while transporting steamers, with the water and steam in the boilers, and how it was meant to dispose of the cooking apparatus? He hoped that success would attend the author's labours in this matter.

Mr A. W. THOMSON asked whether the author had considered the oscillation from the force of the wind on the ship? Mr Smith had spoken of having gradients of 1 in 50. He believed that would prove too stiff, and that a ruling gradient of 1 in 250 was ample.

Mr SMITH, in replying to the discussion, begged to thank the gentlemen who had joined in it for the interest they had shown in the subject he had brought before them, and for the opportunity the discussion had given for further elucidating the mechanical details and principles of the flexible car ship railway, which had necessarily been but briefly alluded to in the paper. The various systems of ship railways proposed for the transport of laden vessels were in no sense a mere extension of the patent slip or the incline at the Monkland Canal, as suggested by Mr Dundas. The main mechanical principle of ship railways was the distribution of the weight of the ship and car over a great number of wheels on parallel lines of railway of the ordinary 4 feet 8½ inch gauge, with 6 foot ways between, so that the maximum pressure on each wheel should not exceed the resistance of the permanent way or the strength of the wheel and axle. The slip and the inclined plane consisted of a single line of railway, and no attempt at a curve or change of gradient could be made upon them. The rigid car system of ship railway in course of construction at Chignecto, Nova Scotia, and proposed for the conveyance of vessels across the Isthmus of Tehuantepec, between the Gulf of Mexico and the Pacific Ocean, was subject to the same disadvantage: the vessel resting on keel and bilge blocks on the car, the latter could not be accommodated to any curve or change of gradient upon the ship railway. The formation of a ship railway line perfectly straight and dead level was practicable only at Chignecto. It was impracticable at Tehuantepec, and it was proposed to get over the difficulty of lateral changes of direction by the introduction of huge floating turntables, and of changes of level by hydraulic lifts. These expedients would be exceedingly costly, and slow in working. Upon the flexible car system, which the working models illustrated, both curves and gradients were introduced as freely as in an ordinary single line railway, while the laden vessel was kept constantly waterborne upon the car. The limit of the goods traffic capacity of a single line of railway given on page 93, was no assumption of Mr Smith's, being obtained from the able work on railway management published last year by Mr Findlay, the general manager of the London and North-Western Railway. The momentum of the vessel and car upon the rails was no barrier to obtaining a high speed; so long as the momentum was equally under control, the same speed as that of an ordinary goods train was equally safe upon the ship railway. The momentum being a function of the weight, the same provision of a great number of wheels provided equally for the application of brake power which would keep the moving car containing the vessel completely under control at a speed of 15 miles an hour. In fact, Mr Smith considered from the present limit of speed upon existing railways being due to the lateral oscillation of the rolling stock, that the introduction of multiple line railways, providing a wheel base 60 or 70 feet wide, would make lateral oscillation impossible, and allow of the attainment of high speeds at present unheard of. There was no greater liability to accident on a ship railway than on any other means of conveyance. The novelty of the system would be met by the gradual gain of experience on small lines at first, and the subsequent introduction of broader lines and heavier ships. Most of the objections urged by Mr Dundas and Mr Simpson to the economic value of ship railways, as a means of inland communication, had been fully met beforehand in the paper, as on page 98, where the enormous value of demurrage due to the transshipment of goods was indicated; on page 87 the value of distribution in large mass; and on page 96, where the sources of economy in transport by ship railway are enumerated. The slipping of the vessels on the cars would be done in much shorter time than 15 minutes each, owing to the fact that they would continue to be waterborne on the cars, the hydraulic cushions accommodating the lines of the vessel automatically. The traffic capacity of a ship railway from this cause, and the high speed of transit, was far higher than that of a ship canal or an ordinary railway. The economic value of the flexible car ship railway would thus make the chief field for its use not merely the replacing of the ship canal in crossing a narrow isthmus, as believed by Mr Simpson, but the much more vast and important function of the transport of goods in large bulk between large cities in populous countries. The finest field in the world for the introduction of ship railways lay in conferring the immense advantages of direct oceanic trade upon the large inland manufacturing and trading cities of England. Every one of these inland cities might be converted into a first-class seaport by the ship railway. The natural tendency of oceanic trade by large vessels was to get as far inland to their final port of call as possible, the case of the rival ports of Greenock and Glasgow on the Clyde being one of the best examples. Mr Smith was indebted to Professor Jenkins for the full discussion of the special features of the flexible car. The exact adjustment of the rigid car to the dimensions of different vessels was one of the chief difficulties to be met at Chignecto, where such a special register of the lines and dimensions of vessels as Professor Jenkins indicated was projected. The use of that ship railway, however, would probably be confined to coasting vessels engaged in local trade. Lloyd's register of shipping contained more than ample dimensions of every vessel afloat to enable the flexible ship car to be adapted beforehand for its reception.

The traffic of the ship railway could no more be accommodated on a single car than could the traffic of an ordinary railway on a single goods waggon. The rolling stock of the ship railway might be varied to suit vessels as trucks were adapted for various classes of goods. Given the length, breadth, and tonnage of a vessel, and a car could be run together on sorting sidings in sections varying in length and number to suit any length of ship: the sides of the sections slide in towards the centre line to suit the width, while the hydraulic cushions adapt the car automatically to a vessel of any lines. The vessel had no part of its surface in contact with the car, the keel, bilge, and every inch of the skin being waterborne. There were therefore no strains placed upon the ship in going over a change of gradient other than the vessel experienced in moderate weather at sea. The effect of passing over a change of gradient was to increase the space between the bottom of the vessel and the car bottom. The increased space was filled with water instantaneously by the subsidence of the water in the vertical portions of the cushions, lowering the head of pressure. This lowering of the head of pressure, which only amounted to a foot or two in the largest vessels, passed along the vessel like a smooth swell on a calm day at sea. The hydraulic cushions fulfilled several important functions in the flexible car ship railway system—1, they kept the vessel wholly and constantly waterborne on the car; 2, they split up the tank represented by the car into separate transverse bands, allowing the car body to be made flexible vertically; 3, they kept the vessel uniformly afloat from stem to stern when the car was inclined on a gradient; 4, they compensated the variations of space between the vessel and the car in passing over a change of gradient; and 5, they formed a self-adjusting packing to fit vessels of various lines to the same car. Mr Smith here removed a 22 lb. block of timber off a hydraulic cushion in a U shaped case, showing how the water in the interior of the cushion subsided instantaneously to the bottom; and on replacing the block how the water instantaneously adapted the cushion to the shape of the block, and how a line marked by Professor Jenkins on the block would have been met equally automatically by the cushion. Professor Jenkins had argued that the water would be forced up out of the cushions by any oscillation or surging of the vessel, instancing a case of the water being forced to a great height from the bilge pipes of a vessel by hydraulic action due to sudden movement of the ship. Mr Smith pointed out that the force required to propel water above its own head was not in any case hydraulic—it must be pneumatic. The elasticity of the air compressed within the bilge pipes instanced by Professor Jenkins would store up the hydraulic power generated by the movement of the vessel and squirt the water to a great height. Mr Smith related the difficulty formerly experienced in maintaining the South Breakwater at Aberdeen Harbour owing to the destructive force of compressed air. The concrete blocks forming the lower portion of the breakwater were repeatedly thrown out of the sea face into the sea, and on investigation beneath the surface in a diving dress Mr Smith discovered that this action took place invariably in front of cavities left in the interior of the structure by the destruction of the timber piles by sea worm. The water from a passing wave flowed in through the open joints of the blocks, which were at the same time sealed up by the wave confining the air in the cavity beneath the solid superstructure, and the pressure per square inch of the compressed air rapidly accumulated on the top of the column of water in the cavity, until, multiplied by the area of the inner end of the block, it blew it out with a force actually explosive. Wherever there was a crack or rift in the superstructure, the water was blown up into the air like an Icelandic geyser to a height of 50 or 60 feet. The grouting of the breakwater airtight had stopped this destructive action. Hydro-pneumatic action was utilised in the Moncrieff gun carriage and the hydraulic elevating ram, but was carefully avoided in the hydraulic cushions for the flexible car ship railway by leaving the ends of the cushions open. The pressure applied by Professor Jenkins suddenly to the model block was equivalent to a sudden dropping from a height 2000 or 3000 tons additional load on to the deck of a vessel—an impossible contingency—and the squirting of water was caused by the admission and sudden compression of air in the cushion. The valuable discovery made by Dr T. F. Macdonald proves that the principle of supporting and moving a heavy and bulky body safely overland by the interposition of hydraulic cushions is one of the most widely applied in Nature. Although, according to Professor Barr, Nature repaired her hydraulic cushions, it was easier for Art to provide any repairs in the case of transporting a vessel. If one or two of the cushions were accidentally damaged they could be withdrawn while the car continued in motion and replaced with new cushions or patched and replaced, the vessel in the meantime settling down an inch or two deeper on the other cushions. In reply to Captain Bain, Mr Smith indicated that the vessels when on the ship railway would legally be at the risk of the carriers, like any other goods, but the principle of insurance could also be applied. He wished it to be clearly understood that vessels would be kept wholly and constantly afloat on the flexible car, and that passing over stones could no more affect the vessel than stones on the sea bottom. The hydraulic cushions were the provision for passing over changes of gradient and keeping the car flexible vertically; the provision for passing round curves and through points and crossings was the compound bogie shown on the diagram and described on page 102. The differentiation of the lateral from the vertical flexibility had simplified the action and economised the weight to be transported. Mr Thomson had referred to wind pressure. This was met laterally by the enormous width of the wheel base, the aggregate gauge for a large ship car being 70 or 80 feet; for a sailing vessel it was considered quite practicable to utilise the wind on the sails for propelling the car. The gradient shown on the working model was 1 in 50, the ruling gradient on the Edinburgh Exhibition ship railway for 30 foot boats was to be 1 in 20, and the only limit to steepness of gradients on the flexible car ship railway was economy of motive power for haulage.

The PRESIDENT said they would all join with him in giving Mr Smith a very hearty vote of thanks for coming to tell them about the ship railway, and had no doubt that when the Edinburgh

Exhibition opened, his model ship railway would be one of the most interesting things exhibited. He had great pleasure in moving a vote of thanks to Mr Smith for his paper.

The vote of thanks was heartily accorded.

On Railway Construction in the West Indies.

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

(SEE PLATE IV.)

Received and held as Read 21st January, 1890.

DESCRIPTION OF COUNTRY.

The subject of railway construction in this country has been well discussed in all its details, and it would perhaps be interesting to some of the members of this Institution to have laid before them a short description of the methods employed in constructing a line of railway, including several large bridges, in a country where no mechanical means were available, and where the steam engine was unknown. I have, therefore, taken advantage of a visit to the Island of Santo Domingo to put together a few facts relative to the construction of the first line of railway in that country.

Santo Domingo is the second largest, the most fertile, and one of the healthiest of the West Indian group. The railway, which has only recently been constructed, extends from the east coast to the interior; but before proceeding to a description of the building of this railway, and, more particularly, of the methods employed in erecting the bridges, I propose to give a short description of the island and its inhabitants.

The area of the island is about 28,000 square miles, or, roughly, equal to the area of Ireland. Its greatest length from east to west is 360 miles, and its greatest breadth from north to south 140 miles. It is divided into two Republics—the Dominican Republic, on the east, occupying about two-thirds of the island, and the Haytian Republic, on the west, occupying the remaining third. The Haytians have a deep-rooted aversion to the white man, and are very jealous about allowing him to settle in their country. The Dominicans, on the other hand, give him every encouragement, the Government being always willing to grant concessions of land to Europeans or Americans. The language spoken by them is pure Spanish.

The population of the Dominican Republic is only about 400,000, of which by far the largest proportion live in the coast towns. As regards its general physical features, the country consists of large and extensive plains separated by ranges of mountains running east and west. These plains are for the most part extremely fertile, and well watered by numerous rivers. In some places the soil consists of pure black leaf mould, extending to a depth of from 18 inches to five feet. On this soil are grown tobacco, coffee, sugar cane, cocoa, bananas, pine apples, oranges, cocoa-nut trees, &c., and the best results are obtained. In other places where the soil is not so rich, these plains are covered with grass, forming pasturage for vast herds of cattle. For the most part, however, the land is still in the virgin state, covered with forest. These forests extend up the slopes of the mountains right to the top, a large proportion of the trees being mahogany, logwood, pine, cedar, lancewood, &c.

The natives are whites (descended from the Spaniards), negroes, and mulattoes. For the most part they are very poor, and only cultivate the soil to supply themselves with the necessaries of life. The climate is hot, but the range of the thermometer is not great, and although there is plenty of rain, it never lasts long at a time. The people, therefore, living in their small wooden houses, suffer no hardships. A great many of them cultivate tobacco, sugar cane, coffee, and cocoa, but only in small patches of about an acre or so, as the exertion necessary to keep a larger clearing in order would be too much for them. Still, when the tobacco produced from all the small clearings comes to be collected it forms a very imposing quantity.

As a rule, all the products have to be conveyed to the coast on horseback, and as the roads are very bad, sometimes two feet deep with mud, this is a very tedious job, costing sometimes as much as the value of the goods themselves. There are several good natural harbours, but nothing has been done to improve them in any way. The largest and best of these is the Bay of Samana, on the east, 25 miles long and 8 miles wide, and deep enough over its entire area to float the largest vessels. A Commission, sent out by President Grant, surveyed and sounded the whole bay, and reported that there was sufficient sea room for all the navies of the world to manœuvre.

From the head of Samana Bay the railway runs westward through the centre of a very fertile valley, called La Vega Real (Royal Valley). It is about 70 miles long and 30 miles wide, and is bounded on the north by the Monte Cristy range of mountains, and on the south by the Cibao range. This valley, with the exception of about 10 miles, is thoroughly drained by the river Yuna and the numerous tributaries which fall into it from the north and south. The railway is 62 miles long, and the terminus is at a town called La Vega, a place of slightly over 2000 inhabitants.

Going westwards from the head of Samana Bay we first cross 10 miles of swamp, covered with the most dense forest and undergrowth, through which daylight can hardly penetrate, and where the mosquito is all-powerful. For the next 24 miles the land is almost all in virgin forest, with a few clearings here and there. Next we have 8 miles of savannah lands, extending to the hills on both sides of the railway; and from these savannahs as far as La Vega, and 5 miles beyond it, the soil is extremely rich, consisting of pure leaf mould. It is on this land that the best tobacco is cultivated, and now that there is a proper means of transport it is expected that the quality will rival that of Havana.

BRIDGES.

The railway keeps the north side of the river Yuna, whose tributaries are so numerous that no less than 132 girder bridges had to be built, varying from 1 span to 7 spans, and in height from 8 feet to 26 feet. There are four types of bridges, and before anything was done each river or stream was carefully measured, and the type to be erected noted, so that, when the time came, the proper materials could be sent on, and no confusion arise. This was very important in this country, where the transport was difficult, and the labourers untrained. The most essential points to be observed, therefore, were to have the separate parts of the ironwork as light as possible, and as easily put together as possible.

TYPES OF BRIDGES.

No. 1.—For large streams, often in flood, carrying down trees, &c.

No. 2.—For large streams, in which the current is sluggish, and therefore no danger to be apprehended from trees being carried down.

No. 3.—For streams where a less span than 25 feet was sufficient.

No. 4.—For the passage of water from one side of the railway to the other during heavy rains.

As all the materials for the bridges had to be sent out from this country, and as there were no means in the island for erecting large girders, it was found necessary to keep the spans small, and also to keep them as far as possible of the same size. After inspecting all the rivers and streams, 25 feet was fixed on as the length of the girders. Thus, for a small stream one span of 25 feet was sufficient, but for larger streams, bridges of two, three, four, &c., spans were erected.

The chief difficulty to overcome was the construction of the abutments and piers. There was said to be no stone in the valley suitable for building, and even if there had been, there were no means of getting it, as everything had to be conveyed on horseback over most difficult roads. The river bottoms consist, on some parts of the line, of soft clay, and on others of sand and gravel, very apt to be scoured out when floods occur, so that even therefore if stone had been available, it would have been found quite impossible to get down for proper foundations. Plenty of good sand and gravel however, could be got for making concrete, and this being the case it was decided to make the piers as follows :—

Cylinders of malleable-iron, ⅛-inch thick, 4 feet in diameter, and in lengths of 6, 3, and 2 feet were made and sent out. These cylinders had a rim of angle-iron 2½″ × 2½″ × ⅜″ round the inside of the top and bottom, except the bottom cylinder of each pier, which had no rim round the lower edge. The rims had ½-inch holes every 12 inches, so that one cylinder could be placed on the top of another and bolted to it. Each of the 6-feet cylinders weighed about 4½ cwt., and they were easily handled by the men.

Having fixed the position of the pier of a bridge, a cylinder, with a cutting edge at the bottom, A, A (see Plate IV.), was forced down through the sand till the upper edge was nearly level with the water. If, however, the water was deeper than 6 feet, another cylinder was bolted to the top before sending it down, the men working from a wooden platform erected in the river. The water was then pumped from the inside of the cylinders, and a man sent down to excavate the sand. Another cylinder, B, was then bolted on to the top, and the whole thing sent down further. When the bottom cylinder was down far enough to be out of the reach of scour, the stuff was excavated down to the bottom and the space filled with concrete. Other cylinders, C, C, were then added to the top and filled with concrete, till the pier reached the required height.

Except in times of flood, the depth of water in the rivers seldom exceeded 3 or 4 feet, but in some of the water-courses called "caños" (old river beds), there is hardly any motion in the water, and the depth often exceeds 6 feet, the bottom consisting of soft material for a considerable depth further. It was in these cases that the most difficulty was met with in sinking the cylinders, as platforms had to be erected in the water from which to let them down. In one or two of the caños some of the piers were sunk as much as 20 feet before the hard was reached. As a rule, however, the beds of the water-courses consisted of clay or coarse sand and gravel.

As an example of the difficulties which sometimes lay in the way of getting down these cylinders, I may mention a case in which, in 10 feet of water, it was found that there was an obstruction under the cutting edge. This was discovered to be the decayed root of a large tree; and the engineer, coming forward at the time, missed the negro foreman. On asking where he was, one of the negroes, pointing to the water, said, "Down there." This was really the case, and he succeeded in remaining under water sufficiently long to tie a rope round part of the root, which was then drawn out by about twenty men.

In another case, when the cylinders for the bridge over the river Jaigua were being sunk, rain in torrents began to fall on the hills, and in a very short time the river was a roaring flood. The water came down so suddenly that the men had hardly time to get clear. On resuming work, when the water had subsided, the cylinders were found to be filled to the top with sand and mud. This had no sooner been cleared out than down came the flood again, filling them up once more, and tilting some of them over, entailing a great amount of time and labour to get them put right again.

Again, in the river Nigua, the centre cylinder had just been put in its place and bolted up, and the men were commencing to put in the concrete, when the river rose, bringing down some heavy timber. The cylinder, although it was founded 8 to 10 feet below the bed of the river, was knocked over, buried in the mud, and lost. In another case, where a three-span bridge had been erected without filling the cylinders with concrete, the whole thing was suddenly swept away and buried in the mud. These examples will give some idea of the circumstances under which the bridges had to be put up.

In almost all the bridges the piers were placed 25 feet apart, centre to centre, and sunk from 6 to 10 feet below the river bed. For the bridges of type No. 1, the piers in the centre of the river were formed of two cylinders put down side by side, 7 feet apart, centre to centre, and tied together by small rolled beams, H, 9 feet long, inserted in the concrete. In a few cases the centre span was made 30 feet. For the bridges of type No. 2 single cylinder piers were sufficient. The abutments in all cases were formed of one or two lengths of cylinders, K, K, as the case required; and the bank sloped down at an angle of 1 to 1 on three sides, and was protected on the river side by large stones. These stones were worked from a limestone quarry in Arenoso, 17 miles from Sanchez, and formed a capital facing, hardening and cementing together on exposure to the weather. This was done after the line had been completed, as the limestone deposit was not discovered till then.

The superstructure of the bridges was very simple. Rolled beams, D,D, 6 in. by 5 in., and weighing 29 lbs. to the foot, were laid two feet apart across the top of each pier, and bolted to the angle iron rim. For double cylinder piers these beams were 11 feet long, and for single cylinders 5 feet. Two rolled beams, E, E, 16 inches by 6 inches, and weighing 62 lbs. per foot, were then placed 3 feet 8 inches apart, centre to centre, with their ends resting on these cross beams. The longitudinal beams, which were nearly all in lengths of 25 feet, were bolted down to the cross beams, and at the junctions were fastened together with fish plates, F, F. The sleepers were bolted to the upper flanges of the beams. In order to prevent any lateral motion, there were put in in each span six bolts, G, G, 3 feet 10 inches long and 1 inch diameter, inside straining tubes, H, H, 2½ inches diameter, the bolts at the ends passing through the fish plates. The long beams weighed about 14 cwt. each, and were hoisted and drawn into position by means of ropes over wooden trestles. The safe distributed load for a 25 foot span of those bridges is about 30 tons. With the present rolling stock any weight that can possibly come on one span does not exceed 25 tons, so that there is a considerable margin of safety.

In the smaller streams, where a less span than 25 feet was sufficient for the passage of the water, the longitudinal beams were made 18 feet long, 12 inches by 5 inches cross section, and weighing 42 lbs. per foot, but everything else was the same as in the larger bridges. This was type No. 3. The bolt holes were all bored before the ironwork for the bridges was sent out, and as the cylinders and beams of each size were made exactly alike, no confusion could arise when they were being used.

The largest bridge is that over the river Camu, about 3 miles from the La Vega terminus. This is a wide river, often in flood, when the water comes down with great velocity, carrying large trees torn up by the roots. This bridge was made with four spans of 50 feet and two of 25 feet, the three centre piers of double cylinders 6 feet in diameter, and in lengths of 3 feet. These piers are 26 feet high, and sunk 15 feet into the gravel and sand down to the hard. The next piers on each side of these are single 6 feet cylinders, and the abutments the usual 4 feet ones. The superstructure was finished in the same way as before described, only, instead of rolled beams for the 50 feet spans plate girders were put on. Each of these girders weighed 4 tons 4 cwts., and as they had to be drawn forward by ropes from the end of the 25 feet spans, the operation of placing them in position was very much more difficult than the placing of the rolled beams weighing not more than 14 cwts.

As tremendous volumes of water fall in a very short time in the valley, shut in as it is between two ranges of hills, it was found necessary to leave in all the embankments a great number of passages for the water to get readily from one side of the railway to the other. In one case 4·80 inches of rain fell in 2 hours 25 minutes, and this was by no means the greatest rainfall.

These passages for the water were made 8 feet in width, the abutments being formed of blocks of concrete, L, L, 9 feet long by 3 feet wide by 4 feet deep. Across these were put six old 75 lb. rails, M, M, in sets of three, 3 feet 6 inches apart, and on these old rails the sleepers rest. About six of these small bridges, type No. 4, were put in to the mile.

The cost of the 25 feet span bridges, including materials, carriage and labour, was as follows:—

Bridges of	1 span,	height	6	feet,	-	£50	0	0
„	2 spans,	„	8	„	-	100	0	0
„	3 „	„	10	„	-	210	0	0
„	4 „	„	12	„	-	330	0	0
„	5 „	„	15	„	-	460	0	0
„	6 „	„	20	„	-	580	0	0
„	7 „	„	25	„	-	700	0	0

The average number of spans is 3, and average height 10 feet. As an example of the details of cost, I will take a 3-span bridge, 10 feet high in the centre, and with piers sunk 8 feet below the river bed.

Excavation, - - -	cubic yards,	14 @ 5/,	=	£3	10	0
Cylinders, - - -	cwts.,	45 @ 15/,	=	33	15	0
Concrete, - - -	cubic yards,	27 @ 40/,	=	54	0	0
Rolled beams, - -	cwts.,	92 @ 12/,	=	55	4	0
Bolts, straining tubes, &c.,	„	17 @ 20/,	=	17	0	0
Protecting slopes, - -	cubic yards,	10 @ 5/,	=	2	10	0
				£165	19	0
	Contingencies, 25 per cent.,			41	9	9
				£207	8	9

The smaller type of bridge, 18 feet span, cost about £40, and the small rail bridges about £30 each.

PIER, ETC.

The commencement of the railway was originally intended to be at Santa Capusa, a small town about four miles eastward from the head of the bay, and this part of the line along the shore between Santa Capusa and Sanchez, the present commencement, was the first thing started. Banks were formed, and a great number of wooden bridges erected. But the nature of the country at this time was very imperfectly understood. Before six months were over, the wooden piles of the bridges were almost eaten through, and the rest of the woodwork was rotting quickly. The sea also was making inroads on the banks, and in some places the whole shore was slipping bodily into the sea. Vigorous attempts, however, were made to protect the banks with stones, collected with great labour, and the woodwork of the bridges was renewed. But it was ultimately seen that no structure made of wood could last any time in this country, and that there were some banks which could not be kept from slipping, so this part of the line, three miles in length, had to be abandoned.

In the meantime, the earthworks up the country were being vigorously pushed forward, but no bridges had been started. It was after the failure of the wooden bridges along the shore that the cylinder bridges were designed, which latter have been found to answer every expectation.

It was decided to make Sanchez the commencement, and a pier resting on wooden piles was erected. These piles were very quickly eaten through by small worms in the water, but by constantly repairing and renewing them the pier was made to last till all the materials had been landed. A new pier was then erected, partly on iron cylinders, and partly on wooden piles sheathed with old copper plates. As these piles decay they will be replaced by cylinders, the requisite number of which are lying ready. The pier is 600 feet long, 12 feet wide for 440 feet, and 30 feet wide for 160 feet at the end, where there is a double line of rails. The end portion rests on 4 feet cylinders filled with concrete, put down in rows 25 feet apart, 3 cylinders 10 feet apart in each row. Two rows of longitudinal iron beams, 16 inches × 6 inches, were bolted on the top of each line of cylinders, and on these the woodwork was bolted. There is only 7 feet of water at the end of the pier, and the difference between high and low water is only 18 inches, so that steamers cannot come alongside, the loading and discharging being done by means of lighters. The cost of the pier when completed with cylinders is estimated as follows:—

Single line with double cylinders for one span of 25 feet—

				£	s.	d.
Cylinders, - -	cwts.,	18 @ 14/,	=	£12	12	0
Concrete, - -	cubic yards,	11 @ 35/,	=	19	5	0
Rolled beams, - -	cwts.,	55 @ 11/,	=	30	5	0
Timber (3 inches thick),	cubic feet,	75 @ 1/2,	=	4	7	6
Labour, &c., - - - - - -				25	0	0
				£91	9	6

Double line with triple cylinders, £136 for one span of 25 feet.

Single line, - -	18 spans @ £92,	=	£1656	0	0
Double line, - -	6 spans @ £136,	=	816	0	0
Permanent way, -	253 yards, @ 10/,	=	126	10	0
	Total cost of pier,		£2598	10	0

EARTHWORKS.

As the means of transporting materials up the country were of the most primitive kind, and as it was absolutely impossible to convey the heavier materials, such as cylinders and rolled beams otherwise than by rail, a bridge could only be built after the rail-laying had been carried up to the edge of the river. The forming of the embankments, however, was carried on at various points. The nature of the country would not admit of any cuttings, and, even as it is, parts of the line are sometimes flooded. The embankments vary in height from 3 feet to 15 feet, the average, however, being only about 4 feet. They were made 12 feet wide at the top, with the usual slope of 1½ to 1. The material was all taken from the sides, the excavations forming ditches for the water. The cost was about £560 per mile to form the banks. The work was let in small contracts to Dominicans, who had to be very sharply looked after; some of them, in fact, were detected making up the banks with brushwood, and spreading a layer of earth over it.

About a mile from Sanchez, there is a swamp 9 miles wide, and this was by far the most formidable difficulty that had to be overcome.

The water, silt, and sand extended to a depth of over 18 feet, and the roots and leaves of the trees had formed a covering over it, but as this was not sufficient to support the weight of a man, and as the surface was covered with the most dense vegetation, the work of laying out this part of the line was both difficult and tedious. The trees and brushwood were cut down for a width of 100 feet, and on 30 feet of this the trees and brush were laid. On this bottoming earth and clay from Sanchez were then deposited. The bank was made 15 feet wide on the top, and such large quantities of stuff were swallowed up that, including the cutting down of the trees, and the carriage of the earth and clay, this part of the line cost £4200 per mile, exclusive of permanent way.

Even when the forming in the swamp was completed and the permanent way laid, it required constant making up, owing to the heavy traffic over it. As much as 250 cubic yards of sand and earth were put in daily for a long time, and this added about £1000 per mile to the cost of forming. There were only two small engines (6 inch cylinders) employed, and they were found well able for the work. One was constantly engaged on the swamp, while the other conveyed the materials up the country. Often the swamp work was stopped by the rain, and then the road became impassable, and bridge-building and rail-laying up the country had to come to a standstill for want of materials, so that the whole of the work up the line was dependent on the condition of the swamp.

In the nine miles of swamp no fewer than 57 rail bridges had to be built to give passage to the water, which had a gradual flow from north to south towards the river Yuna, and preparations are being made for increasing that number. It has taken three years for this part of the line to become consolidated. At first, when the small engine ran over it, its motion resembled that of a boat at sea. Now with the largest engine there is scarcely any vibration, and the swamp is looked on as the best part of the line.

PERMANENT WAY.

The laying of the permanent way was carried on as quickly as possible in the rear of the forming of the banks and bridges, so as to get the materials and men readily from one part of the line to another. The question of ballast was at first a serious consideration before the resources of the valley were known. The first ballast consisted mostly of sand got from the head of Samana Bay, and then a large deposit of good limestone was found near the surface at Arenoso, 18 miles from Sanchez. A quarry was here opened up near the railway, and a stone-breaking machine sent out. Part of the line was ballasted with this limestone, but afterwards in two of the largest rivers, the Yaiba and the Camu, large deposits of excellent gravel were got, and almost the whole of the line has now been ballasted with this, although it had to be conveyed 30 miles in some cases. The cost, including the excavation of the gravel, filling the cars, carriage, and ballasting, was about 2s 6d per cubic yard. A depth of 6 inches of ballast was put under the sleepers, and it was brought up to the level of the top and made 9 feet wide, so that there was about 1 cubic yard of ballast to the running yard. The same men filled the cars and ballasted the line, going and returning with the cars. About 110,000 cubic yards have been put on the line at a cost of over £13,000.

The first sleepers put in were made from the native woods, of which large quantities of seemingly good quality were growing at the sides of the line. A saw-mill having been erected, these were turned out in great numbers, but it was found that they decayed very quickly, and therefore required constant renewing. It was then thought that iron sleepers would need to be sent out, and a malleable-iron sleeper 5 feet 6 inches long, 10 inches wide, plate $\frac{3}{16}$-inch thick, was designed by the Anderston Foundry Co. These would have cost about three times as much as timber sleepers, and as pitch pine sleepers could be got readily from Charleston, in the States, it was decided to give them a trial. They contain little sapwood, and have turned out very well, some of them having now lasted over four years. It is estimated that with proper care they should have a life of six years at least. They cost 2s. each delivered in Sanchez.

The two agents which shorten the life of the sleepers are moisture and vegetation. Where there is the least moisture the flowers and creepers spread over the line in a remarkably short time, so that good open ballast is an absolute necessity in order to let the water drain quickly away. The Dominican foremen knew so little about this that they had to be constantly watched to keep them from mixing the ballast with clay and earth.

The rail-laying was done by platelayers sent out from Glasgow, assisted by native workmen; and when the conditions were favourable they laid at the rate of a mile per week. But the conditions were often the very reverse of favourable. Heavy rains would come on and wash away the banks before they had become solid, and that being the case, the supply of material had to be stopped till the banks were made good again. The platelayers, when they came to a river, had to undertake the erection of the bridge, and taking that into account, the average rate of progress was about two miles a month. Besides this, surfacemen were kept busily employed keeping up the line which was laid. Sometimes the permanent way was covered with as much as 18 inches of water, and when this cleared away there was always a considerable amount of making up to do.

When the work was in full swing there were employed 430 native labourers, at 75 cents a day each. (A considerable number of these men were, or claimed to be, generals in the Dominican army.)

The gauge of the railway is 3 feet 6 inches. The rails weigh 35 lbs. to the yard, and are spiked to the sleepers. The sleepers are 7 feet by 8 inches by 5 inches, and are laid 9 to the rail-length—24 feet. The spikes weigh 5½ ozs., the bolts 7¼ ozs., and the fishplates 4 lbs. each. The cost of the permanent way (not including ballasting) was as follows:—

Sleepers, per mile, - -	number, 1980 @ 2/,	=	£198	0	0
Rails, ,, - -	tons, 55 @ £7,	=	385	0	0
Fishplates, bolts, and spikes,	,, 3½ @ £11,	=	38	10	0
Rail-laying, - - -	yards, 1760 @ 1/,	=	88	0	0
Carriage of materials, -	- - - - -		170	10	0
			£880	0	0

To keep the 62 miles in order—that is, to renew sleepers, keep the weeds off the line, put in ballast when needed, and protect the banks with stones from Arenoso—there are employed 168 men, divided into squads of 14 men each, each squad being overlooked by a capataz or ganger. The line is divided into three sections, the capatazes on each section being under the orders of the section foreman, who again acts under the chief engineer.

The surfacemen and capatazes are all Dominicans, and cannot be trusted to do their work if left alone for any length of time. The capataz at first was usually to be got sitting on an old soap box, with a red umbrella above him, and it took considerable pains to get him to understand that he could not look after his men in that position. Their ideas of what work is had to undergo a thorough revolution. The cost of the upkeep of the line, including ballasting and protecting the slopes, is as follows:—

	Per annum.		
Engineer, section men, capatazes, and surfacemen,	£7,400	0	0
Engines, firemen, and couplers, - - -	1,668	0	0
Renewal of sleepers, - - - -	2,046	0	0
	£11,114	0	0

This comes to about £180 per mile per annum. When the line is fully ballasted and the slopes thoroughly protected, the upkeep should not cost more than £40 per mile per annum.

PLANT, ETC.

There are five stations on the line, including the two termini, there being about 15 miles between each two stations. There is only one train daily in the meantime, going in one direction the one day and returning the next; but this is only a commencement, and it is expected that when the traffic is fully developed, there will be at least two trains per day each way. Including stops, the train takes 7½ hours to accomplish the distance from one end to the other.

The engine has to stop at intervals of ten miles to take in water, so that, taking into account the stops at the stations, the average speed is 12 miles an hour. On some parts of the line, however, a speed of 25 miles an hour is obtained, and this is looked on by the natives as a fearful speed. There are 6 engines, varying in weight from 8 tons to 16 tons, the smaller ones with 6-inch cylinders, and the large one with a 9½-inch cylinder. There is a gradual rise from Sanchez to La Vega, 300 feet in the 62 miles, so that there are no bad gradients. The small engines are, therefore, able to work the traffic on the line with great ease.

There are two passenger cars, built on the American style, about 30 feet long, and 7 feet 6 inches wide; 30 goods vans; and about 60 ballast cars, holding 3 cubic yards each.

The straying of animals on the line is a great annoyance to the engine drivers—they cannot always draw up in time, and as the animals persist in running on ahead, they often come to grief. In this way cows, donkeys, pigs, goats, &c., have been killed in great numbers, but it seldom happens that the engine is knocked off the line. Part of the stoker's duty is to keep a stock of missiles, and look out for these animals to drive them off the line.

BUILDINGS.

The sheds, stores, workshops, &c., are all built of pitch pine, raised two feet off the ground, and roofed with corrugated iron, and are by far the finest buildings in the valley. The principal works are situated at Sanchez, and consist of an engine repairing shop, a waggon building shed, a sawmill, a carpenter's shop, a smithy, a wood shed, an oil shed, an office, and four large stores and goods sheds. At all the intermediate stations there are large stores, and at La Vega large and commodious station buildings have been erected.

COST OF LINE.

The whole cost of the railway may be put down as follows :—

Formation,	miles, 60 @ £560, =	£33,600	0	0
Extra for swamp,	„ 9 @ £4640, =	41,760	0	0
Bridges,		29,420	0	0
Ballasting,	„ 60 @ £220, =	13,200	0	0
Permanent way,	„ 62 @ £880, =	54,560	0	0
Land,	„ 62 @ £200, =	12,400	0	0
Pier,		2,598	10	0
Stations, stores, and workshops,		30,000	0	0
Plant,		12,200	0	0
Payments in connection with passages of men to and from this country, fees to Dominican Government, engineering, &c.,		40,000	0	0
		£269,738	10	0

This comes to, for construction and equipment, about £4350 per mile. There is not included in this the cost of the work between Sanchez and Santa Capusa, which was abandoned after about £15,000 had been spent on it.

MANAGEMENT AND UPKEEP.

For the management and upkeep of the line there are employed altogether 311 officials and men. There are three departments—traffic, locomotive, and engineering, and the general manager superintends all three. Taking first the traffic department, at each of the stations there is a stationmaster, a telegraphist, a store clerk, and one porter. At Sanchez, besides, there is a shipping foreman, with 14 lightermen who load and discharge the vessels, and 26 quay labourers. There are 3 engine drivers, 3 firemen, 3 couplers, 6 men to pump up water for the engines, 3 car greasers, and 2 car conductors. For the protection of the line there are employed 2 watchmen and 4 policemen. A traffic superintendent and a treasurer complete the staff for the management. This department costs about £7600 per annum, or at the rate of about £120 per mile per annum.

In the locomotive department there are—(1) in the machinery shop, a foreman mechanic, with 9 men; (2) in the carpenter's shop, a forman joiner, with 12 men; and (3) in the smithy, a foreman, with 3 men. This department costs about £2000 per annum, or at the rate of £32 per mile per annum.

Total for upkeep and management, £20,700 per annum, or £332 per mile per annum, which it is expected will shortly be reduced to £250.

One of the most serious difficulties with which the railway company have to contend is the nature of the soil on which the works, houses, and line have been built at Sanchez. The material all the way along the shore consists of soft clay, interspersed with sand and gravel, and this clay is continually slipping down towards the shore, unless where held back by the hard parts. It is impossible to drain it, and the company, at considerable expense, are building a dry stone wall along the shore to try and check the slipping.

Another great source of anxiety is the flooding of the rivers, which periodically occurs in the valley. The river Yuna sometimes overflows its banks so as to cover the rails with 15 inches of water at some parts. But, owing to the banks being shallow at these places, little harm is done. The traffic could always be carried on without interruption up till the summer of last year. From the 6th of May till the middle of September there occurred a series of floods beyond all precedent, even in the memory of the oldest inhabitant. For days at a time the rain came down, and the rivers, having their rise on the hills on the sides of the valley, rushed down in such volumes that the water overspread the banks and swept along the ditches on each side of the railway. Long stretches of banking were in this way washed away, only those banks which had been protected with limestone blocks being left standing. The river Camu was one of the worst. A considerable stretch of banking 12 feet high was washed away, and the rails were turned right over and swept up against the trees at the side. The manager immediately got squads of men set to work to make good the gaps with stones and temporary timber erections; but latterly the rain came down in such volumes that the work was destroyed twice. Immense trees were torn up by the roots and carried down by the rivers, but all the bridges stood the test, the foundations in all cases having happily been put down below the reach of the scour.

The valley being now opened up, the resources of the country will become known, and no doubt a larger trade in fruit, logwood, tobacco, cocoa, and other products will shortly be opened up to New York and other markets; and as the island itself becomes developed, it will form a new and important market for the exports of Europe and America.

The discussion of this paper was set down for the 25th of February, 1890. In response to the invitation of the President,

Mr R. SIMPSON said there was nothing very novel in the paper—it was meant to be a description of the construction of a light railway in a country presenting peculiar difficulties. The attention of several Scotch gentlemen had been drawn to the Island of Santo Domingo, and they were impressed with its wonderful productiveness and the want of means of conveying its products to the sea-board, the existing conveyances being merely pack-horses. A concession having been obtained from the Government, a company was formed, and the railway works started without delay; but the nature of the country was very imperfectly understood, and experience had to be gained. Timber being very plentiful, it was considered advisable to build the bridges of wood, and this was done over the first three miles of the line; but it was soon found that this was a mistake, as the wood quickly rotted, and a new style of iron bridge had to be designed and sent out from this country. All the bridges up to this time had stood well, but owing to the exceptionally severe floods last year the banks had given way in parts, and the company were now pitching the slopes to make them stand. Mr Simpson then gave a synopsis of the cost of making the railway and its upkeep, which are given in the paper.

The PRESIDENT said it was very interesting to see what could be done in the way of erecting a railway in an outlandish place, and more especially how bridges of light scantling could be made. He proposed a hearty vote of thanks to Mr Simpson for bringing the paper before them.

The vote was passed unanimously

On the Erection of the Superstructure of the Forth Bridge.

By Mr A. S. Biggart, C.E.

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

Received and Read 25th February, 1890.

In the beginning of the year 1888, I had the honour of laying before the Institution a record of the work of erection, so far as accomplished at that time, at the Forth Bridge. This paper is a continuation of that subject, and though to many here it may be an old tale, still, it completes my promised record of this undertaking. It will be in the recollection of most of you, that the work of erection divided itself into two distinct sections.

The first of these embraced the erection of the main steel piers, in which the system of building from temporary platforms, rising in stages, with the work as it proceeded, was adopted. The second division comprised the erection of the cantilevers and the central girders. In the case of the first bay the building was done partly from platforms and partly by overhang; in that of the remainder by overhang alone. It will be well to begin on this occasion with the erection of the cantilever, although open, to some extent, to the objection of repetition. This part of the work commenced with the building out of the bottom members. The first half was done by means of hydraulic cranes, placed on the top of the cages surrounding these tubes. The cages also provided footing for the men at work. So soon as the first half was completed, they were supported by temporary plate ties. Lifting platforms, similar to those used in the erection of the steel piers, were then built immediately over the tubes, and the platforms were afterwards raised to a horizontal position. Under the outer end of those platforms were placed girders, stretching full across the bridge; one main cross girder for each cantilever. Under these again were affixed, by pins, small cross girders, to the latticed vertical columns which rise at this point. The hydraulic rams, used in raising this end of the working platforms, rested on the small cross girders. The other end (that next the main columns) was raised by hydraulic rams. The rams were secured to the columns at a point about half their full height, and were connected to the platforms by means of steel links. By these rams the platforms were ultimately raised to about half the height of the main piers. During the upward progress, the lower portions of strut 1, and the verticals at the centre of the first bay, were built off them. While this was proceeding, a start was also made to the building out of the top members and the main ties. The top members of the cantilever were built by cranes, and to the framing of these cranes building platforms were hung. By this method the top members were built their entire length; in all cases the top members were built outwards, a full half bay, without receiving any subjacent support. At this point, however, a temporary support was obtained, by raising a column from that part where the struts and ties crossed each other. These supports not only enabled the members to be adjusted, but also furnished sufficient strength to permit of the members being carried forward another half bay, where the support of permanent connections was obtained.

The main ties were also built by the top member cranes being held in position by timber struts and rope ties, till they reached the crossing at the first strut. This mode of building, it will be observed, entailed that when the centre and the end of each bay of the cantilevers were reached, there should be fixed in position, before further progress could be made, the struts, the ties, and the top and bottom members, all being mutually dependent on each other.

While work was thus proceeding, in all the cantilevers, at these various points, it was also necessary at another point, namely, the internal viaduct. These were built by overhang, and supported temporarily, where necessary, by steel wire ropes. They were built by special, double derrick cranes, secured to the top of the viaducts, and were slid forward as required. The special features of these cranes were, double masts and jibs, held in position by steel latticed legs, and hand gearing for the raising and lowering of the jib, and the slewing of the crane only. On all the cranes steel wire ropes were used, actuated by steam winches, placed at any suitable position. The ropes were led from the winches up through the bottom mast pin, and then over the mast and jib, to the rope blocks, used in lifting the load.

The details of the top and bottom member cranes of the cages, and of the working platforms, were fully described in the paper already referred to, and need not be again noticed.

So soon as the first main struts and ties, and the vertical ties rising from the bottom member, were properly connected to one another, at the point where they crossed, and at the same time the temporary columns carried up, and fixed to the under side of the top member, in short, when the first half of the first bay was completed, so far as the main members were concerned, a new development took place at all the outer points. The top members were again built outwards, to meet the rapidly rising struts, and the bottom members were similarly projected to join the downcoming ties. The bracing between the struts, and also that between the bottom members, was placed in position, and to enable the further building out of the internal viaduct to proceed, the supports between the vertical ties at the centre of Bay 1, required for it, were fixed.

With the joining up of these various parts, again, at the end of Bay 1, and the placing in position of the supports for the internal viaduct, and the fixing of the viaduct itself, another stage in the work was completed.

Large platforms were found unnecessary, after the completion of the first half of Bay 1, although many small platforms, of various forms, were in constant use throughout the further progress of the work.

The work, at many of the points mentioned, was very interesting. Especially was this the case at the connections of the struts and ties with the top and bottom members, and also where they cross each other.

Previous to the junction of the struts with the top members, the struts were built their full height, and fixed in proper position by means of ropes and other temporary plant. The special lengths of the top members connecting to the struts were then lifted into position and bolted to these members. The top members were now raised to their exact position by small hydraulic jacks, bearing on the struts, and finally secured. The remaining parts were afterwards bolted up previous to riveting. The top member cranes and platforms were now free to move forward and commence the building of the next bay. The material for the top members was raised from the internal viaduct, it having been previously lifted to this height by the hoists. In building the bottom member and ties the order was the reverse of that described for the struts and top member. The junction parts of these members were built first, and brought to their true position by hyraulic rams, in most cases, though in others, when the junctions were lighter, by ropes and union screws. In all cases the ties were the supports. If any side movement was required, recourse was had to ropes and union screws, fixed to the wind bracing between the bottom members. So soon as the junctions and ties were in their correct place, templets were made, in position, for the webs of the ties, and to these the plates were cut and drilled, and afterwards erected. The remaining portions of the ties and junctions were then completed and riveted up. The building of the next bay of the bottom member was then proceeded with. This portion of the work, excepting in the case of the first bay of the cantilevers, was done by the cranes resting on the internal viaduct, the material being brought underneath in steam barges. At the crossing of the struts and ties a temporary column was raised, capable of carrying the top members, and also assisting them to resist lateral wind pressure. It is at this same crossing that the ties for carrying the bottom members and the internal viaduct are secured. This is effected by plates riveted between the outside of the struts and the inside of the main ties. These plates were left as closing lengths, and were finished from templets before being raised to position. The wind bracing between the struts, not erected by the internal viaduct or top member cranes, was lifted into position by wire rope tackle. In many cases this was done in large sections, weighing up to 8 tons, the parts being not only riveted but also painted before being raised into position. To facilitate the progress of the work, it was essential that the internal viaducts be kept well ahead; for the reason that the cranes there hoisted from the steam barges floating in the river, about 160 feet below, and placed in position, the material required for the bottom members and junctions, the lower half of the struts and ties, the bracing between the bottom members, some of the bracing between the struts, and the whole of the internal viaduct, as well as the permanent supports at the centre and end of each bay for carrying it. The internal viaducts, where built by overhang, had to be carried up by wire ropes. They were adjusted, as to height and line, at each of the permanent supports. Great care had to be exercised, when adjusting any of the connections, to avoid leaving permanent stresses. With this in view, parts of the work were left unriveted till in final position. The building of the first five bays of the cantilevers was but a repetition of that described as regards the order and manner of carrying out the work. Reference has already been made to the closing lengths of the lower ends of the main ties. Such was for the purpose of adjusting, in each bay, any variation from the true dimensions, and thereby made provision for the little inaccuracies that always occur in work of this kind. The sixth bays were the last in the cantilevers, and as there ends were fitted in the yard, before erection, there had to be made, at a different point than in the preceding bays, provision for eliminating any error that might have taken place in the length of the top members or of the ties. For this purpose the ends of the top members, and of the ties at the top junction, next to Bay 5, were left as closing lengths. In erecting Bay 6, the bottom members were built out to the first break, beyond the vertical ties, at the centre of the bay. These ties, and the lower half of the struts, were then erected, thus forming a triangle. The tie plates crossing the struts were then placed in position, and from the ends of these plates wire rope connections were made with the top junction, to enable the whole to be pulled into proper position. As soon as the adjustment was completed, the closing length of each main tie was templeted and fixed in position, and thereafter the lower length of the ties and the outer ends of the bottom member were joined up. The ends of the cantilevers and the struts were then joined, after which the top members were built, backwards, and the closing lengths, as elsewhere, were templeted and placed in position.

In the riveting of the various members of the cantilevers, few machines of a novel type were employed. Such as were special, were virtually used only for the bottom members, and were the same as employed in the riveting of the upright columns. They were described in the paper I have already referred to.

The "Arrol" type of fixed and jointed riveting machines were used for such work as the top members, the main ties, and the internal viaducts. The riveting machines used for the top members, and for the ties, hung from ordinary hand "derrick" cranes, which rested on special platforms, on the upper flanges of the top members; the whole being moved along these members as the work proceeded. Special platforms, with cranes, were also run along the internal viaduct, for the work there as well as for much underneath the level of the viaduct. In addition, wherever it was found necessary to carry on riveting, at any particular point, special platforms and cranes were erected on scaffolding. To give a footing to the men in charge of the machines, employed in such work as the riveting of the main ties, the top and bottom members, or the internal viaduct, small shifting platforms, or continuous scaffolding had to be erected. Much of the continuous scaffolding so employed had been formerly erected for building.

Perhaps the most interesting part of the work of erection was the building of the central girders. Many proposals were looked into before the final decision as to how this was to be done was made.

These proposals emanated from various sources, and included many forwarded communications. The anonymous letter seemed to be the favourite mode of conveying to the Bridge Works the ideas of the great unknown. The most of them only caused merriment to those to whom they were addressed. The outside proposals ranged from the mooring of huge ships in the river, carrying timber staging, to the building of the girders, one half on each cantilever, and afterwards launching them out till they met in mid-stream.

The rapidity and ease with which the cantilevers were built by overhang, was really the main factor in bringing about the decision come to, viz.: to build the central girders, out from the ends of the cantilevers, by overhang. With this mode of erection the men were quite familiar, long before they reached the end of the cantilever. Besides this, the plant used for the cantilevers served for the building of the central girders, thus leaving only the temporary connections, securing the girders to the ends of the cantilevers, and the other connections, required for the joining up, in the centre, to be provided. The mode adopted was, in short, to build and rivet part of the first bay of each half span, including the end posts and cross girders, on a temporary platform supported by the cantilever, and after riveting, to draw it back into its final place, so as to rest on the permanent bearings, provided on the cantilever. Temporary connections were then made between the cantilever and girder, and the work of building out was proceeded with at each cantilever, until the centre was reached, when the joining up at this point, and the removing of the temporary connections at the centre first, and afterwards at the ends took place. To enable this part of the erection to be clearly understood, it will be well to go over it in detail. We will revert to the temporary platform, used for carrying the first part of the girder. The reason for building the end part of the central girders on a platform was this, that the end of the girder was finally placed within the end of the cantilever, and could only be riveted when free of it. Each platform consisted of a couple of long lattice girders secured to the cantilevers, and projecting beyond them sufficiently to give the required bearings. Cross timber beams and planking were now fixed to these girders for the purpose of providing a base for carrying the girders, and supplying, at the same time, a footing for the men. On this platform the lower booms and cross girders of the first half bay were laid, after which, the end posts, the end half of the first struts and ties, and the top booms were placed in position, and the whole riveted up. Underneath the bottom booms, launching ways had been laid, previous to building, and on these ways, the part now completed, was slid back into position, and lowered on to its bearings within the end posts of the cantilevers. This part of the central girder was now carefully adjusted, and set to a position previously determined by calculation, in which allowance was made for drooping due to its own weight, and also that produced by the alterations that would take place in the cantilever while the girder was being built. So soon as this adjustment was completed, strong temporary plate ties were connected to each side of both top booms of the central girder, and the top members of the cantilever. While this was being done, steel wedges were also fixed between steel castings, previously fitted to the ends of the bottom booms of the central girder and the cantilever. The supports on the temporary platform were now removed, and the first half bay of the central girder was then an independent cantilever, the deadweight resting on the permanent bearings, while the pull on the top members, and the thrust on the bottom members, were transferred to the cantilever by the temporary ties and the steel wedges respectively.

The building of the lighter parts of the central girder, while resting on the temporary platform, and of similar parts, till the completion of the work was done by the cranes that built the top members of the cantilevers. These cranes were simply moved forward to their new positions, as the work proceeded in a manner very similar to that described in the paper, dealing with the erection already referred to. The only alteration made in these top member cranes was simply to introduce a few packing blocks, below the girders, to suit the altered angles at which the crane had to work. The large platform, attached to the crane framing, was not required for the building of the central girders, and was consequently removed as soon as the work of building the cantilever was completed.

The order of building the various parts, in each half of the central girders, was different in each case. In one case, the cross girder immediately ahead of the part built, was hung in position first by derricks, after which the bottom booms were placed, and were followed by the one half of the struts and ties and the top booms.

It mattered little whether this order was followed or that where the half of the struts and ties were built first, and the booms and cross girders and other parts fixed thereafter.

As the building proceeded, the work of riveting also went on apace, so that when the two halves of each girder met at the centre, little of this remained to be done. The principal object aimed at in riveting the work, close up to the portion building, was to prevent slipping at the joints, and thus keep the girder to its proper camber. When the cantilevers were out their full length, in order to ascertain the exact length of the central girder, a measurement was taken, by means of a steel wire, stretched between the ends of the cantilevers. The girders had in their centre a closing length, somewhat similar to that left in other parts of the structure, but with this difference, that the one end was drilled and fitted to the booms, leaving the other only to be cut and fitted. To ensure greater accuracy than that obtained from the measurement between the ends of the cantilevers, a second measurement was taken, after the halves of the girder had been built out well nigh their full distance. After this measurement had been ascertained, and allowance made for the probable difference in length, due to the alteration in temperature expected while joining up, the lengths of each half of the two girders were laid out in the yard, at their proper distance apart. A distance of 4″ was left between the webs of the bottom booms, and about 6″ between the top booms. This was to allow for the expansion of the structure, while the girders were still fixed to the cantilevers. The covers joining these ends were now fixed in position. Some of these were permanent, while others were only temporary. The permanent covers were fixed to the vertical webs of the booms, and the temporary to the flanges. In the case of the top booms, the web covers were, at one end, bolted to one half of the girder, while at the other end they were free to slide between the webs of the girder and temporary covers, secured to the top and bottom of the booms, to allow this movement to take place.

Temporary flange plates were also fixed at one end to one half of the girder, but not to the other, as the fixture here had to be done after the girder was carrying its own weight. To fill the spaces between the ends of the webs of the top booms, wedges were prepared long enough to ensure their bearing on the webs. The webs were reinforced at this point with plates, to enable them better to take up the thrust, when the temporary connections to the cantilever were cut away. This thrust at first was practically equal to the full stress on the top booms, as the web and flange covers only came into play after the wedges were acting. In the case of the bottom booms, the flange covers were subject to practically the full tension, as the web covers were only drilled and bolted up at one end, after the flange covers had commenced to act. The temporary flange covers of the bottom booms were drilled and bolted to one of the halves of the central girder, with 1″ bolts through the ordinary rivet holes, but in the other half the temporary connection was made with bolts 1¾″ diameter, thereby entailing fewer bolts, and enabling the final connection to be made more quickly.

As the contraction, due to the ordinary change of temperature in 24 hours, was not enough to fully relieve the wedges between the bottom of the end posts of the girders and cantilevers, it was decided to temporarily lengthen the structure by hydraulic pressure, and thus reduce the thrust on the wedges. It was accordingly arranged to bring the large bolts connecting the temporary covers to the bottom booms into play, only after the ends of the booms had been brought nearer one another by ¾ of an inch than they would naturally be at the temperature calculated on, as likely to prevail at the time of joining. These temporary covers were three deep, in cross section, with the necessary plates between, thus bringing the bolts into quadruple shear. As it was possible that the temperature might be much higher than that calculated on, it was necessary to provide for the expansion of the booms beyond the expected point. This was effected by making the holes in the temporary covers oblong. It has been already mentioned that the wedges between the end of the central girders and cantilevers, would not be relieved by the contraction due to the ordinary change of temperature in 24 hours. To enable the wedges to be removed, independently of changes of temperature, cross girders were attached to the wedges and hydraulic rams, having a large reserve of power, were placed in position between these girders and the bottom booms to force them out if necessary.

While these top and bottom boom covers (temporary and permanent) required for the joining up were being placed in position on the girders, the hydraulic rams and connecting ties for stretching the structure, and the necessary temporary struts and wire rope ties, were being got into position previous to making the final connections. The most suitable time for beginning this operation was between 3 and 4 o'clock in the afternoon, and the *modus operandi* was as follows:—So soon as the expected maximum extension of the structure, on the day fixed for connecting, was attained, the hydraulic hand pumps connected to the stretching rams were set to work, and by their means the structure was artificially lengthened about ¾ of an inch. This lengthening was not equal on both sides of the bridge, as one side was longer than the other at the time of connecting, due to the circumstance that the sun was beating full on the west side and only partially on the east. The artificial extension was accordingly arranged so that the holes in the bottom booms and the gripping end of the oblong holes in the covers were brought into line, thus allowing the bolts to drop in freely. When this was effected it was only the work of about five minutes for the various squads to drive home a few steel drifts, and then drop into the holes and screw up lightly all the large bolts in the joint. The pressure on the pulling rams was now relieved, and the stress they had exerted was transferred to the temporary flange covers. Hand drillers were thereafter set to work to drill the holes through the webs of the bottom booms opposite those in the web covers already drilled. While this was in progress the temporary wire rope ties were being tightened up. After this had been effected nothing else remained to be done till about the time of greatest contraction, which took place about 7 o'clock in the morning. What took place in the interval was this: the stress on the wedges between the bottom ends of the cantilevers and the central girders was, to a certain extent, relieved as the contraction in the structure proceeded, and was transferred to the covers at the centre of the span. As anticipated, it was found in the morning that the wedges were not fully relieved. Had the temperature been exceptionally low and shortened the structure more than that necessary to relieve the wedges, then the girder would have simply risen in the centre, owing to the pulling apart at the ends of that, which for the time being was acting like the chain of a suspension bridge, hung from the ends of two cantilevers. The chain, it will be observed, is made up of the temporary ties between the top ends of the cantilevers and central girders, the two halves of the central span, and the connecting covers at the centre.

On resuming operations next morning the first thing done was to relieve the wedges at the ends of the girders and cantilevers. This was easily accomplished, though care had to be taken to relieve simultaneously all the wedges at each end of the span. It was now found, on trying the camber of the girders, that they had a little too much. All that was necessary to reduce this was a little expansion of the structure, and as time wore on this took place. The correct camber was obtained between 8 and 9 a.m.; thereupon the wedges were driven home between the ends of the webs of the top booms at the centre of the span, and thereafter the web covers were drilled as in the bottom booms. All temporary ties and covers were now tightened up and secured, as, owing to the rapid expansion of the structure at this time of day, all the parts of the girders were quickly taking up the normal stresses resulting from the carrying of the central span. Owing to the bright sunshine on the day on which the first span had its temporary connections cut away from the cantilevers, it was found that the stress on the temporary ties was practically relieved between 11 and 12 o'clock. To expedite the work of relief, advantage was taken of oil heating furnaces placed around each main temporary tie, for the purpose of relieving them in an emergency. These furnaces were set agoing, and soon the ties were at a read heat. On this taking place, it was found there was no stress on the ties. The bolts were accordingly then removed from a joint in the ties, and the girder thereafter allowed to rest wholly on its own bearings on the cantilevers. The work of finishing off was now started, which consisted in removing, one by one, the temporary covers at the point of connection, and replacing them by those permanent ones now in position. The struts and ties, flooring, and other parts were thereafter also completed. The closing of the second central span was practically a repetition of the work of the first, except for a grievous delay caused by the vagaries of the weather.

It might be here mentioned that the permanent bearings of the central span on the cantilevers consist of two kinds—at one end a simple combined rocking pin and plain flat surface bearing is given, while at the other rocking posts, about 40 feet long, are provided to give the travel necessary to take up the expansion of one main span. The rocking posts swing on socket bearings, resting on the bottom booms of the cantilever, while at the upper end ball bearings are fixed to the under side of the booms of the central girders, and these again rest in the sockets on the upper ends of the rocking posts. As the expansion between the extreme in summer and winter might have a range of 18 inches, it was necessary to provide for this by a special rail joint. This has been effected by allowing a rail similar to a lengthened switch rail to slide alongside a solid one, securely riveted to a plate. The sliding rail is held close to the other by clips, bearing on surfaces parallel with the taper of the switch. To keep the gauge, the plate to which these rails are fixed is swivelled over a bearing plate at one end. At the other end it is kept in gauge by having, on each side, a tapered guide, bearing against a block secured to the upper plate. When the switch rail is fixed to the central girder, then the solid rail is fixed to the cantilever, and *vice versa*, so that the traffic will always run off the points.

Having now dealt primarily with the erection of the structure and shown that it really was accomplished by only two different modes, viz., by "platforms" and by "overhang," it will not be out of place to mention, that while both modes served their end, the latter was by far the more satisfactory. The work was done by it as well and as cheaply as by the first, and the time of erecting and cost of making the platforms was entirely saved.

While all among you know, and most have a true conception, born of practical experience, of the immense dimensions of this great undertaking, which has occupied in construction fully seven years, it may still be of interest to add that in carrying out the work about £500,000 was spent in temporary plant. This included such items as steamers, 1,000,000 cubic feet of timber, 1200 tons service bolts, 60 miles of wire ropes, jacks and rams almost innumerable, and other manifold kinds of machinery and plant in proportion. In the bridge proper there have been used about 60,000 tons of steel and iron, 116,000 cubic yards of concrete and rubble masonry, and 635,000 cubic feet of granite.

We add, with a certain amount of sadness, that the completion of this magnificent structure has used up the best energies of many who began with us, and also demanded the all too precious lives of 56 who were suddenly cut off without that warning which usually precedes the end of those who, having served their day and generation, go the way of all the earth.

Turning once more to the bright side of the history of the bridge, we see a class, and this includes the whole engineering profession, who will be much benefited by the conspicuous success with which the work was carried out.

The experiments that were made in connection with the design and execution of the work, and a large practical experience gained in manipulating material and bridge building generally, all this, to our mind, must have a reflex action and impelling influence on engineers and contractors, and more particularly on large numbers of those more immediately connected with the bridge. Looking to this, we are forced to believe, that what is the wonder of to-day will be the commonplace thing of the next generation.

While it is not for me to dwell on the assistance given by the staff, it would be unpardonable did I not refer to that remarkable trio, Sir John Fowler, Mr B. Baker, and Mr William Arrol, who have been throughout the leaders in carrying the Forth Bridge to a successful issue. They have elaborated the design, and carried out the construction, with such conspicuous ability as to command the admiration of their fellow-men, and have made for themselves names which will shine brightly on the fame roll of future generations.

As to the structure itself, no peroration can add to its grandeur. There it stands, and will stand, as its own monument, to tell to future generations, centuries hence, what the yet far from perfect arts of the nineteenth century could accomplish.

Having now redeemed my promise to this Institute, and completed my history of the building of the Forth Bridge, I can only hope, in conclusion, that what has been to me a pleasure, has been, and will be, to you, the members of this Institution, of some profit.

The PRESIDENT said that when they got the paper printed and in their hands they would be better able to discuss it; but he thought it would be well to begin the discussion at once, and he had no doubt Mr Biggart would be pleased to answer any questions. He thought the method of providing for the contraction and expansion of the central girder was very beautiful.

Mr R. SAXTON WHITE said he thought that criticism was disarmed in presence of the conclusion of such a gigantic undertaking as that of the Forth Bridge. Shipbuilders took some credit to themselves when they constructed a ship of 500/600 feet in length, but still that was only about one-third of the length of one of the main spans of the bridge. From the kindness of his friends, Mr

Wm. Arrol and Mr Biggart, he had been able to watch the progress of the bridge from its foundation to its later stages. His first visit was paid when they were busy laying the foundations, and on that occasion Mr Arrol took him to the top of the hill, and pointing to a hill on the opposite shore, he said that was where the bridge was to be. His impression then was that it was utterly impossible to realise the idea of putting a bridge across such a tremendous gap as was shown at the Forth at that place. He had taken the greatest possible interest in the erection, and as a shipbuilder he looked upon it as dwarfing their greatest efforts in building big ships. There was one point which had been referred to by the President—the way in which the expansion and contraction of the central girder was taken up—which he thought most admirable. The form in which it had been done by the use of the rocking pillar was one of the most ingenious things he had ever seen. When they came to look at it, and the more they considered it, he thought the more it would impress them with the genius of the man who devised it. He was not going to discuss the paper, but merely drew attention to one or two points, the principal of which was the marvellous ingenuity displayed by Mr Arrol in adapting special tools to deal with the tubular compression members, and the lattice work tension members, and further, the complete success achieved in dealing with the complicated plates of great thickness forming the skewbacks, which were entirely set by special hydraulic presses, making a most perfect job, as indeed is the whole construction of the bridge.

The PRESIDENT said that no doubt the paper was difficult to discuss, but if any one did not understand the mode in which the work had been completed, he could wait after the close of the meeting, and Mr Biggart would explain the models on the table.

The discussion of this paper was resumed on the 25th March, 1890.

Mr C. P. Hogg said he did not intend to make any remarks on the paper, but he had brought several photographs of an American cantilever bridge, built over the Niagara in 1883, which he would like to show to the members. He thought they might congratulate themselves in having so valuable a series of papers on the Forth Bridge as those brought before them by Mr Biggart, and he hoped that Mr Biggart's example would be followed by others engaged in difficult and exceptional works, so that their Transactions might be enriched by other valuable contributions. To his mind the most interesting part of the bridge was the central girder, looked at either as regards the difficulty of erecting it or the method employed for counteracting the expansion and contraction. He thought this method was exceptionally good. In previous cantilever bridges the expansion, he believed, had been chiefly dealt with by suspended links to allow for the variation of length due to changes of temperature. The rocking bed-plate was now used by engineers, but in this case there was a rocking pillar 40 feet long employed. He would like to ask Mr Biggart to explain the construction of the rocking pillar. At p. 147 Mr Biggart remarks—"So soon as the expected maximum extension of the structure, on the day fixed for connecting, was attained, the hydraulic hand pumps connected to the stretching rams were set to work, and by their means the structure was artificially lengthened about three-quarters of an inch." He would like to know whether this lengthening was caused by bringing the end posts together, or was the structure lengthened from pier to pier?

Mr E. G. Carey said that though but little could be added to the able series of papers Mr Biggart had placed before this Institution, he was anxious to subjoin a brief communication on the materials employed in the superstructure. He might state that since the inception of the undertaking, seven or eight years ago, he had had charge of the inspection and testing of such materials for the engineers of the Forth Bridge—Sir John Fowler and Sir Benjamin

Baker. The steel employed was made wholly by the Siemens-Martin or open hearth process, and was of two qualities, viz., that required to resist compressive strains and that required to resist tensile strains—the former having an ultimate tensile strength of 34/37 tons per square inch, with an elongation of at least 17 per cent. in a length of 8 inches; the latter an ultimate tensile strength of 30/33 tons per square inch, with an elongation of at least 20 per cent. in a length of 8 inches. A cold or temper bend test, at least 1½ inch wide, was made from each slab or bar, and was required to bend without fracture to a curve whose inner radius was equal to one and a half times the thickness of the slab or bar. The tempering was performed by heating the strips to a bright red heat, cooling them to a dark cherry red, and then immersing them in clean water having a temperature of 82° Fah. The whole of the steel in the approach viaduct span was of the 30/33 ton, or mild steel. The principal makers were the Steel Company of Scotland, Limited (Blochairn and Hallside Works); the Landore Company, South Wales (now closed), supplied 12,000 tons; and lesser quantities were manufactured by Messrs D. Colville & Sons, Dalzell Steel Works, Motherwell; the Mossend Steel Works; the Clydesdale Steel Works; Parkhead Forge; Messrs Goodwins, Jardine, & Co.; and the Clydebridge Steel Works. The steel throughout was of excellent quality, and fully complied in every particular with specified requirements. The rivet steel was specified to have an ultimate tensile strength of 26/30 tons per square inch, with an elongation of at least 20 per cent. in 8 inches, the bend test requirements being similar to those for plates or bars. The rivets were made by the Clyde Rivet Company from bars manufactured by the Steel Company of Scotland and the Dalzell Steel Works. The rivets were made wholly of Siemens-Martin steel, and the quality supplied throughout was of a very satisfactory nature. The rails for the Forth Bridge were of Siemens-Martin steel, weighing 120 lbs. per yard, and were manufactured by the Steel Company of Scotland, Limited, at their Newton Works. A tensile test of 36/42 tons per square inch was required, with an elongation of at least 15 per cent.

in a length of 8 inches. The drop test specified was two blows from a weight of 1 ton falling 15 feet, the rails being carried on supports 3 feet 6 inches apart. The requirements were strictly complied with. It is, in conclusion, highly satisfactory to note that in testing upwards of 60,000 tons of this steel, and more especially in the case of the "hard" or 34/37 ton steel, that a steady and continued improvement in the material was noticeable year by year, so that at the present time the metallurgist is able to produce a material most absolutely reliable and homogeneous, eminently suited in every respect to fulfil the most stringent requirements of the engineer or shipbuilder, and commanding in every way his utmost confidence.

Mr DYER, in answer to the call of the President, said it was rather late in the day to raise a discussion on the design and construction of the Forth Bridge, as the work had been successfully carried out in such a manner as to reflect the highest credit on the engineers and contractors, and all the prophesies which had been made either of failure or special difficulty in erection had been falsified. No doubt even the engineers and contractors would admit that in many points both the design and method of construction might be improved in the light of the experience which they had had, but these were mere details which were scarcely worth mentioning in this discussion. He strongly supported what Mr Hogg had said as to how much the Institution was indebted to Mr Biggart for his admirable series of papers on the Tay and Forth Bridges, and on behalf of the members he would ask that he be awarded a very special vote of thanks, and any other honour the Institution might have in its power.

Mr C. C. LINDSAY said it was his privilege and pleasure to see this great work in construction, and to hear Mr Biggart's admirable papers upon it. He had been much impressed with the originality of the machines used in preparing the steel for erection. Though many of them had movements common to other machines in use, each was a new invention well suited to its work. Sir William Arrol's inventiveness had revolutionised bridge making, and most of our bridge builders had profited by it, and they would bear him out in saying that his methods of working were generously shown to any rival maker. He (Mr Lindsay) had been much struck by the enormous cost of the bridge, and especially the cost of the temporary plant. He had tried to fathom the cause, and had come to the conclusion that the cylindrical form of the members was the chief factor in the expense. He thought the bridge as designed and constructed a masterpiece, but that its details might be improved upon. Every practical man knew the difficulty and expense attending the making of junctions between cylindrical parts, such as the details of this bridge presented, in comparison with rectangular or flat surfaces. No doubt the bridge was designed to give a maximum of strength with a minimum of material, and with the view of reducing wind pressure to a minimum; but he did not think that it was necessary to sacrifice facility of construction wholly to such extreme refinements. Such a construction demanded the genius of Sir William Arrol, and he believed that a bridge of the same dimensions might be designed with main members rectangular in section, combining lightness and strength, such as most bridge builders of experience could erect with greater rapidity than the Forth Bridge, and at much less cost. It is well known that steel and iron loses its strength the more it is heated and shaped, and this reduction of strength and expense in working would be avoided by using members rectangular in section; and, further, ordinary machines in use would suffice to prepare the work. He might be considered somewhat bold in criticising this unique structure, but he thought it was their duty to inquire into what ought from what ought not to be followed. He joined very heartily in the opinion expressed, that the Institution had been highly favoured in having such an excellent series of papers brought before it.

Mr W. Renny Watson said no doubt if Sir William Arrol had to begin the bridge again he would make some alterations in its construction, for he believed that a person could always improve on past work. He had no doubt also that the bridge might be made, if rebuilt, a little more symmetrical in appearance, and that the junctions between the tubes which Mr Lindsay had singled out as objectionable might also be improved upon. He would like to know how much less steel the bridge could have been built with, than what was used upon it?

Mr BIGGART said, in reply to the discussion, that during the progress of the bridge there were always individuals ready to assert it could not be built in the manner in which they were proceeding, and with very original suggestions as to how it should be done. There were even men of standing declared it could never be completed on the lines on which it was finished. In reply to Mr Hogg, Mr Biggart drew a diagram on the black board, and explained the form of rocking post used and how the lengthening of the structure took place, remarking that the pulling affected the structure principally between the piers, but practically to an extent over the entire length of the two piers and their cantilevers. The pulling took place at the bottom boom of the central girder, drawing nearer to each other the main piers and with them the outer cantilevers. The drawing amounted to about three-quarters of an inch. Mr Lindsay had referred to the cost of the bridge. Everybody knew that it had caused the railway companies a large expense. The increased expenditure had arisen from various causes. First of all the foundations were more difficult than at first anticipated, and the piers were made larger to ensure that the bridge would not only be a safe structure but the strongest in the world. One of the features of the work was the putting in of plenty of material, and for the lasting qualities of the structure that was certainly a good point. Mr Lindsay said that had the section of the bottom members been rectangular it would have been cheaper to make the joints; but if they had been so they must have been much heavier, which would have added to the weight and necessarily to the cost. There is often, of course, an expensive but theoretical form and an inexpensive practical form. To strike the most economical form, and at the same time retain efficiency, is the combined work of the engineer and manufacturer. To show, however, that this matter was not overlooked, the rectangular section was adopted in Bays 5 and 6. These were changed from a round to a rectangular section to simplify the junctions and reduce the expense. Then it was suggested by Mr Renny Watson—What would we do differently in a future bridge? Certainly there are very many points that would be changed from the Forth Bridge. He had no doubt that in the next bridge that was built of a similar class it would be constructed without platforms such as were used in the raising up of the main piers and the first section of the cantilevers. This alone would greatly reduce the expense. The junctions would also be much simplified in design. In many cases the riveting was very difficult, and they had to design little machines (working with 3 tons pressure per square inch) to make it possible to do the riveting in some of the confined spaces. He had no doubt that much of this could be done away with, and in many other ways the bridge might be made and erected at less cost. In conclusion, he thanked the members for the uniformly kind way in which they had received his papers, and hoped that the hints thrown out by Mr Hogg, Mr Dyer, and Mr Renny Watson would lead others to communicate papers to the Institution, and thus receive a share of the kindness invariably bestowed on those who try to impart information to the members of this Institution that practically belongs to themselves.

The PRESIDENT said that the Institution was exceedingly indebted to Mr Biggart for his valuable papers. He did not know in what other way they could show him their high appreciation of them than by giving him a hearty vote of thanks. No doubt many engineers had prophesied that the bridge on the lines on which it was being built would fail. But what they had been able to see in the completed structure disproved that. He had now great pleasure in proposing that a very hearty vote of thanks be awarded to Mr Biggart for bringing this interesting subject before them.

The vote was unanimously agreed to.

On the Loss by Condensation and Re-evaporation in Marine Engine Cylinders.

By Mr Edward C. Peck.

Received 18th November, 1889; Read 25th February, 1890.

The introduction of the compound engine was a distinct gain over the ordinary condensing engine, and, steps being ultimately taken to carry the principle further, the experience of the last twenty years has resulted in our having arrived at the quadruple engine through a series of added cylinders and increased pressures, showing, however, a decreasing rate of gain in efficiency. A further advance, however, is necessary, and the only question is the direction in which it may be found.

In the present paper, the author does not propose to do more than suggest a direction in which a considerable gain may be secured without multiplying expansions or increasing the already high pressures.

Condensation and re-evaporation in the cylinders has long been recognised as a great source of loss, and it was generally held that by breaking up the operation of expansion into two, three, or four cylinders, we had overcome the difficulty. This, however, is still doubtful. The action of the steam on the walls, cover, and piston of the cylinder, has received very able investigation; but the author is not aware that the ports, and what occurs within them, have had their full share of attention. The conduction of heat into and out of a metal surface is dependent upon the rate of circulation of the heating or cooling medium over it, and this circulation is of greater moment as the difference of temperature between the two becomes less.

Now, the steam passes into and out of the *cylinder* without actually circulating over its surfaces; the vapour in contact with the cylinder surfaces practically remains so, or at most cannot possibly pass over them at a greater speed than that due to the piston speed, while in the case of the *ports* the whole volume is passed through an area (which has generally a very large proportionate perimeter) at about ten times the piston speed. The circulation over the cylinder surfaces is practically nil, and conduction is still further impeded by the condensed water clinging to them, but it is extremely rapid and efficient in the ports, where its high speed also maintains the surfaces clear of water, and in the best possible state for parting with or taking up heat: better conditions in fact could hardly be obtained for promoting condensation or evaporation. While the cylinder walls probably do not rise much above or fall much below a certain mean temperature, each port gets thoroughly heated up to the initial and then thoroughly cooled down to the terminal temperature at every revolution. Steam jacketing may do a great deal to lessen condensation and re-evaporation in the cylinder, but it obviously cannot deal with the serious mischief which thus occurs in the ports, and it may not be too much to say that although the extent of the cylinder surfaces exceeds that of the ports, it is in the latter where the heaviest losses occur. There can be no doubt that, especially in the quadruple engine where this heating or cooling action takes place sixteen times per revolution, we have a state of things which demands a remedy, and any successful attempt to eliminate it would be amply repaid by increased efficiency. If these losses could be eliminated almost entirely, there would obviously be no necessity to carry the compound principle further than the two cylinder engine, unless for the purpose of obtaining the more equal turning moment given by three cranks. In an unjacketed cylinder cutting off at 75 per cent. of the stroke, it has been found that the quantity of steam condensed amounts to about 11 per cent. of the whole quantity admitted to the cylinder. The range of temperature to which the H.P. ports of a triple expansion engine, working at 160 lbs., are exposed are approximately as follows:—

H.P.

$$371^\circ - 310^\circ = 61^\circ$$

That is, to take the case of the H.P., steam of 371° temperature is passed through a port having a temperature of only 310°, and after being reduced to a temperature of 310° is exhausted through a port having a temperature of 371°. The loss of pressure encountered by passing the hot steam through a cool port, and the back pressure obtained by passing the cool steam through a hot port must occasion serious loss, and the present large proportion of port areas which are found necessary, especially in fast running engines, are probably due, in a great measure, to the condensation on entering, and the re-evaporation on leaving the cylinder, causing a loss of head or imposing a resistance which is not really due to want of port area, and would not exist were the temperature of the port the same as that of the passing steam.

The well-known high efficiency of the Corliss type of engine is probably not so much due to careful jacketing and the facility for obtaining a correct distribution as to the separate steam and exhaust ports adopted. In suggesting the adoption of separate steam and exhaust ports for marine engines, the author is aware that the complication involved would present the most important feature for discussion, but although no great economy has ever been gained without incurring extra first cost, it is probable that this first cost would be much less than appears at first sight. For instance, the recognised gain of the triple over the two-cylinder compound is about 25 per cent.; it would therefore only be necessary to effect this saving in the two-cylinder engine to enable us to dispense with the third engine completely. This saving is probably almost within the scope of the separate valves, combined with efficient steam jacketing. The steam valves, link motion, and reversing gear would be at least 25 per cent. lighter, and it would not be a matter of great difficulty, especially in engines with valve gear of the Joy type, to work an exhaust valve on the opposite side of the cylinder by a simple connection with the connecting-rod. Objection may be taken to the increased clearances involved by separate steam and exhaust passages, but beside the fact that clearance in multiple expansion engines is not of such moment as in the simple engine, it must be remembered that for the reasons given above, viz., that the condensation causes loss of head and re-evaporation imposes a resistance in the ports, the proportion of port area, and consequently the clearances, could be considerably decreased, while at the same time the independent exhaust valve would give a facility for a correct regulation of the compression. There is another point in which the adoption of separate valves would be productive of direct advantage. In our present piston valves there is a constant leakage in each valve from steam to exhaust side to an extent proportionate to the size of the valve, which is at least one-third larger than that necessary for steam alone. In addition to this there is the constant loss by conduction through the thin body of the valve from steam to exhaust side. The steam and heat thus passed, as regards the first two or three cylinders, are only partial losses, although probably serious enough in extent, but as regards the L.P. cylinder they are completely lost.

When we consider the losses by radiation, condensation, and re-evaporation, involving loss of head and resistance in ports and also leakage of valves, it appears likely that by the adoption of separate steam and exhaust valves an improvement may be looked for which might in some cases lead to the substitution of a two-cylinder compound for a triple, and at least postpone the further advance in complication involved in quadruples.

The author regrets leaving the subject without being able to offer more than a suggestion in the way of a practical solution, as, pending experiments, it is at present rather a subject of speculation. What we do know, however, is that condensation and re-evaporation exist to a serious extent; that the *initial* condensation and what may be called the *initial* re-evaporation bear a very large proportion of the loss, therefore that the cause should be looked for rather in the passages than in the cylinder itself; and that the valves at present used are unsuitable as a device for dealing with steam of varying temperatures.

It is evident that, just as the isolation of the different stages of the expansion of a given volume of steam has been productive of gain in the different forms of the compound engine, a further gain of considerable importance could be obtained by isolating those parts of each engine which have essentially to do with the extremes of temperature.

The discussion on this paper took place on the 25th March, 1890.

Mr Dyer said Mr Peck's paper did not admit of very much discussion, as it only made suggestions, and did not enter into details either of the theory of condensation and evaporation in cylinders or the methods of avoiding them. Both these subjects had received considerable attention, especially on the Continent, during recent years, but their discussion was beyond the scope of the paper they were considering. Mr Peck's object was the same as his (Mr Dyer's) in a paper[*] which he read before this Institution in November, 1885, in which he tried to show the use and limits of multiple cylinders and steam jackets, and, further, that by a judicious amount of superheating the further multiplication of cylinders might be rendered unnecessary. It was pointed out that when superheated steam is used it is advisable to have separate valves for admission and exhaust, as in the Corliss engine. In marine engines it had not hitherto been the custom to attempt such an arrangement, and the efficiency of the steam had been reduced on the supposition that the necessity for simplicity of construction was greater than that for high efficiency. Mr Peck had pointed out "that the well-known high efficiency of the Corliss type of engine is probably not so much

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[*] Trans. Inst. of Eng. and Shipbuilders Scot., Vol. xxix.

due to careful jacketing and the facility for obtaining a correct distribution, as to the separate steam and exhaust ports adopted. In suggesting the adoption of separate steam and exhaust ports for marine engines, he was quite aware that the complication involved would present the most important feature for discussion, but although no great economy has ever been gained without incurring extra first cost, it is probable that this first cost would be much less than appears at first sight. For instance, the recognised gain of the triple over the two-cylinder compound is about 25 per cent., and it would therefore only be necessary to effect this saving in the two cylinder engine to enable us to dispense with the third engine completely." Those who had visited the recent Paris Exhibition would be struck with the great variety of valve gears to be seen; in fact, for the larger sizes of engines slide valves had almost disappeared, and he (Mr Dyer) thought if engineers only tried, they might devise some form of valve gear which would allow separate passages for the entering and the exhaust steam, and at the same time be strong enough to withstand the constant wear to which it would be subjected in marine engines, as there could be no doubt but that Mr Peck is correct when he says that "the *initial* condensation and what may be called the *initial* re-evaporation bear a very large proportion of the loss, and that therefore the cause should be looked for rather in the passages than in the cylinder itself; and that the valves at present used are unsuitable as a device for dealing with steam of varying temperatures," and, further, "that it appears likely that by the adoption of separate steam and exhaust valves an improvement may be looked for which might in some cases lead to the substitution of a two-cylinder compound for a triple, and at least postpone the further advance in complication involved in quadruples." It is, moreover, highly necessary that engineers should look at their engines as a whole, and not place undue importance on any one feature. For instance, in attending to the efficiency of the steam it may be found that the efficiency of the mechanism has been neglected, as on this point we have practically no information.

Mr JAMES WEIR said that, from the title given to this paper, he fully expected that Mr Peck would have had something important to say, as this subject was the most important factor affecting the efficiency of a steam engine, leaving outside mechanical details or working parts of the engine. Then, the condensation and re-evaporation in the cylinders covered the whole ground on which engineers had brought up the steam engine to its present high state of efficiency, therefore anything said or written on this subject would no doubt, he might say, rivet the attention of every engineer who read the title given to this paper. The author said that he proposed only to suggest the direction whereby an increase of efficiency might be attained without complicating the machine by working the steam through a number of cylinders, as was now the case in triple and quadruple expansion engines. Now, that was certainly a most ambitious suggestion, because since Watt first made his great improvement in reducing the condensation in the cylinder by the introduction of a separate condenser, the only universally admitted improvement for the purpose of further minimising the loss due to condensation had been by compounding the engine. Mr Peck suggested that the metal forming the ports or steam passages in the cylinders were much more efficient as condensers of the steam than the other internal parts of the cylinders. He stated, in his paper, that the conduction of heat into and out of a metal surface was dependent upon the rate of circulation of the heating or cooling medium in contact with it. Now, what he wanted to ask Mr Peck was this—Did this law or statement apply to saturated steam as we have it in the cylinders? This was such an important question that the answer Yes or No was not sufficient. Did he ever take means to test it? or had he learned it from some authority who had tried the experiment? or had he merely thought so, and taken it for granted that steam would behave as a permanent gas or liquid when in contact with a conducting surface? He would like to know upon what considerations, theoretical or practical, he based the law just mentioned, because the results of all his (Mr Weir's) investigations and experiments seemed to point to something in the opposite direction, namely, that the metal surfaces were heated by the condensation of the steam, and cooled by the evaporation of the water so formed, and that the evaporation was a very close measure of the condensation. Again, it might have been some phenomenon Mr Peck had observed that suggested the idea; if so, he might say what it was, and by this means put some one on the right track for improving the steam engine. Any information regarding triple and quadruple engines, with separate passages for steam and exhaust, would be of the greatest possible importance to engineers, especially the makers of such engines, who were always on the outlook for reliable data. But the whole value of this paper, as a contribution to the engineering knowledge of the present day, rested on the assumption that condensation in the port passages was the principal cause of the low efficiency of the compound engine; and when a satisfactory reason had been given for assuming this, Mr Peck's paper would rank as a valuable contribution to the Transactions of this Institution.

Mr JAMES ROWAN said it seemed to him that Mr Peck had neglected a good many important facts that came into play on the subject. At page 160 Mr Peck remarks—"In an unjacketed cylinder cutting off at 75 per cent. of the stroke it has been found that the quantity of steam condensed amounts to about 11 per cent. of the whole quantity admitted to the cylinder." By that he presumed Mr Peck meant that a loss of 11 per cent. took place in such cylinders under the circumstances stated. But it ought to be remembered that this was one of those losses that could not be done away with, for he believed that if the steam was allowed to go into the cylinder of an engine in a perfectly dry state, the cylinder would very soon be cut up. Mr Peck made special reference to the very high efficiency of the Corliss type of engine; but it should be remembered that there is no reason why the ordinary marine engine of the present day should not be equally efficient, and as a matter of fact he believed it was so. He was of opinion that Mr Peck was overstating the great economy which he had anticipated would be derived from adopting separate steam and exhaust ports; for it should be remembered that while the steam exhausts from the cylinder, the steam port is in contact with the steam leaving the cylinder and consequently reduces it to the temperature of the exhaust.

Mr PECK, in reply, said—

I am sorry that Professor Dyer's remarks, in his paper of 1885, with regard to separate valves, had escaped my notice; but am pleased to find that he agrees with me in respect to the principal object of the paper. Mr Dyer referred to the practical disappearance of flat valves in modern engines caused by the necessity of avoiding the serious wear and tear caused by their use under high pressures. I made an attempt in 1885 in this direction in a form of Relieved Slide Valve, which was carefully tested on a high speed engine under a high pressure, and with perfectly satisfactory results. An account of the experiments was published in *Engineering*, of August 13th, 1886.

Mr Weir found fault with the title of the paper and also referred to my "ambitious suggestion, because the only universally admitted improvement for the purpose of further minimising the loss due to condensation had been by compounding the engine." Well, that is precisely the principles I would apply to the *ports*, viz., that of "compounding" them or separating that part of their duty which had to do with the high temperature steam from that which had to be done at a low temperature.

Mr Weir says further on that his investigations and experiments seemed to point in the *opposite* direction, viz., "that the metal surfaces were heated by the condensation of the steam, and cooled by the evaporation of the water so formed, and that the evaporation was a very close measure of the condensation." I have nowhere said anything to the contrary of this, and in fact I believe most engineers will entirely agree with Mr Weir there; but, if these words were applied to what takes place in the ports, instead of in the cylinder during admission and expansion (which latter case I suspect Mr Weir must have had in his mind) they would simply amount to a statement that a certain per centage (probably very large) of steam brought to the cylinder port never enters the cylinder, but is trapped by the cold port and sent back, in the case of the L.P. to the condenser, wasted.

What takes place within the cylinder proper has little or nothing to do with the question raised by this paper; which was principally to draw the attention of engineers to the bad engineering involved in the use of a cold port for hot steam, and of a hot port for cool steam. That the quantity of steam condensed immediately on the opening of the valve is very considerable, appears to me to receive further proof in the fact that so much lead is necessary to keep up the pressure at the beginning of the stroke, in spite of the high velocity of the steam, compared to the piston speed, and of the fact that the piston is at that moment actually *decreasing* the space to be filled.

Mr Rowan did not think these losses could be done away with, because if the steam were to go into the cylinder in a dry state the latter would soon be cut up.

No doubt wet steam is a valuable lubricant, but I think the unavoidable fall of temperature due to expansion and exhaust would always induce sufficient condensation, on the admission of fresh steam, to lubricate the cylinder without, as Mr Rowan appears to think, its being necessary to condense a quantity which would impair the efficiency.

My reference to the Corliss engine was meant of course to apply to the arrangement of ports, the Corliss gear being admittedly impracticable on board ship.

In thanking the Institution for having so favourably received the paper, I must apologise for having unintentionally disappointed some by its title; but I trust that, although merely in the form of a suggestion, it will receive in abler hands that investigation and experiment which it undoubtedly demands.

The PRESIDENT moved a vote of thanks to Mr Peck for his paper, and said that, like Mr Rowan, he did not know that the Corliss engine was more efficient than other well-constructed engines. Many forms of cut-off valves, both with separate ports and other ways, have been tried from time to time in marine practice, by various firms and marine engineers of the highest skill, but they had all to give way to the compound engine with the ordinary slide valve. Mr Spencer and Mr Inglis had tried hard to make the Corliss engine a success in marine practice at a time when engineers generally had less confidence in the compound engines than they have now, that the subject is better understood. These engines did not fail because they were not well designed and constructed, for both Mr Spencer and Mr Inglis were men of great skill and ability, the one as a marine engineer and the other as a land engine maker. These engines were found in practice not able to stand the hard work which the marine engine had to undergo, It was a very different thing for a land engine to be kept in order. with its nightly stoppages, in comparison with a marine engine having to run in many cases for twenty days or so right on end, the latter requiring to be more simple and substantial in its construction ; and it must be remembered that if anything in the way of separate ports or improved valves could make a single engine more economical, the same would apply equally to the compound engine. The question of compounding or not compounding lay altogether outside of these details. He might say that he agreed very much with what Mr Weir had said about condensation and re-evaporation in the cylinder. The action was very much like what takes place in the reverberatory furnace. The heat parted with to the metal of the cylinder, ports, &c., on entering, is given back again during the exhaust, and in all forms of the compound engine the range of temperature in the various cylinders is much reduced below what it would be for any given amount of power in a single cylinder engine with any form of ports or cut-off. The heat given up to the metal on entering the cylinder, ports, &c., of a single cylinder engine, would, when exhausting, be discharged to the condenser, or the atmosphere, and lost, whereas with compound cylinders the heat parted with during exhaust of the first, would be used up in the second, and so on to the third and fourth cylinders as the case might be. This is one of the principal reasons why steam used on the compound cylinder system was more economical than when used in a single cylinder.

Mr **Dyer** asked to be allowed to say, in reply to the remarks of the President, that he had in mind the attempts made by Messrs Spencer & Inglis upwards of twenty years ago, but the whole subject had been much advanced since that time, and what was then thought impossible may now be comparatively easy if only seriously attempted.

The vote of thanks to Mr Peck was carried unanimously.

The "Rota" Engine.

By Mr J. MACEWAN ROSS.

(SEE PLATE VIII.)

Received 20th and Read 25th March, 1890.

THE object of the paper which I have the honour of bringing before the Institution, is not to discuss the subject of rotary engines in general, but rather to describe the latest design of the "Rota" engine, to which I have given close attention for a considerable time. Before doing so, however, and disclaiming the intention of entering on anything like a history of the rotary engine, it may be interesting to refer to the earliest attempts of which we have any record, to produce what is really deserving of the name of a rotary steam engine.

In the year 1769 James Watt obtained a patent to give "circular motion to a wheel," or in other words a rotary engine; but from the obscurity of the specification, and the fact that no drawing accompanied it, it is supposed that little more than a crude idea of its structure had suggested itself to the mind of the inventor. This is the first notice we have of the conception of a rotary engine.

The first one of which we have record as being actually made, was manufactured in the works of Bolton & Watt at Birmingham. It was described by Watt as "a steam wheel, moved by force of steam, acting in a circular channel against a valve on one side, and against a column of mercury or other fluid metal on the other side."

Various experiments were tried with the engine, but the results being unsatisfactory it was thrown aside.

In 1782 Watt obtained a second patent for two devices on a similar principle. One of these is shown in Plate VIII., Fig. 1. C, is a cylinder; A, an axle with fixed piston on it; E, a valve or flap of the same radius as the cylinder. Steam enters at G and exhausts at H.

As can easily be imagined, the shocks caused by the motion of the valve, shifting to make way for the piston, say 1000 times per minute, along with the liability to derangement, doomed it to the same fate which overtook Watt's first attempt. In 1784, two years later, he patented another rotary engine, but the power developed was so trifling that it was abandoned.

More than a century has elapsed since Watt's praiseworthy attempts to secure rotary motion from steam. Since then many attempts have been made in the same direction, but the results have not been so satisfactory, nor the progress so rapid, as we have witnessed in many other fields of mechanical invention. The chief reason for this, in my opinion, is that the principle usually adopted in designing rotary engines, has hitherto been, to have a fixed cylinder, with one or more pistons revolving in contact with the inner surface of the cylinder.

Now as a high speed is necessary to develop power, it follows that the surfaces in contact are working at a destructive velocity.

In the engine now about to be described, it is claimed that this fatal defect has been overcome.

Three of the first "Rota" engines were exhibited at the recent Exhibition in Glasgow, two being in the stand of Glen & Ross, and the other was chosen to drive the "Blackman" air propeller for ventilating the machinery annexe. It was in constant use during the whole time of the Exhibition, running continuously 13 hours per day, at 600 revolutions per minute, and the superintending engineer testified to the excellent work performed. Those three engines each developed about 5 H.P., one of them being of the reversing type.

Coming now to the latest modification of the "Rota" engine (see Plate VIII., Figs. 2-6), it possesses several important advantages over those first engines now referred to, the chief being, that in less space double the power is obtained. Figs. 2 and 3 represent the engine in sectional elevation. It consists of a cylindrical casing, A, with closed ends or covers, through whose axis, from either end, pass two central hollow drums, B, fixed to and carried by their respective brackets, XX′, and having cast in them ports for admission and exhaust of steam at both ends. The drums, B, are divided by central webs (see Fig. 2) running their entire length, to form admission and exhaust passages, *bb′*, from which the inlet and exhaust ports, *cc′*, are carried to the interior of the casing. A series of segmental pistons, EE, are fitted between the casing, A, and drums, B, which fill up to a greater or less extent what forms the steam space within the casing.

The crank shaft, D, Fig. 4, passes through bearings bored eccentrically in the drums, and is made with four arms or cranks, which also act as slides, and which are fitted into slide blocks, F, fitted into their respective pistons. The pistons are thus held in equal and equidistant angular positions, relatively with the axis of the main casing, A. The slide blocks in the pistons are allowed to oscillate, in order to accommodate themselves to the different angular positions of the cranks, which reciprocate radially through them, relatively with the axis of the main casing. As the distance of the pistons from the axis of the crank shaft varies according to their position around the drum, B, their distance apart also varies, because simply they get farther from the centre on the crank arms; those pistons bearing on the portion of the drums having least eccentricity being close together, and those on the opposite side being farthest apart. When the pistons travel round the drum, their speed is therefore highest at the point of greatest eccentricity, and the ports *cc′* are formed to admit steam between each pair of pistons as they pass the point of least eccentricity, and to exhaust as they pass the line of greatest eccentricity of the drums. The steam is cut off at any desired point, and expands while the piston in front of it is impelled forward at a greater velocity than that following it. The intervening space increases until the point of greatest eccentricity is reached, when the exhaust of steam between that pair of pistons takes place through the ports, C′, in the drums. Each succeeding piston is acted upon in like manner, and a continuous rotative motion is thus imparted to the crank shaft, there being no dead point, and all parts are in perfect equilibrium. It must be clearly understood that the drums are fixed into the brackets, while the casing is in no way connected either to the crank shaft or to the pistons, but is free to rotate upon the drums and accommodate itself to the friction within the engine. Each cover of the casing has cast upon it a sleeve, which is carried along around the drum into a stuffing box in the bracket, and those sleeves form the bearings upon which the casing revolves. The sole plate is so made, that steam entering at branch pipe, S (see Fig. 3), to which the governor is fixed, passes up a steam way formed in bracket, X, also along one side of the sole plate to bracket, X′, and so is admitted into the interior of the casing through both drums, at the same time.

Similarly the exhaust steam passes down both brackets, and exhausts at branch T.

It will be seen from Fig. 2 that the steam chamber between the bottom pair of pistons is just opening to steam, and the chamber at the top is opening to exhaust. In order to describe more clearly the cycle, suppose the middle of a side chamber to be full of steam, then the pressure would act against both pistons equally; but you will observe that the upper crank is much longer than the lower one, so that the upper crank will turn in an upward direction, taking the others round with it, until the chamber reaches the top centre, when exhaust will take place through port, C′; and meanwhile the bottom chamber will be round to half stroke and getting full steam, so that there are always two cranks doing work at the same time, and thus there is no dead point. The pistons therefore act as their own valves (the ports being in the fixed drums), so that the chambers only take what steam they require, and leave no passages full of steam after cut off takes place.

There is a steam space formed in the outside of each piston, so that the accumulated steam pressure acting between them and the casing is made almost to balance the centrifugal force of the pistons. It must also be noted that there is no *side* pressure on the pistons, and therefore if fitted accurately at first they should wear well.

This accuracy is easily attained, as all the work is done on the lathe, the pistons being cast all together, as shown on Fig. 5, with distance pieces between each, and are not separated until they have been turned and fitted to the drum, casing, and covers. Each piston and crank arm is fitted with suitable springs, those in the cranks being so arranged as to mutually accommodate themselves, should there be any end movement of the shaft. Let us now consider some of the results which are produced when the engine is working. The pistons, which are close together when in the bottom position, are 3 inches apart when at the top, which is 3 inches travel in half a revolution, or a speed of 6 inches per revolution.

Now, suppose the engine to be running at its normal speed—800 revolutions per minute--the relative speed of piston is 800 × ·5 feet = 400 feet per minute, and as there are four steam spaces, we have a total "outward" stroke in each revolution of 12 inches, and yet the speed of piston is only 400 feet per minute.

The speeds of the various surfaces working in contact are also very low, as will be seen from the adjoining table :—

	Pressures on surfaces working in contact, in lbs. per sq. inch.	Speeds of surfaces working in contact, in feet per minute.
Outside of pistons and casing, -	50	283
Slide blocks and crank arms, -	435	266
Crank shaft journals, - -	78	366
Casing journals on drums, -	40	900

Although the latter speed, viz., the bearings of the casing, seems high, still it is under constant pressure, and is well lubricated from holes being bored through into the exhaust passage *b′* in the drum.

The pressure on the journals can be reduced by turning the drums round into such a position that the pressure of the steam will more than overcome the weight of the casing, and therefore put the pressure on the bottom side of the drum instead of on the top side, which is very nearly the case in Fig. 2.

The main feature in the speeds of surfaces in contact may be more easily seen by returning to the principle of Watt's engine. (See Fig. 1.) For comparison, suppose an engine of each type with casings, say 12 inches diameter, or 3 feet circumference, running at 800 revolutions per minute, the speed of the piston against the inner surface of the casing in Watt's type would be 800 × 3 feet = 2400 feet per minute, while in the "Rota" engine it would only be 260 feet, or 2140 feet per minute less.

A sight feed lubricator is fitted to the top of the bracket of each engine, as shown in the outside view, so that the oil is carried along the drum into the interior of the casing; this arrangement lubricates all the working parts in a thoroughly efficient manner.

The PRESIDENT said this was a very interesting paper, and he hoped that after reading it in the Transactions they would be able to discuss it fully at the next meeting.

The discussion of this paper took place on the 29th April, 1890.

The PRESIDENT said that the paper read by Mr Ross at the last meeting was a very interesting one. Many had tried to make rotary engines in the past, but usually after a little success they were found to be wanting. There was one feature he observed in the engine under notice which somewhat qualified the main objection to all former attempts of this kind—the excessive friction on the interior of the cylinder of the engine. This was sought to be obviated by permitting the cylinder to revolve with the piston.

Mr THOMAS BURT remarked that this engine was certainly very ingenious. He did not think that the friction had been entirely got rid of, and he was of opinion that the centrifugal force would not be neutralised by the ring. He questioned much if the power claimed could be got out of it. He would have liked that the break-power which was expended had been stated, so as to enable them to judge what the engine was capable of doing.

Mr W. J. **MILLAR** (the Secretary) said it would be interesting if any of the members could give information as to whether or not there was a boat sailing on the Clyde some 40 years ago propelled by a rotary engine. He had seen some statements made to the effect that there was such a steamer; and that reminded him that when he brought forward his paper on "Early Clyde Steamers," in December, 1880, the discussion was left open to enable him to get whatever data he could on the subject. Since then he had got some additional facts, such as the lengths and breadths of some of the early steamers and where they went to; but he had not felt that he had as yet received sufficient additional information to bring the subject up again, but hoped to be able to do so next session. With this in view, any information about the rotary steamer would be most interesting.

Mr **HUGH MUIR** believed there was a rotary engine in a boat on the river, and that she was a complete failure. It was a paddle steamer, with small wheels.

Professor **BARR** said he had not had any experience in regard to rotary engines. It was easy to design a rotary engine that would work perfectly well for a little, but the difficulty was how to keep it in working order, especially to keep the pistons and valves, or their equivalents, tight. Unfortunately, as this paper came forward at the close of the University Session, he had not been able to read it before the meeting. From a look through it that evening he did not see anything in the paper that would lead him to think that adequate provision had been made in that engine for keeping the working parts steam-tight. If Mr Ross had adopted any plan for the purpose of accomplishing that, it would be of interest to the members if he would point it out, for that had been the difficulty hitherto with rotary engines.

Mr D. C. HAMILTON asked how much steam per indicated horsepower was used in this engine. It was well known how much steam was used per indicated horse power in triple expansion and such like engines; but from what he knew of rotary engines, he believed the consumption of steam was excessive for the power exerted.

The PRESIDENT said he remembered a gentlemen in Dundee 25 years ago making a rotary engine, which was made on the principle of giving windage where the friction appeared. In the engine made by Mr Ross he understood that the periphery and the side wall friction was modified as the cylinder was free to revolve with the piston. But the engine he had referred to was a very true fit in all respects, and was so constructed that it almost touched the side walls and the periphery. It had a little windage, and theoretically it looked as if it might last very well, if it could be made so mathematically correct that it almost touched the metals and yet did not touch them. The difficulty with all these engines was that one could not get a true forward push: there was always a side push, so that the piston hobbled about and decreased the power. Usually a rotary engine did very well for a while with small work, with everything being nice and fair about it; but after a while it began to be lobe-sided, a little off the truth, and soon did no good.

Mr ROSS, in reply, remarked that he had little to say after the discussion on his paper. He was not astonished to be reminded that many rotary engines had been tried and had failed; but the engine under discussion was completely different from all of them. They would pardon him for saying that, from the remarks made, he was afraid the members had not grasped the main improvements embodied in the design of the engine. He might refer to one or two points in the discussion. Mr Burt said that the centrifugal force of the pistons must still act against the outer casing. Well, as previously described, there is a space formed in the periphery of each piston, into which steam is admitted, and, if desired, entirely overcomes the centrifugal force by acting between the pistons and the outer casing. However, the pistons are so designed as to give a pressure of 50 lbs. per square inch on their peripheries, due to the excess of centrifugal force over the steam pressure, so that the pistons only bear on the centre drums, but have no pressure upon them, while the springs keep them steam tight. This, he hoped, would clearly explain how easily the centrifugal force is overcome. Two of the engines of the old type were already at work, one having driven the wood working machinery in a pattern shop for about two years, and the other had been driving two large tapeing machines for about a year. Those engines had given every satisfaction, although very inferior to the engines that were now being made, as the latter would give twice the power in less space, and a great many disadvantages existing in the former type had been entirely overcome. Then the Secretary had spoken of a rotary engine which had been tried in a Clyde steamer. While not, in the meantime, going the length of implying that the present arrangement would be suitable for large vessels, he (Mr Ross) was quite certain they could be applied to launches with success, as the main object in such engines was to get as much power as possible in a small space, and he was satisfied they would compare favourably with others. Then with regard to the tightness of the pistons and valves, as there are no separate valves, the pistons acting as their own valves, he was satisfied that if they saw an engine actually made, with one of the covers off, they would have less doubt on that point. He had had an engine running at no more than 15 revolutions per minute. Now a rotary engine did not usually run as slowly as that, and this was due to the fact that there was no dead point. He could not yet say how the consumption of steam compared with other well made simple engines, but he was at present making an engine from which exhaustive tests would be taken. The reduction in friction in this, compared with other rotary engines was very clearly shown by the model, which he then worked by hand in demonstration of his remark, and said that no parts of it were working together, in contact, at a greater speed than in ordinary engines, although the engine was running at 1000 revolutions per minute, and this was due to the differential motion of the pistons, combined with the outer casing being allowed to revolve.

The PRESIDENT moved a vote of thanks to Mr Ross for his paper. It was fair to say, that perhaps they did not know very much about this engine. He observed when he heard the paper read that there was a novel principle in this rotary engine, and that principle was of a cylinder running along with the piston and thus reducing the friction. There were very many purposes to which a rotary engine could be applied. It would be a very good thing if this engine, described by Mr Ross, should turn out to be able to do all that it was stated it could do, for if so there must be a great future for it in driving electrical dynamos, &c.; for a direct engine for such a purpose was preferable to our having to depend on belts and pulleys.

The vote of thanks was carried unanimously.

On the Delivery of Water through Copper Wire Cloth Strainers.

By Mr John Barr, Secretary Glenfield Co., Ltd.

(SEE PLATE IX. AND X.)

Received 20th and Read 25th March, 1890.

Having had occasion to make a few experiments on the quantity of water that certain meshes of copper wire cloth strainers would deliver per square foot of area, under certain heads, and no tabulated results of such deliveries being in existence to the writer's knowledge, he thought it might be useful to waterworks engineers to have these recorded in the Transactions of the Institution.

In order to make the tables as complete as possible, specimens of wire cloth were obtained of meshes other than those at first experimented with. The results of the whole are now given.

The deliveries were obtained by means of an ordinary notch gauge.* See Fig. 1, Plate IX., where an experimental box and notch gauge is exhibited. The formula used was that given by Box, and is as follows—

$$G = d \times \sqrt{d} \times l \times 2{\cdot}67,$$

in which G = gallons discharged per minute,

d = depth of overflow in inches,

l = length of weir in inches.

Two classes of copper wire cloth strainers were experimented upon.

1st—The ordinary square meshed wire cloth. Table No. I. (See Plate X.)

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* The gauge used was the Birmingham Wire Gauge.

2nd—Cloth with wires running parallel to each other, held together by a copper ribbon. Table II. (See Plate X.)

The latter description of cloth is finding considerable favour amongst waterworks engineers on account of its greater durability, and also as it is more easily cleaned than the square meshed cloth.

The approximate cost per square foot (and equivalent price per pound) is given in the tables.

In many works, where it is not necessary to filter the water, it is simply passed through copper screens. The fineness of the mesh depends on the character of the water. To ascertain the best mesh to use for any water must form the subject of actual experiment, and will depend on the facilities for cleaning the cloth. The finer the cloth, the oftener it must be cleaned. It is wonderful how soon fine meshes get choked, even with water which looks to be fairly pure. In taking deliveries from the finer meshes of square meshed cloth, the spaces choked up so rapidly that the water had to be first screened through cloth of 120 mesh (the finest used). Even then the piece experimented upon choked up so fast that the cloth had to be cleaned after each experiment. Water from river Irvine was used in the experiments.

Taking the two descriptions of cloth, with a similar area of clear waterway per superficial foot, the parallel wire cloth gives a much better delivery than the square mesh cloth, especially at low heads. For instance, taking 39 square inches per superficial foot—

Square mesh gives 62 gallons per minute under $\frac{1}{4}''$ head.
Parallel „ „ 110 „ „ „ „

The former costs 1s 7d per superficial foot, the latter 2s 3d, so that, in proportion, the latter is quite as cheap as the former, taking area of waterway as a basis of comparison; but, on the other hand, the square meshed cloth is a finer screen, being ·0065 width of each space, as against ·019 for the parallel mesh.

The reason of the smaller delivery of the square mesh cloth is, of course, that the friction of the water passing through so many small openings is much greater than in the parallel mesh.

Again, taking a comparison with *equal width of each space* as a basis, we have —

	Width.	Area p. sup ft.	Price p. ft.	Galls. p. min. under ¼″ head.
Square mesh, -	·0230	70 sq. in.	0/11	195
Parallel „ -	·0224	34 „	2/6	121

Showing that, so far as cost per superficial foot, on the basis of equal width of space, is concerned, the square meshed cloth is about one-third the cost of parallel mesh.

Suppose we have half a million gallons of water per 24 hours to strain, and that we wish the space not to exceed one-fiftieth of an inch, and that we agree to pass a maximum quantity of 3 gallons per minute through each superficial foot of cloth, we would require $\frac{500,000}{24 \times 60 \times 3} = 116$ superficial feet of cloth. Square meshed cloth (with space ·023 inch wide) gives 70 square inches per superficial foot, and delivers 195 gallons per minute under ¼″ head; parallel meshed cloth (with space ·0205 inch wide) gives 35 square inches per superficial foot, and delivers 121 gallons under ¼″ head; so that, to have cloth of the parallel wire description equal in delivery power to the square mesh, we would require about one and a-half times the quantity of cloth. Notwithstanding this, it is probable that the parallel cloth would be found much the cheaper in the long run, being so much stronger and more easily cleaned.

It should be borne in mind that cloth of the parallel wire description will allow a piece of foreign matter to pass that would be stopped by square mesh. Take the two last examples. The largest piece that could be passed by square mesh would be ·020″ × ·020″, but in the case of parallel cloth it would be ·020″ × ·370″.

It is usual to run the parallel wires the long way of the screen, and support the cloth by brass cross bars. Fig. 2 shows the usual method of attaching the cloth to timber frame, and supporting with brass bars. Sometimes cloth of square mesh is supported by octagonal meshed cloth—about 1 inch mesh—the whole, in turn, being supported by brass bars. Occasionally galvanized iron wire cloth is used, but there can be little doubt but that copper is much superior.

Fig. 3 shows the usual method of placing vertical screens in duplicate slots in suitable cast-iron frames.

Through the courtesy of the engineers of the waterworks mentioned in Table No. III., the writer is enabled to give the mesh of wire cloth used, and the approximate quantity of water passed per superficial foot—in actual practice. It will be observed that the delivery varies considerably, but for the finer meshes of strainer cloth, the average seems to be about 16 gallons per minute per superficial foot.

In many cases the straining well is octagonal in form, a hand crane is placed in the centre to raise the screens for washing, duplicate grooves being provided, so that one screen may be in use while the other is being washed.

Screening cannot be supposed to replace filtration, as it merely serves to keep leaves, straw, and other suspended matter out of the pipes. Very often the screens are put over the draw off in clear water tanks, even although the water may have been previously filtered and screened.

In some small works where the supply is amply abundant (from a stream or from springs), the water is passed over a sloping screen (see Fig. 4). This has the merit of being self-cleansing—the water falling through the screen forming the town's supply. A fine gravel or sand bed if placed under the screen further purifies the water.

In the new works for supply of water to Liverpool—at Lake Vyrnwy Water Tower—in Wales, very elaborate and complete cleaning arrangements will shortly be in use ; the cloth used will be square mesh of about 120 spaces per lineal inch. No doubt descriptions of the arrangement will be published when the works are completed.

It may not be generally known that air has a strange reluctance to pass through wire cloth—particularly the finer meshes under water. An air valve on a water main, with a wire screen on its inlet, will not discharge air from the main. If a piece of wire cloth is put under water, and some air put under a part of it that is bulged out to prevent the air escaping at the sides, the cloth may be sunk under water many feet deep, and the air will keep under the cloth, refusing to pass up through the meshes, unless the cloth be suddenly depressed with some force, when the air will pass through and rise to the surface.

Although the deliveries given are approximately correct, they do not profess to be so exact as to form a reliable basis for constructing a formula for ascertaining the delivery of cloth, differing in mesh from the examples given in the Tables. The law that the delivery is proportionate to the square root of the head, comes out approximately near the truth. But if the Tables are found useful in affording at a glance the approximate delivery of wire cloth strainers under various heads, within reasonable working limits, they will have served their purpose.

The discussion of this paper was postponed till next meeting.

The discussion of this paper took place on the 29th April, 1890.

Mr **Charles C. Lindsay** remarked, in reply to a call from the chair, that he had nothing very definite to say on this paper. Some time ago, in arranging the straining wells in connection with waterworks in the East, the question of the kind of wire cloth to be used having to be decided, he had looked carefully into the matter, and had selected the copper ribbon cloth as the best for straining purposes, combined with being cleaned readily itself; and he had accordingly adopted it, and it had been found to work very well. When Mr Barr proposed to read this paper, he had asked him (Mr Lindsay) if he could say anything as to the quantity of water delivered at these works; but he regretted that there had not been sufficient time to get the desired information. The reports as to the action of the strainers were very satisfactory.

Mr Arthur W. Thomson, on the invitation of the President, said that he had to congratulate Mr Barr on his paper, and wished to call special attention to the excellence of the drawings which accompanied it, and which for clearness and distinctness could hardly be surpassed. The subject of the flow of water was one for which Professor James Thomson had done much; and as one of his students, he (Mr Thomson) was thus led to take a lively interest therein, and to make for himself measurements of flow of water over weirs and with varying heads. The empirical formula given on page 181, for obtaining the volume of water passing over a weir, was perhaps satisfactory enough for many purposes; but he thought that for the construction of tables such as those given at the end of the paper it was not sufficiently exact. This source of inaccuracy, together with the difficulty of keeping the head of pressure of water constant, of making an accurate measurement of that head, and of preventing the water having a velocity of approach, gave results—Tables Nos. I. and II.—which could be considered only as rough approximations to the truth. This was evident when some of the results were compared; for instance, take the 2nd, 6th, and 7th lines of Table No. I., and the 1st and 4th lines of Table No. II., and compare the delivery in gallons per minute under the various heads of pressure of water. No doubt these were real difficulties, and perhaps not easily overcome; but since Mr Barr knew well of their existence, he had no doubt that that gentleman would devise means for overcoming them; and the whole subject could not be left in better hands.

Mr William B. Bryan, Engineer to East London Waterworks Company, by invitation, sent the following communication:—

The paper by Mr Barr is a most valuable one to waterworks engineers. The whole of the unfiltered water passing to the filter beds of the East London Waterworks Company passes through screens of copper wire, as shown on Table No. 2. After the water is filtered, and before going to the engine sumps, it passes through other screens made of similar wire, but of much smaller mesh. These latter are for the protection of the valves at the various engines. The screens have worked most successfully for some years, and between 40 and 50 million gallons daily are passed through them. There is no difficulty in cleansing them. They were all supplied by the Glenfield Company.

Mr BARR, in reply, said that he had no doubt the formulæ were just as Mr Thomson had mentioned, but as that given by "Box" was one pretty generally used, he thought it might be taken as being pretty near the truth. Regarding the apparent anomalies in the deliveries of the various meshes of wire cloth given in the tables, he might explain that in taking the deliveries of the wider meshes at the beginning of the table it was rather difficult to define the exact level of the water passing over the weir, as when such large quantities were passing, notwithstanding the fact that the water was baffled by the intercepting boards, as shown on the drawing, the surface was somewhat disturbed when passing over the weir. He had taken the figures as nearly as could be ascertained. He knew that in comparing the results from the different meshes of cloth and taking the theoretical quantity that ought to be passed by an opening giving the clear area of waterway, as shown on the table, viz., the velocity due to the square root of the head multiplied by 8, the result due to this rule would require to be multiplied by ·8, ·7, or ·6, depending upon the fineness of the mesh. In the finer meshes the results were considerably below what would be given according to calculation, due no doubt to the great friction of the water passing through the large number of small openings.

The PRESIDENT said this was a very interesting and valuable paper to waterworks engineers, and he had therefore much pleasure in proposing a vote of thanks to Mr Barr for bringing it before the Institution.

The vote was cordially passed.

Mr JOHN MAYER proposed a vote of thanks to the retiring Councillors for their services.

Mr DUNDAS proposed a vote of thanks to the President for the able manner in which he had conducted the business of the session. Mr Kemp had been well known to the Institution for many years, and during the last twelve months he had had the honour of occupying the chair of the Institution; and the excellent way in which he had presided at the Council as well as the Institution meetings warranted them in giving him a hearty vote of thanks.

These motions were heartily carried.

The PRESIDENT said he could only thank them for the cordial way in which they had responded to the proposal of Mr Dundas.

This closed the session.

Institution of Engineers and Shipbuilders
IN SCOTLAND
(INCORPORATED).

THIRTY-THIRD SESSION, 1889-90.

MINUTES OF PROCEEDINGS.

THE FIRST GENERAL MEETING of the THIRTY-THIRD SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd October, 1889, at 8 P.M.

Mr EBENEZER KEMP, President, in the Chair.

The PRESIDENT delivered his Introductory Address. On the motion of Mr GEORGE RUSSELL, a hearty vote of thanks was awarded the President for his Address.

A Paper on "A University Faculty of Engineering," by Mr HENRY DYER, C.E., M.A., was read, the discussion being deferred till next General Meeting.

The following Medals and Premiums awarded at Annual General Meeting of the Institution, held on 23rd April, 1889, were presented, viz. :—

The Marine Engineering Medal to Mr NISBET SINCLAIR, for his Paper on "Experiments on the Strength of Copper Steam Pipes made at Lancefield."

The Railway Engineering Medal to Mr ROBERT SIMPSON, C.E., B.Sc., for his Paper on "The Construction of the Glasgow City and District Railway."

And a Premium of Books to Mr GEORGE C. THOMSON, F.C.S., for his Paper on "Copper and Copper Castings."

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr WILLIAM AITCHISON, Mechanical Engineer, Demerara.
Mr EVELYN GEORGE CAREY, Civil Engineer, Dalmarnock Iron Works.
Mr DAVID W. CUTHBERT, Mechanical Engineer, 122 West Nile Street.
Mr PETER FERGUSON, Engineer and Shipbuilder, Phœnix Works, Paisley.
Mr JAMES STUART, Civil Engineer, 16 Robertson Street.
Mr GAVIN WILSON, Civil Engineer, 16 Robertson Street.
Mr GEORGE ALMOND, Engineer, Bolton.
Mr W. S. CUMMING, Shipbuilder, Barrow.
Mr HENRY MACLELLAN BLAIR, Engineer, Clutha Iron Works.
Mr GEORGE H. SLIGHT, Jr., Civil Engineer, Northern Lighthouse Board, Edinburgh.
Mr GEORGE C. THOMSON, Engineer, The Dunfermline Foundry Company, Dunfermline.
Mr LINDSAY BURNET, Engineer, Moore Park Boiler Works, Govan.
Mr HUGO MACCOLL, Engineer, Sevilla, Spain.

AS A GRADUATE:—

Mr BRUCE R. WARDEN, App. Mining Engineer, 5 Eton Gardens.

THE SECOND GENERAL MEETING of the THIRTY-THIRD SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 19th November, 1889, at 8 P.M.

Mr EBENEZER KEMP, President, in the Chair.

The Minute of General Meeting of 22nd October, 1889, was read and approved, and signed by the President.

The Discussion of Mr HENRY DYER'S Paper on "A University Faculty of Engineering," was proceeded with, and adjourned till next General Meeting. On the motion of the PRESIDENT a vote of thanks was awarded Mr Dyer for his Paper.

The following Papers were read:—

On "The Alexander-Thomson Moment Delineator and its Application to Maximum Bending Moments due to Moving Loads," by Mr ARTHUR W. THOMSON, C.E., B Sc., and

On "The Utilisation of the Water of Condensation from Steam Pipes and Cylinders," by Mr PETER FYFE.

The Discussions of these Papers were deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr WILLIAM ADAM, Mechanical Engineer, 42 Garturk Street, Govanhill.

Mr BARKLY GILLESPIE DICKSON, Mechanical Engineer, Eagle Gold Mining Company, Johannesburg, S.A.R.

Mr GILBERT M. HUNTER, Civil Engineer, Tocopilla, Chili.

Mr ANGUS MURRAY, Mechanical Engineer, 4 Sutherland Terrace, Dowanhill.

AS A GRADUATE:—

Mr WILLIAM NAPIER BELL, Engineering Student, 19 Eaton Place, Hillhead.

THE THIRD GENERAL MEETING of the THIRTY-THIRD SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 17th December, 1889, at 8 P.M.

Mr EBENEZER KEMP, President, in the Chair.

The Minute of General Meeting of 19th November, 1889, was read and approved, and signed by the President.

The Discussion of Mr HENRY DYER'S Paper on "A University Faculty of Engineering," was proceeded with and terminated.

Discussions of the following Papers were adjourned till next General Meeting, viz., on "The Alexander-Thomson Moment Delineator and its Application to Maximum Bending Moments due to Moving Loads," by Professor THOMAS ALEXANDER, M.A., and Mr ARTHUR W. THOMSON, C.E., B.Sc., and

On "The Utilisation of the Water of Condensation from Steam Pipes and Cylinders," by Mr PETER FYFE.

A Paper by Mr WM. SMITH, C.E., on "The Economic Value of Ship Railways" was read, and the discussion deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows: —

AS MEMBERS:—

Mr WILLIAM BROWN, Mechanical Engineer, Glasgow Locomotive Works.

Mr WILLIAM PATON BUCHAN, Sanitary and Ventilating Engineer, 24 Renfrew Street.

Mr ALFRED E. LONERGAN, Engineer, Whitefield Works, Govan.

AS GRADUATES:—

Mr JOHN ANDERSON, Draughtsman, 5 Park Street, Cambuslang.

Mr WILLIAM KING, Draughtsman, Greenbank Place, Cathcart.

Mr ARTHUR M. MORRISON, Apprentice Locomotive Engineer, Laurel Bank, Partick.

THE FOURTH GENERAL MEETING of the THIRTY-THIRD SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 21st January, 1890, at 8 P.M.

Mr EBENEZER KEMP, President, in the Chair.

The Minute of General Meeting of 17th December, 1889, was read and approved, and signed by the President.

The Discussions of the following Papers were proceeded with, viz., on "The Alexander-Thomson Moment Delineator and its Application to Maximum Bending Moments due to Moving Loads;" by Professor THOMAS ALEXANDER, M.A., and Mr ARTHUR W. THOMSON, C.E., B.Sc., and

On "The Utilisation of the Water of Condensation from Steam Pipes and Cylinders," by Mr PETER FYFE.

Also, on Mr WILLIAM SMITH'S Paper on "The Economic Value of Ship Railways."

Votes of thanks were awarded the authors of the Papers.

Mr ROBERT SIMPSON'S Paper, on account of the lateness of the hour, was held as read, and the discussion deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr JOHN W. ALLAN, Mechanical Engineer, Oakbank, Shandon.
Mr R. J. BEVERIDGE, Engineer, 20 Albert Drive, Crosshill.
Mr ALEX. F. G. BROWN, Engineer, Swindrige Muir, Dalry.
Mr JOHN CAMPBELL, Mechanical Engineer, St Petersburg New Water Works Co., Limited.
Mr JAMES EASTHOPE, Mechanical Engineer, 36 Oswald Street.
Mr THOMAS FIELD, Engineer, 3 Knowe Terrace, Pollokshields.
Mr PETER HAMPTON, Mechanical Engineer, 47 Summer Street.
Mr JAMES HARVEY, Mechanical Engineer, 36 Oswald Street.

Mr Alexander Kidd, Mechanical Engineer, 36 Oswald Street.
Mr Edward Mowbray Salmon, Mechanical Engineer, 36 Oswald St.

AS GRADUATES :—

Mr Wm. Caird, App. Engineer, R. Napier & Sons, Lancefield Street.
Mr A. Scott Younger, Draughtsman, 15 Arlington Street.

The Fifth General Meeting of the Thirty-third Session of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 25th February, 1890, at 8 p.m.

Mr Ebenezer Kemp, President, in the Chair.

The Minute of General Meeting of 21st January, 1890, was read and approved, and signed by the Chairman.

The President referred to the death of Mr Thomas Napier, who for a period of eleven years had acted as Sub-Librarian to the Institution and Philosophical Society, and moved that a vote of sympathy should be passed and forwarded by the Secretary to Mr Napier's relatives.

The motion was unanimously adopted.

Mr Simpson gave some further information in connection with his Paper on "Railway Construction in the West Indies," and as there were no further remarks by Members, the discussion was closed and a vote of thanks awarded Mr Simpson for his Paper.

A Paper on "The Erection of the Superstructure of the Forth Bridge," by Mr Andrew S. Biggart, C.E., was read; a discussion followed, Mr Biggart giving explanations by means of models, and was continued till next General Meeting.

A Paper on "The Loss by Condensation and Re-Evaporation in

Marine Engine Cylinders," by Mr **Edward C. Peck**, was read, the discussion of which was deferred till next General Meeting.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS :—

Mr **W. Alexander**, Mechanical Engineer, Helen Street, Govan.
Mr **Donald Cameron**, Civil Engineer, Municipal Offices, Exeter.
Mr **Wm. Ireland**, Mechanical Engineer, 7 Ardgowan Ter., Glasgow.
Mr **Andrew Stewart**, Mechanical Engineer and Iron Tube Manufacturer, 41 Oswald Street, Glasgow.
Mr **Robert M'Master**, Shipbuilder, Linthouse, Glasgow.

AS GRADUATES :—

Mr **John Buttery**, Apprentice Engineer, Hyde Park Locomotive Works, Glasgow.
Mr **Robert F. Miller**, Civil Engineering Draughtsman, 10 Windsor Terrace, West, Glasgow.
Mr **E. Steven Paterson**, Apprent. Civil Engineer, Glassford Manse.

THE SIXTH GENERAL MEETING of the THIRTY-THIRD SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 25th March, 1890, at 8 P.M.

Mr **Ebenezer Kemp**, President, in the Chair.

The Minute of General Meeting of 25th February, 1890, was read and approved, and signed by the President.

The discussion of Mr **Andrew S. Biggart's** Paper on "The Erection of the Superstructure of the Forth Bridge," was proceeded with and terminated.

The discussion of Mr **Edward C. Peck's** Paper on "The Loss by Condensation and Re-evaporation in Marine Engine Cylinders," was proceeded with and terminated.

Votes of thanks were awarded the authors for their Papers.

The following Papers were read :—

On "The 'Rota' Engine," by Mr **J. MacEwan Ross**; and on "The Delivery of Water through Copper Wire Gauge Strainers," by Mr **John Barr**.

The discussions of these papers were deferred till next General Meeting.

On the motion of the President, Mr **Andrew A. Haddin** and Mr **Arthur W. Thomson** were unanimously chosen as Auditors of the Treasurer's Annual Financial Accounts for Session.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS LIFE MEMBERS :—

Mr **Colin Houston**, Marine Engineer, Harbour Engine Wks., G'gow.
Mr **James Stewart**, Marine Engineer, Harbour Engine Works, G'gow.

AS MEMBERS :—

Mr **John R. Bird**, Mechanical Engineer, 10 Morrison St., Glasgow.
Mr **George R. Brace**, Naval Architect, Messrs Wm. Denny & Sons, Dumbarton.
Mr **William Brown**, Civil Engineer, Old Hall, Kilmalcolm.
Mr **William Cameron**, Mechanical Engineer, Grahamston Foundry, Barrhead.
Mr **John Cochrane**, Engineer, Barrhead.
Mr **James W. Robb**, Mechanical Engineer, 6 Stonefield Terrace, S.S., Glasgow.
Mr **Wm. G. Wrench**, Mechanical Engineer, 5 Oswald St., Glasgow.

AS GRADUATES :—

Mr **J. M. Adam**, Engineer's Assistant, 40 St. Enoch Sqr., Glasgow.
Mr **James Andrew**, Assistant Engineer, Gavinburn, Old Kilpatrick.

Mr JAMES E. GOVAN, Student Engineer, 182 Bath Street, Glasgow.
Mr JOHN MACFARLANE SLOAN, App. Engineer, 5 Somerset Place, Glasgow.
Mr C. B. WILLIAMS, App. Engineer, 483 Springburn Road, Glasgow.

THE THIRTY-THIRD ANNUAL GENERAL MEETING of the INSTITUTION was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 29th April, 1890, at 8 P.M.

Mr EBENEZER KEMP, President, in the Chair.

The Minute of General Meeting of 25th March, 1890, was read and approved, and signed by the President.

The Treasurer's Statement of Annual Financial Accounts was submitted, and unanimously adopted.

A vote of thanks was awarded the Auditors of the Accounts.

On the motion of Mr C. C. LINDSAY, seconded by Mr JAMES MOLLISON, the Institution Medal was unanimously awarded to Professor JAMIESON, for his paper on "The Designing of Continuous Current Dynamo Machines."

On the motion of Mr GEORGE HERRIOT, seconded by Mr HUGH MUIR, the Marine Engineering Medal was unanimously awarded to Professor JENKINS, for his paper on "The Stability of Oil Carrying Steamers."

Premiums of Books were unanimously awarded Mr CHARLES LANG for his paper on "Evaporation," and to Mr ANDREW BROWN for his paper on "Dredging and Dredging Appliances."

The Election of Office-Bearers then took place:—

Mr ROBERT DUNDAS, proposed by Mr James Mollison, and seconded by Mr William Murdoch, was unanimously elected a Vice-President.

Mr **George Herriot**, proposed by Mr D. C. Hamilton, and seconded by Mr C. P. Hogg, was unanimously elected a Vice-President; and by a majority of votes, the following gentlemen were elected Councillors, viz.:—Professor **Archd. Barr**, B Sc., **James Mollison**, **Andrew S. Biggart**, **James Riley**, and Professor **Jamieson**.

The discussion of the following Papers took place and were terminated:—

On "The 'Rota' Engine," by Mr J. **MacEwan Ross**, and

On "The Delivery of Water through Copper Wire Cloth Strainers," by Mr **John Barr**.

Votes of thanks were awarded the authors of these papers.

The **President** announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr **Alex. Drew**, Civil Engineer, 7 Willowbank Crescent, Glasgow.
Mr C. J. **Jackaman**, Civil Engineer, Dalmarnock Ironworks, Glasgow.
Mr **Hugh Neilson**, Engineer and Steel Manufacturer, Clyde Bridge Steel Works, by Cambuslang.

AS GRADUATES:—

Mr **George Wilson**, Mechanical Draughtsman, 37 Berkeley Terrace, Glasgow.
Mr **Joseph Nayler**, Student Engineer, 7 Hampden Terrace.

On the motion of Mr **John Mayer**, a cordial vote of thanks was passed to the Retiring Councillors for their services; and on the motion of Mr **Robert Dundas**, a similar vote of thanks was passed to the President.

TREASURER'S STATEMENT—1889-90.

GENERAL FUND.

Dr.

	£	s.	d.	£	s.	d.
To Balance in Union Bank at close of Session 1888-89,				£343	16	9
Subscriptions received :						
Session 1889-90, ..	£715	0	0			
Arrears of Previous Sessions,	53	10	0			
	£768	10	0			
Deduct Entry Money transferred to Building Fund, ..	13	10	0			
				755	0	0
Sales of Transactions, ...				2	2	6
Bank Interest, ...				2	9	6
				£1103	8	9

Cr.

	£	s.	d.		£	s.	d.
By Amount paid Treasurer of House Committee as Institution's proportion of Expenditure, for Session 1889-90, ...					£155	0	0
Taxes, ...					3	17	1
Printing, ...					177	18	4
Lithography, ...					62	15	0
Premium for Paper, ...					5	0	0
Graduate Section Medal, Session 1888-89, ...					1	7	6
Salary to Secretary, ...					150	0	0
Commission Collection of Arrears of Subscriptions, viz. :—							
For Session 1889-90, ...	£435	0	0				
For Previous Sessions, ...	53	10	0				
	£488	10	0	at 5 %	24	8	6
Postages, ...					45	18	2
Delivery of Annual Volumes, ...					5	6	11
Stationery, &c., ...					7	17	9
New Books for Library, ...					18	12	10
Binding Periodicals in Library, ...					4	17	0
Furnishings for Library, ...					2	8	0
Cash to New Buildings Account to meet Interest on Loan, from Medal Funds, ...					16	0	0
Petty Cash, ...					1	15	5
Balance in Union Bank, ...					420	6	3
					£1103	8	9

MARINE ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1888-89, ...	£27 1 4	*By* Medal, ...	£10 0 0
Interest on Capital lent to New Buildings Account,	10 0 0	Balance in Union Bank, ...	28 18 7
,, Mortgage, Glasgow Corporation,	1 11 10		
Bank Interest, ...	0 5 5		
	£38 18 7		£38 18 7

RAILWAY ENGINEERING MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1888-89, ...	£30 0 4	*By* Medal, ...	£10 0 0
Interest on Capital lent to New Buildings Account,	6 0 0	Balance in Union Bank, ...	26 19 0
,, Mortgage, Glasgow Corporation,	0 12 8		
Bank Interest, ...	0 6 0		
	£36 19 0		£36 19 0

GRADUATE MEDAL FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1888-89,	£3 7 4	*By* Balance in Union Bank, ...	£4 0 7
Interest on Mortgage, Glasgow Corporation,	0 12 8		
Bank Interest, ...	0 0 7		
	£4 0 7		£4 0 7

BUILDING FUND.

Dr.		Cr.	
To Balance in Union Bank at close of Session 1888-89,	£54 10 1	*By* Balance in Union Bank, ...	£119 19 11
Entry Money, ...	13 10 0		
Two Life Members at £20, ...	40 0 0		
Interest on Mortgage, Glasgow Corporation,	11 8 0		
Bank Interest, ...	0 11 10		
	£119 19 11		£119 19 11

NEW BUILDINGS ACCOUNT.

Dr.			Cr.		
To Capital to meet Cost of New Buildings, viz. :—			*By* Paid on New Buildings, ...		...£2,047 8 1
From General Fund, ...	£542 15 7		Interest on Loans, viz. :—		
,, Marine Engineering Medal Fund, ...	351 11 2		To Marine Engineering Medal Fund,	£10 0 0	
,, Railway Engineering Medal Fund, ...	213 13 3		,, Railway Engineering Medal Fund,	6 0 0	
,, Building Fund, ...	939 8 1				16 0 0
		£2,047 8 1			
Cash received from General Fund to meet Interest on Loans, ...		16 0 0			
		£2,063 8 1			£2,063 8 1

Glasgow, *21st April, 1890.*—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) A. A. HADDIN,
ARTHUR W. THOMSON, } Auditors.

SUBSCRIPTION ACCOUNT.

Dr.

To Subscriptions due as per Roll :—			
Arrears due at close of last Session, ...		£104 0 0	
Deduct Irrecoverable, ...		38 10 0	
		£65 10 0	
Add elected at Annual General Meeting of 23rd April, 1889, ...		6 0 0	£71 10 0
Session 1889-90 :—			
389 Members	at £1 10 0 —	£583 10 0	
8 New Members	,, 2 10 0 —	20 0 0	
13 ,,	,, 2 0 0 —	26 0 0	
21 ,,	,, 1 10 0 —	31 10 0	
34 Associates	,, 1 0 0 —	34 0 0	
186 Graduates	,, 0 10 0 —	93 0 0	
			788 0 0
			£859 10 0

Cr.

By Subscriptions received, as per Cash Book, viz.:—			
Arrears of Sessions previous to Session 1889-90, ...			£53 10 0
Session 1889-90 :—			
352 Members	at £1 10 0 —	£528 0 0	
7 New Members	,, 2 10 0 —	17 10 0	
13 ,,	,, 2 0 0 —	26 0 0	
21 ,,	,, 1 10 0 —	31 10 0	
32 Associates	,, 1 0 0 —	32 0 0	
160 Graduates	,, 0 10 0 —	80 0 0	
			715 0 0
Arrears due for Session 1889-90, ...		£73 0 0	
Arrears due for previous Sessions,		18 0 0	
			91 0 0
			£859 10 0

BANK ACCOUNT.

Dr.

To Balances at close of Session 1888-89 :—	
General Fund, ...	£343 16 9
Marine Engineering Medal Fund, ...	27 1 4
Railway Engineering Medal Fund, ...	30 0 4
Graduate Medal Fund, ...	3 7 4
Building Fund, ...	54 10 1
Amounts lodged, Session 1889-90, ...	537 6 0
Interest, Session 1889-90, ...	3 13 4
	£999 15 2

Cr.

By Amounts Drawn, Session 1889-90, ...	£399 10 10
Balances in Union Bank, ...	600 4 4
	£999 15 2

CAPITAL ACCOUNT.

GENERAL FUND.						
Loan to New Buildings Account, ...	£542	15	7			
Cash in Union Bank, ...	420	6	3			
				£963	1	10
MARINE ENGINEERING MEDAL FUND.						
Loan to New Buildings Account, ...	£351	11	2			
Mortgage, Glasgow Corporation, ...	50	0	0			
Cash in Union Bank, ...	28	18	7			
				430	9	9
RAILWAY ENGINEERING MEDAL FUND.						
Loan to New Buildings Account, ...	£213	13	3			
Mortgage, Glasgow Corporation, ...	20	0	0			
Cash in Union Bank, ...	26	19	0			
				260	12	3
GRADUATE MEDAL FUND.						
Mortgage, Glasgow Corporation, ...	£20	0	0			
Cash in Union Bank, ...	4	0	7			
				24	0	7
BUILDING FUND.						
Amount to New Buildings Account, ...	£939	8	1			
Mortgage, Glasgow Corporation, ...	360	0	0			
Cash in Union Bank, ...	119	19	11			
				1,419	8	0
ARREARS OF SUBSCRIPTIONS.						
Arrears due for Session 1889-90, ... —	£73	0	0			
Do. previous Sessions, ...	18	0	0			
				91	0	0
				£3,188	12	5

HOUSE EXPENDITURE ACCOUNT. (ABSTRACT 1889-90.)

Dr.		
To Rents for Letting Rooms, ...		£75 17 6
Amounts Received by Treasurer to meet Expenses, viz.:—		
From Institution of Engineers and Shipbuilders, ...	£155 0 0	
From Philosophical Society, ...	146 17 0½	
		301 17 0½
Balance due Treasurer, ...		7 8 5½
		£385 3 0

Cr.	
By Balance due Treasurer, ...	£15 11 4½
Interest on Bond, ...	124 4 4
Expense of Transfer of Bond, ...	31 13 8
Salary to Curator, ...	91 13 4
Salary to Attendant at Library, Cleaning, &c., ...	43 17 4½
Taxes, ...	25 10 2
Feu-duty, ...	0 18 2
Gas Rates, ...	8 5 6
Water Rates, ...	5 12 6
Coals, ...	10 17 1
Insurance, ...	7 15 0
Repairs, ...	19 4 6
	£385 3 0

The Account of the House Committee is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Philosophical Society.

W. J. MILLAR, *Secretary to House Committee.*

DECEASED MEMBERS.

During the Session the following gentlemen have been removed by death from the roll of Members.

Mr John Carrick joined the Institution in 1862. As City Architect and Superintendent of Works for many years, Mr Carrick's name was a household word in Glasgow, and his great ability in constructive and decorative detail was widely known. His long official experience of the development of the city, and the active part which he took in all that related to the design and construction of buildings, the laying out of streets, drainage and sanitary improvements, rendered his services of inestimable value to the community.

Mr Carrick, from his onerous official duties, was no doubt prevented from taking any active part in the management of the Institution, but his long connection with it for a period of nearly thirty years showed his continued interest in its welfare.

Mr Robert Cassels' name has for long been associated with the Institution, he having become a Member in 1859. In 1879, when, at the invitation of the Institution, the Institution of Mechanical Engineers made Glasgow their place of summer meeting, Mr Cassels acted as a member of General Reception Committee.

As an active member of the Glasgow Iron and Steel Company, Mr Cassels has long been well known.

Mr Thomas Gray, C.B., was elected an Honorary Member of the Institution in 1889. Mr Gray, as assistant secretary to the Board of Trade, was well known, not only to those more especially concerned in the building and equipment of the Mercantile Marine service, but to many outside of the Department who had the welfare of our seamen and fishermen at heart.

Mr Gray's qualifications are well summed up in a notice of his career which appeared in *The Times*, which states:—"By the death of Mr Thomas Gray, of the Board of Trade, the public have lost an excellent servant, and his colleagues an old and valued friend. . . . He was one of those men whose energy would have made a mark in any sphere of life, and who, if engaged in business, would probably have amassed a large fortune. He came into the Board of Trade about the year 1851, as a boy clerk, at 15s a week, was attached to the Marine Department, and won his spurs by making himself master of the business of surveying steamships—a branch of work to which he always remained much attached. There was something of genius in his rapid comprehension of mechanical problems, and his knowledge of ships and their machinery was as accurate and extensive as that of a shipbuilder or an engineer. In all subjects connected with the mercantile marine and with the welfare of seamen, in the abolition of crimping, in the improvement of officers, in wreck inquiries, in the commercial code of signals, in all the legislation and administration arising out of Mr Plimsoll's move, he took a leading, helpful, and useful part. The rules of the road at sea he made almost his own, and his rhymes on that subject are as well known among seafaring men as 'Rule Britannia,' and have been translated into all languages."

Outside his immediate vocation Mr Gray's death will be much felt, especially in connection with the Mission to Deep Sea Fishermen, in which he took a deep interest as a member of council.

Mr Gray died on 15th March, 1890, aged 58.

Dr JOULE'S name has been associated with the Institution almost from its commencement. He was elected an Honorary Member in 1859, and took an interest in its progress. In 1865 he contributed a paper entitled "Self-acting Apparatus for Steering Ships," and presented the Library with copies of his papers, as many as forty-one, such contributions appearing in the catalogue.

Dr Joule has for long been a prominent figure in the scientific world, due to his experimental researches, investigations, and papers read before various societies, both at home and abroad, and from which he received many honours. His name is perhaps best known to engineers from his experiments and determination, in 1843, of the mechanical equivalent of heat, and of which the late Professor Rankine, in the introduction to his "Manual of the Steam Engine," says:—

"The numerical results at first obtained were, as was to be expected in a new kind of experiment, somewhat rough and inexact; but, by long perseverance, Mr Joule increased the exactitude of his methods of experimenting, until he succeeded in ascertaining, by experiments on the friction of water, oil, mercury, air, and other substances, to the accuracy of $\frac{1}{300}$ of its amount, if not more closely still, the *mechanical equivalent of a unit of heat; that is, the number of foot pounds of mechanical energy which must be expended in order to raise the temperature of one pound of water by one degree.* For Fahrenheit's degree that quantity is 772 foot pounds; for the Centigrade degree, $\frac{9}{5} \times 772 = 1389{\cdot}6$ foot pounds. This, the most important numerical constant in molecular physics, has been styled by other writers on the subject 'Joule's Equivalent,' in order that the name of its discoverer may be perpetuated by connection with the most imperishable of memorials—a truth. Mr Joule at the same time proved by experiment the law which had previously been only a matter of speculative theory with others: that not only heat and motive power, but all kinds of physical energy, such as chemical action, electricity, and magnetism, are convertible and equivalent; that is to say, that any one of those kinds of energy may, by its expenditure, be made the means of developing any other in certain definite proportions."

Dr Joule was born at Salford on 24th December, 1818, and died at Sale, near Manchester, on 11th October, 1889.

Mr JOHN LANGLANDS became an Associate of the Institution in 1878, and although not taking any active part in the general work of the Institution, he was well known to many of the Members in connection with shipping interests.

Mr Langlands was a member of the Reception Committee of the Institute of Naval Architects, Glasgow Meetings, held in 1877 and 1888.

Mr J. L. LUMSDEN joined the Institution in 1865. He was born and educated at Dunfermline, and served an apprenticeship with a millwright there, afterwards serving an apprenticeship as a joiner and shipwright with Messrs Caird & Co., Greenock. He afterwards went to Messrs Robert Napier & Sons, and served as an engineer for several years, and it was here that the late Mr John Elder became acquainted with him.

When Messrs Randolph, Elder, & Co. first commenced to build ships in Govan, Mr Elder selected Mr Lumsden to take charge of the shipyard drawing office, a position which he ably held until his promotion as manager of the extensive shipbuilding yard at Fairfield under the late Sir William Pearce.

Mr Lumsden left Fairfield early in 1882, to commence business as a consulting naval architect, and at the time of his death had formed a valuable and extensive connection in Liverpool among shipowners.

Mr Lumsden, at the time of his death, was aged 51.

Mr J. B. AFFLECK M'KINNEL joined the Institution in 1873, He was born in 1829, near Dumfries, in which town he received the earlier part of his education, afterwards attending the Glasgow University. From an early age he showed much aptitude for mechanical pursuits. Having obtained an extensive knowledge of both theoretical and practical engineering, Mr M'Kinnel returned to Dumfries, and became partner in the Palmerston Iron Works; and afterwards, in 1870, established the Dumfries Iron Works, which he carried on until his death in January, 1890.

Mr M'Kinnel, from his wide experience, was much employed in arbitration cases. His largest engineering work was the construction of the railway viaduct across the river Urr in Kirkcudbrightshire. Mr M'Kinnel was much respected by his workmen, one of his proudest boasts being that during the whole course of his business career he had never had a strike in his works.

Mr MATTHEW PRIOR became a Member of the Institution in 1875. During Sessions 1875-76 and 1876-77, he contributed two papers — viz., on "Buckley's Patent Metallic Piston," and on "Compound Engines."

Mr Prior was a native of Nottinghamshire, and from an early age devoted himself to the study of engineering; and afterwards, in the practice of his profession, invented various appliances for steam machinery—amongst others, piston rings and springs, improvements in preventing deterioration of screw propellers and shafts, the use of zinc plates in steam boilers, &c.

Mr Prior's health having given way, he retired to Jersey, where he died on 3rd July, 1890, in the 61st year of his age.

Mr JOHN WEIR SMITH became a Member of the Institution in 1887. His apprenticeship as an engineer was served with Messrs Duncan Stewart & Co., and Messrs W. & A. M'Onie, Glasgow. In 1873 he removed to Liverpool and entered the works of Messrs James Jack & Co., and was there until he left for Pernambuco, Brazil, to take the management of Messrs Bowmans' Heirs' foundry. This position he held until his death at Casa Bowman, Pernambuco, on 24th November, 1889, at the age of 39. He received numerous marks of the firm's appreciation of his services. During his apprenticeship he attended various classes, and obtained many certificates and prizes in engineering science.

Mr Smith, although abroad, took much interest in the prosperity of the Institution, expressing from time to time his readiness to be of service to any of the Members who might visit Brazil.

REPORT OF THE LIBRARY COMMITTEE.

DURING the present session 325 Books have been lent out to 361 borrowers, to which might be added the Books used in reference. 41 volumes and 3 pamphlets have been added, 6 of these volumes being donations. Framed Portraits of James Watt and Henry Bell were also presented to the Institution.

On behalf of the Institution, the Committee now beg to tender its best thanks for the presentations made.

The Institution exchanges Transactions with 41 Scientific Societies; 15 weekly, 2 fortnightly, 14 monthly, and 4 quarterly periodicals are received regularly in exchange for the Transactions. The greater number of the periodicals are regularly bound, and make 50 volumes, the total number of books and periodicals bound during the session being 22.

There are 1380 bound, and 250 unbound volumes in the Library.

It may be mentioned that Members of all classes have the privilege of using, for reference, the Library of the Philosophical Society.

DONATIONS TO LIBRARY.

The New Tay Bridge, by Crawford Barlow. From Messrs Wm. Arrol & Co.

Preliminary Reports on Metal Tracks for Railways, by E. E. R. Tratman, C.E. From Department of Agriculture, Washington.

Triple Expansion Engines and Steamship Capability, by Thomas Wingate. From the Author.

Canadian Palæontology. From the Geological Survey, Canada.

Framed Portraits of James Watt and Henry Bell From Andrew Stewart, Esq.

Steel: its Manufacture, Properties, and Uses, by James Riley. From the Author.

Electrical Distribution of Energy in Mines, by A. T. Snell. From the Author.

Plans, Photos, and Report, Conservation of Water, New South Wales, Royal Commission, 1889. From J. Bailie Henderson, Esq., C.E., Government Hydraulic Engineer, Queensland.

Trans. Edinburgh Architectural Association, Vol. I. From the Association.

Mean Scottish Meteorology, 1805 to 1887. From Professor C. Piazzi Smith, LL.D.

The Law and Practice of New South Wales Letters Patent. From C. G. Hepburn, Esq.

Atti del Collegio degli Ingegnerie ed Architetti, Palermo.

Report on Horse Power of Marine Engines, by the Council of the North-East Coast Institute of Engineers and Shipbuilders. From the Institute.

The Caledonian Railway, its Origin, by George Graham, C.E. From the Author.

The Clyde from its Source to the Sea, by W. J. Millar. From the Author.

NEW BOOKS ADDED TO LIBRARY.

Manual of Marine Engineering—Seaton.
Pattern Makers' Assistant—Rose.
The Complete Practical Machinist—Rose.
Manufacture and Distribution of Coal Gas—Richards.
Portland Cement, its Manufacture and Uses—Reid
Direct Acting Pumping Engine—Gosling.
Elements of Graphic Statics—Von Otto.
Text Book on Steam and Steam Engine—Jamieson.
Marine Propellers—Barnaby.
Iron and Steel Founding—Wylie.
Factory Accounts—Clarke & Fells.
Principles and Elements of Graphic Statics—Clarke.
English and American Yachts—Burgess.
Transmission of Power by Wire Ropes—Stahl.

The Power and Speed of Steam Vessels—Bury.
Quantity Surveying—Leaning.
A Manual of Procedure by Provisional Order—Cotton.
The Practical American Millwright and Miller—Craik.
Engineering Specifications and Contracts—Haupt.
Engineering Sketch Book—Barber.
American Foundry Practice—West.
Foundations and Foundation Walls—Bauman.
Practical Treatise on Hydraulic Mining in California—Bowie.
Practical Manual of Mineral Mines and Mining—Osborn.
The Use of Steel—Barber.
Steam Boilers—Thurston.
Chemical Technology—Groves & Thorpe.
Steam Engine Indicator—Graham.
Slide Valve—Auchinclos.
Designing Wrought and Cast Ironwork—Adams.
Electrical Telegraph Tables—Clark & Sabine.
Service Chemistry.
Steam Engine—Forbes.
Alternating Currents of Electricity Blakesley.
The Law Relating to Electric Lighting—Bower & Webb.
The Marine Transport of Petroleum—Little.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C. :—

Bristol Naturalists' Society, Bristol.
Institution of Civil Engineers.
Institution of Civil Engineers of Ireland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Institute of Marine Engineers.
Institute of Mining and Mechanical Engineers.
Iron and Steel Institute.
Liverpool Polytechnic Society.

Liverpool Engineering Society.
Literary and Philosophical Society of Manchester.
Manchester Association of Engineers.
Midland Institute of Mining, Civil, and Mechanical Engineers.
Mining Institute of Scotland.
North-East Coast Institution of Engineers and Shipbuilders.
Patent Office, London.
Philosophical Society of Glasgow.
Royal Scottish Society of Arts.
Royal Dublin Society.
South Wales Institute of Engineers.
Society of Engineers.
Society of Arts.
The Sanitary Institute of Great Britain.
The Hull and District Institution of Engineers and Naval Architects.
The Junior Engineering Society.

American Society of Civil Engineers.
American Society of Mechanical Engineers.
Association des Ingénieurs de Gand, Belgium.
Austrian Engineers' and Architects' Society, Vienna.
Bureau of Steam Engineering, Navy Department, U.S.A.
Engineers and Architects' Society of Naples.
Geological Survey of Canada.
Master Car Builders' Association, U.S.A.
Royal Society of Tasmania.
Royal Society of Victoria.
Royal Academy of Sciences, Lisbon.
Smithsonian Institution, U.S.A.
Société des Ingénieurs Civils de France.
Société Industrielle de Mulhouse.
Société d'Encouragement pour l'Industrie Nationale.
Société des Anciens Elèves des Ecôles Nationales d'Arts et Métiers.
Société des Sciences Physiques et Naturelles de Bordeaux.
The Canadian Institute, Toronto.

The Canadian Society of Civil Engineers.
The Engineering Association of New South Wales.
The Technical Society of the Pacific Coast, U.S.A.

COPIES OF THE TRANSACTIONS ARE FORWARDED TO THE FOLLOWING COLLEGES, LIBRARIES, &C.:—

Glasgow University.
University College, London.
M'Gill University, Montreal.
Stevens Institute of Technology, U.S.A.
Cornell University, U.S.A.
Mitchell Library, Glasgow.
Stirling's Library, Glasgow.
Dumbarton Free Library.
Lloyds' Office, London.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
Mercantile Marine Service Association, Liverpool.
The Yorkshire College, Leeds.
Trinity College, Dublin.

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Colliery Guardian.
Engineering.
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Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Journal de l'Ecole Polytechnic.
L'Industria.

Nature.
Portfeuille Economique des Machines.
Revue Industrielle.
Revue Maritime et Coloniale, Paris.
Stahl und Eisen.
The American Manufacturer and Iron World.
The Contract Journal.
The Engineer.
The Indian Engineer.
The Journal of Commerce.
The Machinery Market.
The Marine Engineer.
The Mechanical World.
The Practical Engineer.
The Scientific News.
The Steamship.

CHAS. C. LINDSAY,
Librarian and Convener.

29th April, 1890.

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 Librarian.

Members have also the privilege of consulting the Books in the Library of the Philosophical Society.

The use of Library and Reading Room is open to Members Associates, and Graduates.

The Library is open during Summer from 9-30 a.m. till 5 p.m., and on Saturdays till 2 p.m.

The Portrait Album lies in the Library for the reception of Members' Portraits.

Members are requested when forwarding Portraits to attach Signature to bottom of Carte.

The LIBRARY COMMITTEE are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to Library.

The Council, being desirous of rendering the Transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such Papers should be sent to the Secretary, so that the dates of reading may be arranged.

Annual Subscriptions are due at the commencement of each Session, viz. :—

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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 1889-90.

HONORARY MEMBERS.

Professor CHARLES PIAZZI SMYTH, LL.D., F.R.S.E., Clova, Ripon.

Professor Sir WILLIAM THOMSON, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow.

Professor JOHN TYNDALL, D.C.L., LL.D., F.R.S., &c., Hindhead House, Haslemere.

HIS GRACE THE DUKE OF SUTHERLAND, Trentham, Stoke-upon-Trent.

Lord ARMSTRONG, C.B., LL.D., D.C.L., F.R.S., Newcastle-on-Tyne.

Professor H. VON HELMHOLTZ, Berlin.

MEMBERS.

DATE OF ELECTION.			
1889, Nov. 19:	William	Adam,	42 Garturk St., Govanhill.
1889, Apr. 23:	James	Adamson,	St. Quivox, Stopford Road, Upton Manor, Essex.
1883, Mar. 20:	Geo. A.	Agnew,	2 Osborne Terrace, Govan, Glasgow.
1889, Oct 22:	William	Aitchison,	Vryheid Lust, Plantation, Demerara.
1859, Jan. 19:	James	*Aitken, Jun.,	Shipbuilder, Whiteinch, Glasgow.
1860, Dec. 26:	William	Aiton,	Sandford Lodge, Peterhead.
1887, Jan. 25:	Prof. Thomas	Alexander,	C.E., Trinity College, Dublin.
1890, Feb. 25:	William	Alexander,	Helen Street, Govan.
Original:	Alexander	Allan,	Glen House, The Valley, Scarborough.
1872, Feb. 27:	A. B.	Allan, C.E.,	Burgh Surveyor, Burgh Chambers, Govan, G'gow.
1890, Jan. 21:	John W.	Allan,	Oak Bank, Shandon.
1869, Jan. 20:	William	Allan,	Scotia Engine Works, Sunderland.
1864. Dec. 21:	James B.	Alliott,	The Park, Nottingham.
G. 1880, Feb. 24: M. 1889, Oct. 22:	George	Almond,	Hordern Cottage, Belmont, near Bolton.
G. 1865, Feb. 15: M. 1877, Dec. 18:	Wm. M.	Alston,	50 Sardinia Terrace, Hillhead, Glasgow.
1886, Dec. 21:	Alexander	†Amos,	Sydney, New South Wales.
1886, Dec. 21:	Alexander	†Amos, Jun.,	247 George Street, Sydney, New South Wales.
G. 1874, Feb. 24: M. 1880, Nov. 23:	James	Anderson,	100 Clyde St., Glasgow.
1888, Jan. 24:	F. W.	Anderson,	———

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

1860, Nov. 28:	Robert	Angus,	Lugar Ironworks, Cumnock.
1887, Dec. 20:	W. David	Archer,	Edin Villa, Dalmuir.
1875, Dec. 21:	Thomas A.	Arrol,	18 Blythswood Square, Glasgow.
1885, Jan. 27:	Sir Wm.	†Arrol, LLD.,	10 Oakley Ter., Glasgow.
Original:	David	Auld,	65 Rochester St., Glasgow.
1885, Apr. 28:	John	Auld,	Whitevale Foundry, Glasgow.
1881, Oct. 25:	Allan W.	Baird,	Eastwood Villa, St. Andrew's Drive, Pollokshields, Glasgow.
1880, Feb. 24:	William N.	Bain,	Collingwood, Pollokshields, Glasgow.
1887, Nov. 22:	Michael R.	Barnett,	Brookhouse Hall, Caton, Lancaster.
1876, Jan. 25:	James	Barr,	Underwood House, Paisley.
1882, Mar. 21:	Prof. Archd.	Barr, D.Sc., C.E.,	7 North Park Terrace, Hillhead, Glasgow.
1881, Mar. 22:	George H.	Baxter,	Barclay, Curle, & Co., Stobcross Engine Works, Glasgow.
G. 1877, Nov. 20: M. 1887, Apr. 6:	J. T.	Baxter,	9 Brighton Terrace, Govan, Glasgow.
1875, Jan. 26:	Charles	Bell,	21 Victoria Place, Stirling.
	David	*Bell,	19 Eton Place, Hillhead, Glasgow.
1880, Mar. 23:	Imrie	Bell, C.E.,	36 Kersland Terrace, Hillhead, Glasgow.
1889, Jan. 22:	W. Reid	Bell, C.E.,	204 St. Vincent Street, Glasgow.
1890, Jan. 21:	R. J.	Beveridge,	20 Albert Drive, Crosshill, Glasgow.
G. 1883, Mar. 20: M. 1884, Nov. 25:	Andrew S.	Biggart, C.E.,	Baltic House, Baltic Street, Bridgeton, Glasgow.

1884, Mar. 25:	John Harvard	Biles,	Clydebank Shipyard, near Glasgow.
1890, Mar. 25:	John R.	Bird,	10 Morrison St., Glasgow.
1866, Dec. 26:	Edward	Blackmore,	Rookwood Road, Stamford Hill, London, N.
1864, Oct. 26:	Thomas	Blackwood,	Shipbuilder, Port-Glasgow.
1869, Feb. 17:	Geo. M'L.	Blair,	127 Trongate, Glasgow.
G. 1884, Jan. 22: M. 1889, Oct. 22:	H. MacLellan	Blair,	Clutha Iron Works, Vermont Street, Glasgow.
1867, Mar. 27:	James M.	Blair,	2 Bute Gardens, Hillhead, Glasgow.
1883, Jan. 23:	Chas. C.	Bone, C.E.,	Corporation Water Works, City Chambers, Glasgow.
1883, Oct. 23:	William L.	Bone,	Ant and Bee Works, West Gorton, Manchester.
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, C.E.,	109 Bath Street, Glasgow.
G. 1873, Dec. 23: M. 1884, Jan. 22:	James	Broadfoot,	55 Finnieston St., Glasgow.
1865, Apr. 26:	Walter	*Brock,	Engine Works, Dumbarton.
1890, Jan. 21:	Alex. F. G.	Brown,	Swindrige Muir, Dalry.
1859, Feb. 16:	Andrew	*Brown,	London Works, Renfrew.
G. 1876, Jan. 25: M. 1885, Nov. 24:	Andrew M'N.	Brown,	Castlehill House, Renfrew.
1886, Mar. 23:	George	Brown,	Kirklee, Dumbarton.
1885, Apr. 28:	Walter	Brown,	Castlehill, Renfrew.
1880, Dec. 21:	William	Brown,	Albion Works, Woodville Street, Govan, Glasgow.
G. 1874, Jan. 27: M. 1884, Jan. 22:	William	Brown,	Houston Terrace, Paisley Road, Renfrew.
1889, Dec. 17:	William	Brown,	Glasgow Locomotive Works, Glasgow, S.S.

1890, Mar. 25:	William	Brown,	Old Hall, Kilmalcolm.
1858, Mar. 17:	James	Brownlee,	23 Burnbank Gardens, Glasgow.
1877, Oct. 30:	Robert	Bruce,	Ethelburga House, 70 Bishopgate Street Within, London.
1889, Dec. 17:	W. Paton	Buchan,	21 Renfrew St., Glasgow.
1860, Dec. 26:	James C.	Bunten,	100 Cheapside St., Glasgow.
1866, Apr. 26:	Amedee	Buquet, C.E.,	15 Chemiss, St. Martin, Pontoise, S. O. France.
G. 1872, Oct. 24: M. 1885, Nov. 22:	Hartvig	Burmeister,	Rahr & Raundrup, 1 Princess Street, Manchester.
G. 1876, Dec. 19: M. 1889, Oct. 22:	Lindsay	Burnet,	Moore Park Boiler Works, Govan, Glasgow.
1880, Dec. 21:	James W.	Burns,	5 Cecil Street, Paisley Rd., W., Glasgow.
1881, Mar. 22:	Thomas	Burt,	26 Carrington St., Glasgow.
1878, Oct. 29:	Edward B.	Caird,	777 Commercial Rd., Limehouse, London.
1878, Dec. 17:	James	Caldwell,	130 Elliot Street, Glasgow.
1890, Feb. 25:	Donald	Cameron,	Municipal Offices, Exeter.
1885, Mar. 24:	John B.	Cameron,	160 Hope Street, Glasgow.
1875, Dec. 21:	J. C.	Cameron,	24 Pollok Street, Glasgow.
1889, Apr. 23:	John	Cameron,	London Works, Renfrew.
1890, Mar. 25:	William	Cameron,	116 Crosby Street, Maryport, Cumberland.
1890, Jan. 21 :	John	Campbell,	Vaselievsky Ostroff, 1st Line, No. 20, St. Petersburg.
1889, Oct. 22 :	Evelyn G.	Carey, C.E.,	Dalmarnock Iron Works, Bridgeton, Glasgow.
1868, Dec 23:	David	Carmichael,	Ward Foundry, Dundee.
1859, Nov. 23:	Peter	Carmichael,	Dens Works, Dundee.
1881, Nov. 22:	John H.	Carruthers,	Craigmore, Queen Mary Avenue, C'shill, Glasgow.

1883, Jan. 23: John	Clark,	British India Steam Navigation Co., 203 West George Street, Glasgow.
1860, Apr. 11: James	Clinkskill,	1 Holland Place, Glasgow.
1884, Feb. 26: James T.	Cochran,	1 India Buildings, Water Street, Liverpool.
1890, Mar. 25: John	Cochrane,	Engineer, Barrhead.
1881, Oct. 25: George	Cockburn,	Rhodora Villa, St. Andrew's Drive, Pollokshields, Glasgow.
G. 1876, Dec. 19: M. 1884, Mar. 25: Charles	Connell,	Whiteinch, Glasgow.
G. 1877, Dec. 18: M. 1885, Nov. 24: James	Conner,	c/o Neilson & Co., Hyde Park Locomotive Works, Glasgow.
1864, Feb. 17: James	Copeland,	16 Pulteney St., Glasgow.
1864, Jan. 20: William R.	Copland, C.E.,	146 West Regent Street, Glasgow.
1868, Mar. 11: S. G. G.	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1866, Nov. 28: M'Taggart	Cowan, C.E.,	109 Bath Street, Glasgow.
1868, Apr. 22: David	Cowan, C.E.,	Mount Gerald House, Falkirk.
1861, Dec. 11: William	Cowan,	46 Skene Terr., Aberdeen.
1883, Dec. 18: Samuel	Crawford,	Clydebank, near Glasgow.
1881, Mar. 22: William	Crockatt,	26 Nithsdale Drive, Pollokshields, Glasgow.
G. 1882, Feb. 21: M. 1889, Oct. 22: W. S.	Cumming,	8 Hartington St., Barrow-in-Furness.
1866, Dec. 26: James L.	Cunliff,	Plewlands House, Merchiston, Edinburgh.
1872, Nov. 26: David	Cunningham, C.E.,	Harbour Chambers, Dundee.
1884, Dec. 23: Peter N.	Cunningham,	645 Alexandra Parade, Glasgow.

1869, Jan. 20:	James	Currie,	16 Bernard Street, Leith.
1889, Oct. 22:	David W.	Cuthbert,	122 West Nile Street, Glasgow.
1888, Jan. 24:	John	Darling,	34 Queen Square, Glasgow.
G. 1874, Feb. 24: M. 1882, Dec. 19:	James	Davie,	8 Park Terrace, Govan, Glasgow.
1861, Dec. 11:	Thomas	Davison,	248 Bath Street, Glasgow.
G. 1881, Mar. 22: M. 1888, Dec. 18:	David	Davidson,	Ellenslee, Radnor Park, Dalmuir.
1864, Feb. 17:	St. J. V.	Day, C.E.,	———
1869, Feb. 17:	James	Deas, C.E.,	Engineer, Clyde Trust, 7 Crown Gardens, Glasgow.
1882, Dec. 19:	J.H.L. Van	Deinse,	Heerengracht No. 81, Amsterdam.
1883, Nov. 21:	James	Denholm,	5 Derby Terrace, Sandyford Street, Glasgow.
1866, Feb. 14:	A. C. H.	Dekke,	Shipbuilder, Bergen, Norway.
	Peter	*Denny, L.L.D.	Helenslee, Dumbarton.
1887, Oct. 25:	James	Denny,	Engine Works, Dumbarton.
1888, Feb. 21:	Archibald	Denny,	Braehead, Dumbarton.
1888, Feb. 21:	Peter	Denny, jun.,	Bellfield, Dumbarton.
1878, Mar. 19:	Frank W.	Dick,	Hallside Steel Works, Newton.
1890, Nov. 19:	B. Gillespie	Dickson,	Eagle Gold Mining Co., Johannesburg, S.A.R.
G. 1873, Dec. 24: M. 1878, Jan. 22:	James S.	Dixon, C.E.,	97 Bath Street, Glasgow.
1871, Jan. 17:	William	Dobson,	The Chesters, Jesmond, Newcastle-on-Tyne.
1864, Jan. 20:	James	Donald,	Abbey Works, Paisley.
1876, Jan. 25:	James	Donaldson,	Almond Villa, Renfrew.
1863, Nov. 25:	Robert	Douglas,	Dunnikier Foundry, Kirkcaldy.

1886, Nov. 23:	Patrick	Doyle, C.E.,	19 Lall. Bazar St., Calcutta.
1890, Apr. 29:	Alexander	Drew, C.E.,	7 Willowbank Crescent, Glasgow.
1884, Dec. 23:	John W. W.	Drysdale,	46 Circus Drive, Glasgow.
1882, Oct. 24:	Chas. R.	Dubs,	Glasgow Locomotive Works, Glasgow.
1886, Nov. 23:	John	Duncan,	Ardenclutha, Port-Glasgow.
1887, Apr. 6:	D. J. Russell	Duncan, C.E.,	Kilmux, Leven, Fifeshire.
1881, Jan. 25:	Robert	Duncan,	Whitefield Engine Works, Govan, Glasgow.
1873, Apr. 22:	Robert (*Member of Council.*)	Dundas, C.E.,	3 Germiston Street, Glasgow.
1869, Nov. 23:	David Jno.	Dunlop,	Inch Works, Port-Glasgow.
1877, Jan. 23:	John G.	Dunlop,	J. & G. Thomson, Clydebank, Dumbartonshire.
1880, Mar. 23:	Hugh S.	Dunn,	Earlston Villa, Caprington, Kilmarnock.
1886, Oct. 26:	Peter	Dunn, C.E.,	3 Germiston St., Glasgow.
1883, Oct. 23:	Henry	Dyer, D.Sc., M.A.,	8 Highburgh Terrace, Dowanhill, Glasgow.
1890, Jan. 21:	James	Easthope,	36 Oswald St., Glasgow.
1876, Oct. 24:	Jn. Marshall	Easton,	Redholm, Helensburgh.
1885, Feb. 24:	Francis	Elgar, LL.D.,	Director, H. M. Dockyard, Admiralty, London, S.W.
G. 1869, Nov. 23: M. 1878, Mar. 19:	John	Ferguson,	Shipbuilder, Leith.
1889, Oct. 22:	Peter	Ferguson,	Phœnix Works, Paisley.
1890, Jan. 21:	Thomas	Field,	3 Knowe Terrace, Pollokshields, 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,	Alexandria Place, Colt Terrace, Coatbridge.
Original:	William	Forrest,	66 Bath Street, Glasgow.
1872, Nov. 26:	Thomas	Forrest, M.E.,	Dumfries Ironworks, Dumfries.
1883, Dec. 18:	Lawson	Forsyth,	10 Grafton Sq., Glasgow.
1870, Jan. 18:	William	Foulis,	Engineer, Corporation Gas Works, City Chambers, Glasgow.
1880, Nov. 2:	Samson	Fox,	Leeds Forge, Leeds.
1879, Nov. 25:	John	Frazer,	P. Henderson & Co., 15 St. Vincent Place, Glasgow.
1885, Jan. 27:	Peter	Fyfe,	1 Montrose St., Glasgow.
1858, Nov. 24:	James M. *(Past President; Member of Council, and Honorary Treasurer.)*	Gale, C.E.,	Engineer, Corporation Water Works, City Chambers, Glasgow.
1862, Jan. 8:	Andrew	Galloway, C.E.,	St. Enoch Station, Glasgow.
1887, Oct. 25:	Lewis P.	Garrett,	19 Renfield St., Glasgow.
1888, Mar. 20:	Ernest	Gearing,	Leontine Oak Road, Woolston, Southampton.
1888, Dec. 18:	E. W.	Gemmell,	Board of Trade Offices, 7 York Street, Glasgow.
G. 1873, Dec. 23: M. 1882, Mar. 21:	Andrew	Gibb,	Rait & Gardiner, Millwall Docks, London.
1886, Nov. 23:	Paterson	Gifford,	6 Union Street, Glasgow.
1859, Nov. 23:	Archibald	*Gilchrist,	11 Sandyford Place, Glasgow.
G. 1866, Dec. 26: M. 1878, Oct. 29:	James	Gilchrist,	Stobcross Engine Works, Finnieston Quay, Glasgow.
1859, Dec. 21:	David C.	Glen,	14 Annfield Place, Dennistoun, Glasgow.
1864, Feb. 17:	James	Goodwin,	Ironfounder, Ardrossan.

1866, Mar. 28:	Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.
1868, Mar. 11:	Joseph	Goodfellow,	3 Towerhill Terrace, Springburn, Glasgow.
1882, Apr. 25:	H. Garrett	Gourlay,	Dundee Foundry, Dundee.
	Edwin	*Graham,	Osbourne, Graham, & Co., Hylton, Sunderland.
1858, Mar. 12:	George	Graham, C.E.,	Engineer, Caledonian Railway, Glasgow.
1876, Jan. 25:	Thomas M.	Grant,	108 Hill Street, Glasgow.
1862, Jan. 8:	James	Gray,	Pathhead Colliery, New Cumnock, Ayrshire.
1881, Dec. 20:	L. John	Groves,	Engineer, Crinan Canal, Ardrishaig.
1872, Feb. 27:	A. A.	Haddin, C.E.,	131 West Regent Street, Glasgow.
1881, Jan. 25:	William	Hall,	Shipbuilder, Aberdeen.
1876, Oct. 24:	David	Halley,	Burmeister & Wain, Copenhagen, Denmark.
G. 1874, Feb. 24: M. 1885, Nov. 24:	Archibald	Hamilton, C.E.,	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.,	Ardedynn, Kelvinside, Glasgow.
	John	*Hamilton,	22 Athole Gardens, Gl'gow.
G. 1869, Nov. 23: M. 1875, Feb. 23:	J. B.	Hamond,	———
1890, Jan. 21:	Peter	Hampton,	47 Summer St., Glasgow.
G. 1880, Nov. 2: M. 1884, Jan. 22:	Bruce	Harman,	Lancefield House, Lancefield Street, Glasgow.
1878, Mar. 19:	Timothy	Harrington,	61 Gracechurch Street, London, E.C.
G. 1874, Feb. 24: M. 1880, Nov. 23:	C. R.	Harvey,	166 Renfrew St., Glasgow.

1890, Jan. 21: James Harvey, 36 Oswald St., Glasgow.
1887, Feb. 22: John H. Harvey, Benclutha, Port-Glasgow.
1864, Nov. 23: John Hastie, Kilblain Engine Works, Greenock.
1871, Jan. 17: William Hastie, Kilblain Engine Works, Greenock.
1879, Nov. 25: A. P. †Henderson, 30 Lancefield Quay, Glasgow.
1877, Feb. 20: David *Henderson, Meadowside, Partick, Glasgow.
1873, Jan. 21: John †Henderson, Jun., Meadowside, Partick, Glasgow.
1879, Nov. 25: John L. †Henderson, Meadowside, Partick, G'gow.
1878, Dec. 17: William Henderson, Meadowside, Partick, Glasgow.
1888, Dec. 18: J. Bailie Henderson, C.E., Govt. Hydraulic Engineer, Brisbane, Queensland.
1870, May 31: Richard Henigan, C.E., Alma Road, Avenue Place, Southampton.
G. 1881, Oct. 25:
M. 1887, Oct. 25: Charles G. Hepburn, 130 Elizabeth Street, Sydney.
1877, Feb. 20: George Herriot, (*Member of Council.*) Board of Trade Offices, 7 York Street, Glasgow.
1888, Dec. 18: Wm. Seymour Hide, Engine Department, East Cowes, Isle of Wight.
Laurence *Hill, C.E., 2 Alfred Terrace, Hillhead, Glasgow.
1880, Nov. 2: Charles P. Hogg, C.E., (*Member of Council.*) 175 Hope Street, Glasgow.
1883, Mar. 20: John Hogg, Victoria Engine Works, Airdrie.
1880, Mar. 23: F. G. Holmes, C.E., 109 Bath Street, Glasgow.
1883, Mar. 20: Matthew Holmes, Netherby, Lenzie.
1890, Mar. 25: Colin †Houston, Harbour Engine Works, 60 Portman St., Glasgow.

1888, Mar. 20:	Robert	Houston,	13 Craignethan Gardens, Partick, Glasgow
Original:	James	Howden,	8 Scotland Street, Glasgow.
Original:	Edmund	*Hunt,	87 St. Vincent St., Glasgow.
G. 1886, Oct. 26: M. 1889, Nov. 19:	Gilbert M.	Hunter, C.E ,	Anglo-Chilian Railway Co., Tocopilla, Chili.
1881, Jan. 25:	James	Hunter,	Aberdeen Iron Works, Aberdeen.
G. 1873, Dec. 23: M. 1885, Nov. 24:	Guybon	Hutson,	Kelvinhaugh Engine Works, Glasgow.
G. 1873, Dec. 23: M. 1877, Feb. 20:	P. S.	Hyslop,	Mendoza, Argentine Republic.
1861, May 1:	John	Inglis,	Point House Shipyard, Glasgow.
1890, Feb. 25:	William	Ireland,	7 Ardgowan Terrace, Glasgow.
1889, Jan. 22:	John	Irving,	Avenue End, Cardross.
1879, Jan. 21:	Thos. F.	Irwin,	2A Tower Chambers, Old Churchyard, Liverpool.
1890, Apr. 29:	C. J.	Jackaman, C.E.,	Dalmarnock Iron Works, Bridgeton, Glasgow.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan, Glasgow.
1889, Mar. 26:	Prof. Andw.	Jamieson, C.E.,	The Glasgow and West of Scotland Technical College, Bath St., Glasgow.
1888, Jan. 24:	Prof. Philip	Jenkins, (*Member of Council.*)	Glasgow University.
1884, Jan. 22:	J. Yate	Johnson, C.E.,	115 St. Vincent Street, Glasgow.
1879, Feb. 25:	David	Johnston,	Eden Villa, Govan, G'gow.
1883, Jan. 23:	F. C.	Kelson,	Angra Bank, Waterloo Park, Waterloo, Liverpool.

1872, Mar. 26:	Ebenezer	Kemp, (*President.*)	Linthouse Engine Works, Govan, Glasgow.
1875, Nov. 23:	William	Kemp,	Helen St. Engineering W'ks, Govan, Glasgow.
1878, Mar. 19:	Hugh	Kennedy,	Redclyffe, Partickhill, Glasgow.
1877, Jan. 23:	John	Kennedy,	R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.
1876, Feb. 22:	Thomas	Kennedy,	Water Meter Works, Kilmarnock.
1890, Jan. 21:	Alexander	Kidd,	36 Oswald St., Glasgow.
	David	*Kinghorn,	12 Bute Gardens, Hillhead, Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	Tower Buildings, Water Street, Liverpool.
1885, Nov. 24:	Frank E.	†Kirby,	Detroit, U.S., America.
1864, Oct. 26:	Alex. C.	Kirk, LL.D., (*Past President.*)	19 Athole Gardens, Kelvinside, Glasgow.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, 99 Southwark Street, London, S.E.
1885, Jan. 27:	Charles A.	Knight,	107 Hope Street, Glasgow.
1880, Mar. 23:	Frederick	Krebs,	c/o L. H. Carl, Copenhagen, Denmark.
1858, Apr. 14:	David	Laidlaw,	Chaseley, Skelmorlie, by Glasgow.
1884, Mar. 25:	John	Laidlaw,	98 Dundas Street, S.S., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 East Milton Street, Glasgow.
1875, Oct. 26:	William	Laing,	17 M'Alpine St., Glasgow.
1880, Mar. 20:	Andrew	Laing,	1 Broomhill Terrace, East, Partick, Glasgow.

1880, Feb. 24:	James	Lang,	℅ George Smith & Sons, City Line, 45 West Nile Street, Glasgow.
1884, Feb. 26:	John	Lang, Jun.,	Church Street, Johnstone.
1888, Feb. 21:	George B.	Laurence,	Clutha Iron Works, Paisley Road, Glasgow.
Original:	James G. *(Past President.)*	*Lawrie,	12 Bowmont Gardens, Glasgow.
G. 1873, Dec. 23: M. 1876, Oct. 24:	Charles C. *(Member of Council; Honorary Librarian.)*	Lindsay, C.E.,	167 St. Vincent St., Glasgow.
1889, Dec. 17:	Alfred E.	Lonergan,	Whitefield Engine Works, Govan, Glasgow.
1884, Feb. 26:	John	List,	3 St. John's Park, Blackheath, London, E.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.
1888, Feb. 21:	Hugh D.	Lusk,	Rosebank, Greenock.
1885, Oct. 27:	John	Lyall,	69 St. Vincent Crescent, Glasgow.

1858, Feb. 17:	David	M'Call, C.E.,	160 Hope Street, Glasgow.
1874, Mar. 24:	Hector	MacColl,	MacIlwaine & MacColl Ld., Shipbuilders and Engineers, Belfast.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
G. 1881, Dec. 20: M. 1889, Oct. 22:	Hugo	MacColl,	Fabrica de Portilla, White & Co., Sevilla, Spain.
1883, Oct. 23:	James	M'Creath, C.E.,	208 St. Vincent Street Glasgow.
1871, Jan. 17:	David	M'Culloch,	Vulcan Works, Kilmarnock.
1884, Feb. 26:	James	M'Ewan,	Cyclops Foundry, 50 Peel Street, London Road, Glasgow.
1880, Nov. 2:	James W.	Macfarlane,	16 Queen's Crescent, Cathcart, Glasgow.

1886, Oct. 26:	Walter	Macfarlane,	12 Lynedoch Cres., Glasgow.
G. 1874, Feb. 24: M. 1885, Nov. 24:	George	M'Farlane,	65 Great Clyde Street, Glasgow.
1886, Jan. 26:	Thomas	M'Gregor,	10 Mosesfield Terrace, Springburn, Glasgow.
1887, Nov. 22:	Hugh	M'Intyre,	19 Albion Cres., Partick, Glasgow.
1887, Apr. 6:	Edward	Mackay,	8 George Square, Greenock.
1881, Mar. 22:	William A.	Mackie,	3 Broomhill Terrace, Partick, Glasgow.
1888, Apr. 24:	James	M'Kechnie,	Engine Department, Martinez Rivas Palmer, Bilbao, Spain.
G. 1880, Nov. 2: M. 1885, Dec. 22:	Robert	M'Laren,	Eglinton Foundry, 22 Canal Street, S.S., Glasgow.
	Sir Andw.	*Maclean,	Viewfield House, Partick, Glasgow.
1884, Dec. 23:	James	M'Lellan,	————
1886, Dec. 21:	William T.	†Maclellan,	Clutha Iron Works, Glasgow.
1890, Feb. 25:	Robert	M'Master,	Linthouse, Glasgow.
	John	*M'Millan,	Shipbuilder, Dumbarton.
	William	*MacMillan,	19 Elgin Terrace, Partick, Glasgow.
1884, Dec. 23:	John	M'Neil,	Helen St., Govan, Glasgow.
1883, Jan. 23:	James	M'Ritchie, C.E.,	Singapore.
1875, Dec. 21:	George	Mathewson,	Bothwell Works, Dunfermline.
1884, Apr. 22:	Henry A.	Mavor,	56 George Sq., Glasgow.
1876, Jan. 25:	William W.	May,	11 Grey Road, Walton, Liverpool.
1887, Jan. 25:	Henry	Mechan,	17 Fitzroy Place, Glasgow.
G. 1876, Oct. 24: M. 1882, Nov. 28:	James	Meldrum, C.E.,	3 Elmbank Street, Glasgow.

1883, Jan. 23:	William	Melville, C.E.,	Caledonian Ry., Buchanan Street, Glasgow.
1881, Mar. 22:	William	Menzies,	7 Dean Street, Newcastle-on-Tyne.
G. 1873, Dec. 23: M. 1881, Nov. 22:	John F.	Miller,	Greenoakhill, Broomhouse.
Original:	James B.	Mirrlees,	45 Scotland Street, Glasgow.
1886, Jan. 26:	Alexander	Mitchell,	4 Bellevue Terrace, Springburn.
1888, Nov. 20:	Thomas	Mitchell,	7 Knowe Terrace, Pollokshields, Glasgow.
1876, Mar. 21:	James	Mollison, (*Vice-President.*)	Lloyd's Register, 36 Oswald Street, Glasgow.
1869, Dec. 21:	John	Montgomerie,	210 Great Northern Ter., Possil Park, Glasgow.
1883, Nov. 21:	Joseph	Moore,	1099 Adeline Street, Oakland, California.
1862, Nov. 26:	Ralph	Moore, C.E., (*Member of Council.*)	13 Clairmont Gardens, Glasgow.
1878, Apr. 23:	Robert H.	Moore,	Mount Blue Works, Camlachie, Glasgow.
1888, Mar. 20:	William	Morison,	25 St. Vincent Crescent, Glasgow.
G. 1878, Dec. 17: M. 1883, Jan. 23:	Robert	Morton,	75 Buchanan St., Glasgow.
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,	Newport House, Eardisley.
1882, Feb. 21:	George	Munro,	254 Bath Street, Glasgow.
1882, Dec. 19:	Robert D.	Munro,	Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.
Original:	James	Murdoch,	Shipbuilder, Port-Glasgow.

1880, Jan, 27:	William	Murdoch,	79 Robertson Street, Glasgow.
G. 1878, May 14: M. 1889, Nov. 19:	Angus	Murray,	4 Sutherland Ter., Dowanhill, Glasgow.
1886, Jan. 26:	James	Murray,	8 Brown Street, Glasgow.
1877, Jan. 23:	Robert	Murray,	Exchange Buildings, Bowlalley Lane, Hull.
1881, Jan. 25:	Henry M.	Napier,	Shipbuilder, Yoker, near Glasgow.
1857, Dec. 23:	John	†*Napier.	———
1881, Dec. 20:	Robert T.	†Napier,	Shipbuilder, Yoker, near Glasgow.
1890, Apr. 29:	Hugh	Neilson,	Clyde Bridge Steel Works, by Cambuslang.
1869, Nov. 23:	Theod. L.	Neish,	22 Holyrood Crescent, Glasgow.
1883, Dec. 18:	Thomas	Nicol,	6 Rosevale Terrace, Partick, Glasgow.
1884, Dec. 23:	Wm. H.	Nisbet,	Mavisbank, Partickhill, Glasgow.
1887, Apr. 6:	William	Nish,	Anchor Line Offices, 7 Bowling Green, New York.
1876, Dec. 19:	Richard	Niven, C.E.,	3 Park Terrace, Ayr.
1861, Dec. 11:	John	Norman,	475 New Keppochhill Road, Glasgow.
1886, Jan. 26:	George	Oldfield,	Sharp, Stewart, & Co., Atlas Works, Springburn, Glasgow.
1882, Jan. 24:	Robert S.	Oliver, C.E.,	Highland Railway Co., Inverness.
1860, Nov. 28:	John W.	Ormiston,	Douglas Gardens, Uddingston.

1885, Mar. 24:	Alex. T.	Orr,	Fletcher & Co., Tilbury Docks, Essex.
1867, Apr. 24:	T. R.	Oswald,	Shipbuilding and Engineering Works, Milford Haven.
1883, Nov. 21:	W. L. C.	Paterson,	19 St. Vincent Crescent, Glasgow.
1887, Nov. 22:	Prof. George	Paton, C.E.,	Royal Agricultural College, Cirencester.
1889, Feb. 26:	John	Paton, C.E.,	74 Forth Street, Pollokshields, 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, C.E.,	Strand Street, Kilmarnock.
G. 1873, Dec. 23: M. 1888, Oct. 23:	Edward C.	Peck,	Yarrow & Co., Poplar, London.
1868, Dec. 23:	Eugène	Perignon, C.E.,	105 Rue Faubourg St. Honoré, Paris.
1887, Oct. 25:	Robert Band	Pope,	Leven Shipy'd, Dumbarton.
1887, Apr. 6:	Theodor J.	Poretchkin,	Russian Imperial Navy, c/o Blackley Young & Co., 103 Holm St., Glasgow.
	John	*Price,	6 Osborne Villas, Jesmond, Newcastle-on-Tyne.
1875, Dec. 21:	Matthew	Prior,	1 St. Helier's Villas, Millbrook, Jersey.
1877, Nov. 20:	F. P.	Purvis,	Don Villa, Greenock.
1868, Dec. 23:	Henry M.	Rait,	155 Fenchurch Street, London.
1873, Apr. 22:	Richard	Ramage,	Shipbuilder, Leith.
1872, Oct. 22:	David	Rankine,	75 West Nile St., Glasgow.

1886, Mar. 23:	John F.	Rankin,	Eagle Foundry, Greenock.
1881, Jan. 25:	Charles	Reid,	Lilymount, Kilmarnock.
1883, Nov. 21:	George W.	Reid,	Highland Railway, Inverness.
1868, Mar. 11:	James *(Past President.)*	Reid,	Locomotive Works, Springburn, Glasgow.
1869, Mar. 17:	James	Reid,	Shipbuilder, Port Glasgow.
	John	*Reid,	Shipbuilder, Port-Glasgow.
1880, Apr. 27:	John	Rennie,	Ardrossan.
G. 1873, Dec. 23: M. 1881, Nov. 22:	Charles H.	Reynolds,	Sir W. G. Armstrong, Mitchell & Co., Walker Shipyard, Newcastle on-Tyne.
1886, Apr. 27:	James	Riley,	Steel Company of Scotland, 23 Royal Exchange Sq., Glasgow.
1890, Mar. 25:	James W.	Robb,	Kirkpark House, Carluke.
1876, Oct. 24:	Duncan *(Member of Council.)*	Robertson,	8 Brighton Place, Govan, Glasgow.
1863, Nov. 25:	William	Robertson, C.E.,	123 St. Vincent Street, Glasgow.
1884, Apr. 22:	R. A.	Robertson,	8 Park St. East, Glasgow.
1888, Apr. 24:	J. F.	Robinson,	Atlas Works, Springburn, Glasgow.
Original:	Hazltn. R. *(Past President.)*	*Robson,	14 Royal Cresct., Glasgow.
1877, Feb. 20:	Jno. MacDonald	Ross,	11 Queen's Cres., Glasgow.
1861, Dec. 11:	Richard G.	Ross,	1 Greenhead St., Glasgow.
G. 1864, Nov. 23: M. 1870, Jan. 18:	Alex.	Ross, C.E.,	Lynnwood, Alva.
Original:	David *(Past President.)*	*Rowan,	231 Elliot Street, Glasgow.
G. 1875, Dec. 21: M. 1885, Jan. 27:	James	Rowan,	231 Elliot Street, Glasgow.
1888, Dec. 18:	Thomas	Rowley,	Board of Trade Offices, 7 York Street, Glasgow.
G. 1858, Dec. 22: M. 1863, Mar. 4:	George	Russell,	Engineer, Motherwell.

1881, Feb. 22:	Joseph	Russell,	Shipbuilder, Port-Glasgow.
1890, Jan. 21:	Edward Mowbray	Salmon,	36 Oswald St., Glasgow.
1876, Oct. 24:	Peter	Samson,	Board of Trade Offices, Downing Street, London, S.W.
1885, Feb. 24:	James	Samuel, Jun.,	185 Kent Road, Glasgow.
1883, Feb. 20:	John	Sanderson,	Lloyd's Registry, 36 Oswald Street, Glasgow.
1882, Dec. 19:	Prof. Jas.	Scorgie, F.C.S.,	Civil Engineering College, Poona, India.
G. 1879, Mar. 25: M. 1888, Oct. 23:	John	†Scobie,	c/o Senores C. J. Tetley & Co., Calle Marco Avellaneda, Tucuman, Argentine Republic.
1872, Jan. 30:	James E.	Scott,	52 Coal Exchange, London.
1881, Jan. 25:	John	Scott,	Whitebank Engine Works, Kirkcaldy.
1860, Nov. 28:	Thos. B.	*Seath,	42 Broomielaw, Glasgow.
1875, Jan. 26:	Alexander	Shanks,	Belgrade, Aytoun Road, Pollokshields, Glasgow.
1889, Mar. 26:	John W.	Shepherd,	Penarva, Partickhill, G'gow.
1858, Nov. 24:	William	Simons,	Tighnabruaich, Argyleshire.
1862, Jan. 22:	Alexander	Simpson, C.E.,	175 Hope Street, Glasgow.
1887, Jan. 25:	Robert	Simpson, B.Sc.,	175 Hope St., Glasgow.
G. 1877, Mar. 20: M. 1887, Dec. 20:	Nisbet	Sinclair,	8 Strathallan Terrace, Partick, Glasgow.
G. 1882, Nov. 28: M. 1889, Oct. 22:	Geo. H.	Slight, Jun.,	Northern Lighthouse Board, 84 George St., Edinburgh.
1871 Mar. 28:	Hugh	Smellie,	Belmont Grange Terrace, Kilmarnock.
Original:	Alexander	Smith,	57 Cook Street, Glasgow.
1880, Nov. 2:	Alexr. D.	Smith,	5 Belmar Terrace, Shields Road, Pollokshields, Glasgow.

1869, Mar. 17:	David S.	Smith,	Hellenic Steam Navigation Co., Syra, Greece.
1871, Dec. 11:	Hugh	Smith,	9 Kelvinside Terrace, N., Glasgow.
1888, Oct. 23:	James	Smith,	Waterloo Estates, Trinidad, West Indies.
1870, Feb. 22:	Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn, Glasgow.
1887, Jan. 25:	Peter A.	Somervail,	35 Burnbank Gardens, Glasgow.
1883, Oct. 23:	Andrew	Sproul,	10 Virginia St., Greenock.
1886, Feb. 23:	George	Stanbury,	14 Berkeley Road, Crouch End, London, N.
1883, Dec. 18:	Alex. E.	†Stephen,	12 Park Terrace, Glasgow,
	John	†*Stephen,	Linthouse, Govan, Glasgow.
1881, Nov. 22:	Alex.	Steven,	Provanside, Glasgow.
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.
1874, Oct. 27:	Peter	Stewart, (*Member of Council.*)	53 Renfield Street, Glasgow.
G. 1873, Dec. 23: M. 1882, Oct. 24:	W. B.	Stewart,	18 Newton Place, Glasgow.
Original:	Patrick	Stirling,	The Great Northern Railway, Doncaster.
1881, Jan. 25:	Walter	Stoddart,	Caledonian Railway, Carstairs.
1889, Oct. 22:	James	Stuart, C.E.,	16 Robertson St., Glasgow.
1877, Jan. 23:	James	Syme,	8 Glenavon Ter., Partick, Glasgow.
1879, Oct. 28:	James	Tait, C.E.,	Wishaw.

1885, Apr. 28: Peter Taylor, Dock Shipbuilding Yard, Port-Glasgow.
1879, Mar. 25: Staveley Taylor, Russell & Co., Shipbuilders, Greenock.
1873, Dec. 23: E. L. Tessier, Veritas Office, 29 Waterloo Street, Glasgow.
1885, Jan. 27: George W. Thode, 107 Hope Street, Glasgow.
1889, Feb. 26: John Thom, Inverkip.
1887, Apr. 26: Arthur W. Thomson, B.Sc., 79 West Regent Street, Glasgow.
1882, Apr. 25: Geo. P. Thomson, Clydebank, Dumbartonshire.
1883, Dec. 18: George Thomson, 9 Buckingham Ter., Partick, Glasgow.
G. 1874, Feb. 24:
M. 1889, Oct 22: George C. Thomson, The Dunfermline Foundry Company, Dunfermline.
1886, Mar. 23: James Thomson, jun., C.E., M.A., Ordnance Works, Elswick, Newcastle-on-Tyne.
1874, Nov. 24: Prof. James Thomson, C.E., LL.D., F.R.SS.L. & E., (*Past President.*) 2 Florentine Gardens, Hillhead Street, Glasgow.
1868, Feb. 12: James M. Thomson, 36 Finnieston St., Glasgow.
1882, Mar. 21: James R. Thomson, Clydebank, Dumbartonshire.
1868, May 20: John Thomson, 36 Finnieston St., Glasgow.
1875, Jan. 26: Robert S. Thomson, 3 Melrose Street, Queen's Crescent, Glasgow.
1864, Feb. 17: W. R. M. Thomson, 96 Buchanan St., Glasgow.
1878, May 14: W. B. Thompson, Ellengowan, Dundee.
1874, Oct. 27: Prof. R. H. Thurston, M.E., C.E., Sibley College, Cornell University, Ithaca, N.Y., U.S.A.
1875, Nov. 23: John Turnbull, Consulting Engineer, 255 Bath Street, Glasgow.
1876, Nov. 21: Alexander Turnbull, St. Mungo's Works, Bishopbriggs, Glasgow.

1880, Apr. 27:	John	Tweedy,	Neptune Works, Newcastle-on-Tyne.
1865, Apr. 26:	W. W.	Urquhart,	Blackness Foundry, Dundee.
1883, Jan. 23:	Peter	Wallace,	Ailsa Shipbuilding Co., Troon.
1885, Mar. 24:	W. Carlile	Wallace,	Castle Shipyard, Port-Glasgow.
1886, Jan. 26:	John	Ward, (*Vice President.*)	Leven Shipyard, Dumbarton.
1875, Mar. 23:	G. L.	Watson,	108 W. Regent St., Glasgow.
1864, Mar. 16:	W. Renny	Watson, (*Vice-President.*)	16 Woodlands Ter., Glasgow.
G. 1875, Dec. 21: M. 1886, Oct. 26:	R. G.	Webb,	Richardson & Cruddas, Byculla, Bombay.
G. 1878, Dec. 17: M. 1887, Nov. 22:	Robert L.	Weighton, M.A.,	St. Peter's Works, Newcastle-on-Tyne.
	John	*Weild,	Underwriter, Exchange, Glasgow.
1874, Dec. 22:	George	Weir, M.E.,	18 Millbrae Cres., Langside, Glasgow.
1874, Dec. 22:	James	Weir, M.E., (*Member of Council.*)	Silver Bank, Cambuslang, near Glasgow.
G. 1876, Dec. 19: M. 1884, Feb. 26:	Thomas D.	Weir, C.E.,	F.C. Central de Venezuela, Caracas, Venezuela, South America.
1889, Apr. 23:	Thomas	Weir, M.E.,	China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China.
1869, Feb. 17:	Thomas M.	Welsh,	52 St. Vincent Cres., Glasgow.
1868, Dec. 23:	Henry H.	West,	14 Castle Street, Liverpool.

1883, Feb. 20:	Richard S.	White,	Fairfield Works, Govan, Glasgow.
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.
1876, Oct. 24:	Francis W.	Willcox,	45 West Sunniside, Sunderland.
1884, Dec. 23:	James	Williamson,	Barclay, Curle, & Co., Whiteinch, Glasgow.
1883, Feb. 20:	Robert	Williamson,	Lang & Williamson, Engineers, &c., Newport, Mon.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.
1887, Oct. 25:	David	Wilson,	Arecibo, Porto Rico, West Indies.
1889, Oct. 22:	Gavin	Wilson, C.E.,	16 Robertson St., Gl'gow.
1868, Dec. 23:	James	Wilson, C.E.,	Water Works, Greenock.
1870, Feb. 22:	John	Wilson,	165 Onslow Drive, Dennistoun, Glasgow.
1858, Jan. 20:	Thomas	†*Wingate,	Viewfield, Partick, G'gow.
1888, Nov, 20:	John	Wotherspoon,	Rossbank, Port-Glasgow.
1890, Mar. 25:	William G.	Wrench,	5 Oswald St., Glasgow.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.

ASSOCIATES.

	Thomas	*Aitken,	8 Commercial Street, Leith.
1888, Nov. 20:	Capt. John	Bain,	4 Edelweiss Ter., Partick, Glasgow.
1883, Oct. 28:	John	Barr,	Secretary, Glenfield Co., Kilmarnock.
1882, Dec. 19:	William	Begg,	Gartfern, High Crosshill, Rutherglen.
1884, Dec. 23:	W. S. C.	Blackley,	10 Hamilton Crescent, Partick, 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.
1885, Feb. 24:	Robert	Darling,	Bankhead, Laverock Road, Trinity, N.B.
1859, Nov. 23:	Sir A. Orr	Ewing, Bart.,	M.P., 2 W. Regent Street, Glasgow.
1885, Mar. 24:	James S.	Gardner,	136 George Street, G'gow.
1863, Mar. 18:	Robert	Gardner,	136 George Street, G'gow.
1860, Jan. 18:	George T.	Hendry,	79 Gt. Clyde St., Glasgow.
1882, Oct. 24:	Wm. A.	Kinghorn,	81 St. Vincent Street, Glasgow.

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

1884, Feb. 26:	C. R. L.	Lemkes,	194 Hope Street, Glasgow.
1888, Jan. 24:	Thos. S.	M'Innes,	56 Waterloo Street, G'gow.
1886, Jan. 26:	Capt. Dun.	M'Pherson,	3 Cecil Street, Paisley Rd., W., Glasgow.
1873, Feb. 18:	John	Mayer, F.C.S.	11 Balmoral Crescent, Crosshill, Glasgow.
1874, Mar. 24:	James B.	Mercer,	Broughton Copper Works, Manchester.
	George	*Miller,	1 Wellesley Place, Glasgow.
1865, Dec. 20:	John	Morgan,	Springfield House, Bishopbriggs, Glasgow.
1883. Dec. 18:	W. M'Ivor	Morison,	Mayfield, Marine Place, Rothesay.
	James S.	*Napier,	33 Oswald Street, Glasgow.
	John	*Phillips,	17 Anderston Quay, G'gow.
1869, Nov. 23:	Capt. John	Rankine,	31 Airlie Terrace, Pollokshields, Glasgow.
1867, Dec. 11:	William H.	Richardson,	19 Kyle Street, Glasgow.
1889, Jan. 22:	William	Rigg,	3 Grantly Place, Shawlands, Glasgow.
1888, Jan. 24:	Samuel	Smillie,	71 Lancefield St., Glasgow.
1876, Jan. 25:	George	Smith,	45 West Nile St., Glasgow.
	John	*Smith,	Aberdeen Steam Navigation Co., Aberdeen.
	Malcolm M'N.	*Walker,	45 Clyde Place, Glasgow.
	H. J.	*Watson,	5 Oswald Street, Glasgow.
1882, Dec. 19:	John D.	Young,	Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.
	William	*Young,	Galbraith Street, Stobcross, Glasgow.

GRADUATES.

1890, Mar. 25:	J. M.	Adam,	40 St. Enoch Sq., Glasgow.
1882, Nov. 28:	William H.	Agnew,	Engine Drawing Office, Naval Construction and Armament Co., Barrow-in-Furness.
1880, Nov. 2:	James	Aitken,	32 Clarendon Road, West Green, Tottenham, London.
1888, Jan. 24:	H. Wallace	Aitken,	Netherlea, Pollokshields, Glasgow.
1885, Dec. 22:	John Henry	Alexander,	42 Sardinia Terrace, Hillhead, Glasgow.
1888, Jan. 24:	James	Allan,	144 Buccleuch St., Glasgow.
1889, Dec. 17:	John	Anderson,	5 Park Street, Cambuslang.
1890, Mar. 25:	James	Andrew,	Gavinburn, Old Kilpatrick.
1888, Oct. 23:	Donald S.	Arbuthnot,	3 Germiston St., Glasgow.
1888, Apr. 24:	Harry D. D.	Barman,	2 Gilmour St., Byres Road, Partick, Glasgow.
1885, Dec. 22:	Peter M'L.	Baxter,	c/o Cox & Co., Engineers, &c., Falmouth.
1887, Apr. 26:	Thomas	Bell,	Little Park Cottage, Yoker.
1889, Nov. 19:	W. Napier	Bell,	19 Eaton Place, Hillhead, Glasgow.
1885, Mar. 24:	Alexander	Bishop,	3 Germiston St., Glasgow.
1885, Oct. 27:	Archibald	Blair,	12 Arthur Street, Glasgow.
1884, Jan. 22:	George	Blair, Jun.,	6 Alfred Terrace, Hillhead, Glasgow.
1885, Oct. 27:	William C.	Borrowman,	53 Bentinck St., Glasgow.
1888, Jan. 24:	Mark	Brand, B.Sc.,	Faulds Park, Baillieston.
1886, Oct. 26:	James	Brown,	Engine Dept., Martinez, Rivas & Palmer, Bilbao, Spain.

1883, Apr. 24:	Arthur R.	Brown,	—
1879. Feb. 25:	Alex. T.	Brown,	6 Olrig Terrace, Glencairn Drive, Pollokshields, Glasgow.
1883, Dec. 18:	Eben. H.	Brown,	15 Moor Ter., Hartlepool.
1881, Jan. 25:	Matthew T.	Brown, B.Sc.,	194 St. Vincent Street, Glasgow.
1888, Mar. 20:	James	Brown,	Simpson & Wilson, C.E., 175 Hope St., Glasgow.
1890, Feb. 25:	John	Buttery,	Hyde Park Loco. Works, Glasgow.
1890, Jan. 21:	William	Caird,	2 Derby Terrace, Glasgow.
1888, Jan. 24:	Angus	Campbell,	31 Elderslie St., Glasgow.
1884, Feb. 26:	John	Cleland, B.Sc.,	Woodhead Cottage, Old Monkland.
1881, Nov. 22:	Alfred A. R.	Clinkskill,	1 Holland Place, Glasgow.
1884, Feb. 26:	Alexander	Conner,	9 Scott Street, Glasgow.
1885, Dec. 22:	Benjamin	Conner,	9 Scott Street, Glasgow.
1884, Jan. 22:	Alex. M.	Copeland,	—
1880, Dec. 21:	Sinclair	Couper,	Moore Park Boiler Works, Govan, Glasgow.
1885, Oct. 27:	Francis	Coutts,	21 Roslin Ter., Aberdeen.
1884, Jan. 22:	James	Dalziel,	20 Kelvinhaugh Street, Glasgow.
1886, Mar. 23:	Thomas	Danks,	Local Board Offices, Pentre Rhondda, Pontypridd, Wales.
1888, Dec. 18:	Harry L.	Davies,	104 West Princes Street, Glasgow.
1883, Dec. 18:	William	Denholm,	8 Merkland Street, Partick, Glasgow.
1883, Feb. 10:	Lewis M. T.	Deveria,	c/o P. M'Intosh & Son, 129 Stockwell St., Glasgow.

1886, Nov. 23: Thomas Dick, c/o Wm. Dick, 917 Union St., San Francisco, U.S.A.
1888, Mar. 20: B. B. Donald, 9 Balgray Ter., Springburn, Glasgow.
1883, Oct. 23: Harry W. Downes, Martinez Rivas & Palmer, Bilbao, Spain.
1886, Nov. 23: George F. Duncan, Ardenclutha, Port-Glasgow.
1884, Jan. 22: William Dunlop, 31 Hartington Street, Barrow-in-Furness.

1885, Mar. 24: Robert Elliot, B.Sc., 3 Langside Ter., Langside, Glasgow.

1878, Jan. 22: James R. Faill, 7 Winton Drive, Kelvinside, Glasgow.
1882, Feb. 21: Albert E. Fairman, Blairburn, Helensburgh.
1880, Dec. 21: Henry M. Fellows, Westbourne Lodge, Great Yarmouth.
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1881, Nov. 22: Charles J. Findlay, 10 Bruce Street, Hillhead, Glasgow.
1883, Oct. 23: Duncan Finlayson, 15 Copeland Road, Govan, Glasgow.
1869, Oct. 26: F. P. Fletcher, ———
1886, Apr. 27: John I. Fraser, 13 Sandyford Pl., Glasgow.

1885, Oct. 27: Henry G. Gannaway, 23 Bede-Burn Road, Jarrow-on-Tyne.
1889, Apr. 23: Hugh Gardner, c/o R. T. Moore, C.E., 160 Hope Street, Glasgow.
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1883, Jan. 23: John A.	Inglis,	23 Park Circus, Glasgow.
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1888, Apr. 24: R. E. Kinghorn, 12 Bute Gardens, Hillhead, Glasgow.

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1889, Apr. 23:	John	Miller,	658 Govan Road, Glasgow.
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1885, Dec. 22: William B. Morison, 90 Great Mersey St., L'pool.
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1887, Dec. 20: David Myles, 231 Elliot Street, Glasgow.

1890, Apr. 29: Joseph Nayler, 7 Hampden Terrace, Mount Florida, Glasgow.
1886, Jan. 26: Thomas Nicholson, 6 Annfield Place, Glasgow.

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1879, Nov. 25: Alex. R. Paton, Redthorn, Partick, Glasgow.
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1881, Oct. 25: William T. Philp, Laird Bros., Birkenhead.
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1885, Jan. 27: James L. Proudfoot, 135 George St., Edinburgh.

1880, Nov. 2: Matthew Rankine, 3 Wilton Crescent, Glasgow.
1886, Dec. 21: Andrew T. Reid, 10 Woodside Terrace, Glasgow.
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1884, Dec. 23: James G. Reid, Mitsa Bishi Dockyard and Engine Works, Nagasaki, Japan.
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1884, Feb. 26: Walter Reid, 118 Ingleby Drive, Glasgow.
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Boiler Trials; Trail.
Bridge Construction; Fidler.
British Association; Annual Report, 1885.
—— Association; Annual Report, 1886.
—— Association; Annual Report, 1887.
—— Association; Annual Report, 1888.
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—— Mining; Hunt.

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Die Schippmachine; Busley.
—— Wasseräder; Bach.

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—— Institute of Technology, Annual Catalogue and President's Report.
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