

WILLIAM HOULDSWORTH McCONNEL.
 JOHN RICHARD MACGACHEN.
 GEORGE HARRY LE MAISTRE.
 ERNEST DE MÉRINDOL MALAN.
 FREDERICK WILLIAM MAUNSELL.
 JOHN HENRY MEDLICOTT.
 ARTHUR MEYRICK MOORE.
 GEORGE MORISON, JUN.
 KEITH WILLIAM MURRAY.
 CUTHBERT JAMES O'BRIEN.
 THOMAS WILLIAM POTTER.
 THOMAS THEOPHILUS PRENTICE.
 JOHN LAMBE RIGDEN.
 WILLIAM FLEET ROBERTSON.
 HENRY FILLMER RUTTER.
 ROBERT JULIAN SCOTT.

FRANCIS MARTIN SMITH.
 JAMES CAMPBELL SMITH.
 ALFRED WOLRYCHE STANSFELD.
 EDMUND PALEY STEPHENSON.
 JOHN HENRY SWAINSON.
 THEODORE MARTIN TEED.
 ARTHUR TIMMINS.
 ARTHUR STUART VOWELL.
 GEORGE KINDERSLEY WASEY,
 WILLIAM WATSON, B.A.
 HENRY ARTHUR WHITE.
 HENRY WALL WILKINSON.
 CLAUDE ST. MAUR WILLIAMS.
 GILBERT PERCY WILLIAMS.
 ROWLAND RICE WILLIAMS.
 FREDERICK JAMES WILSON.

The following Candidates were balloted for and duly elected as :—

Members.

HENRY ROBERT PASLEY CARTER.
 THOMAS CLAXTON FIDLER.
 CHARLES O'NEILL.

THEOPHILUS SEYRIG.
 HERBERT WALLIS.
 THOMAS PARKER WATSON, M.A.

Associate Members.

WILLIAM CRICKMAY.
 GODFREY DARBISHIRE, Stud. Inst. C.E.
 ALEXANDER DOWNIE.
 JOSEPH FRANCIS.
 LIONEL PHILIP PAYNE GALLWEY.
 GEORGE ABRAHAM GOODWIN.
 JOHN HORAN, B.E.
 HUGH GIFFEN McKINNEY.

ADAM PRIMROSE.
 HENRY DE QUINCY SEWELL.
 JOHN STANDFIELD.
 REGINALD FOSTER WARD.
 HENRY WOOLCOCK.
 WILLIAM BARTON WORTHINGTON, B.Sc.,
 Stud. Inst. C.E.

Associates.

WILLIAM MARTIN CUNINGHAM.

JOSEPH MONTAGUE LIVESEY.
 WILLIAM HAMPSON TOPHAM.

Mr. BARLOW addressed the Meeting in the following terms, on taking the chair, for the first time, after his election as President :—

The important rank which The Institution of Civil Engineers has acquired in this country, and the estimation in which it is held in foreign countries, while they are circumstances of which all must feel proud, necessarily impose upon its members, and especially on those who take a leading part in its affairs, duties

of corresponding responsibility. In assuming the position of President to which you have elected me, and for which my best thanks are due as being the highest honour my professional brethren can bestow, I feel it to be accompanied by obligations of so onerous a character, that I should have hesitated to undertake them, unless I could rely with confidence on your aid, not only to maintain, but if possible to raise, the standing which the Institution has attained.

It becomes my duty this evening to offer some observations in the nature of an address; but the variety of subjects which have been so ably treated by my predecessors in office render this task one of considerable difficulty.

Having commenced my professional career in the same year as that in which the Institution received its Royal Charter, namely 1828, I propose to draw attention to the great changes and progress in engineering which have arisen since that time; because those changes have had a marked effect on the conditions of daily life. It is in fact difficult for those who lived fifty years ago to recall all the circumstances of those times, so much have the facilities now enjoyed become a matter of habit; but it is not claiming too much to say, that some of the most important of those facilities are the direct result of the applications of engineering science.

There is one circumstance of my early life which left a strong impression on my mind, and which I may be pardoned for mentioning, namely, the first time I was present at a meeting of the Institution. This was in 1827. I went accompanied by my brother, Mr. P. W. Barlow, who was then an Associate, and is now one of our oldest Members. There were several men present whose names are well known, among them Mr. Joshua Field, Mr. James Simpson, Mr. (now Sir) John Macneill, and Mr. Henry Robinson Palmer. But the one who riveted my attention was the great Thomas Telford, who occupied the chair, and who seemed to me a superior being, gifted with higher attributes than ordinary men. It appears by the records of the Institution that the number of persons present at that meeting, including visitors, was twenty-three—and that was considered a well-attended meeting.

Of the large features of change since the Institution received its Royal Charter, there are none which have produced so marked an influence on the well-being of this country, and on the world at large, as the improvements in the means of communication, by the application of steam to locomotion on land and on sea, and by the utilisation of some of the powers of electricity in the transmission

of intelligence. It is not alone in the economical results, or in the impulse and larger area given to commercial enterprise, that advantage arises; but mutual interests become established between the inhabitants of different countries, people are induced to travel and enlarge their sphere of observation, dwellers in distant places are brought together, and the opportunities for interchange of ideas and thought are increased.

For some time previous to 1828, an improvement had been urgently demanded in the means of transport for goods and minerals. The canals, which in this country date from about the year 1758, were estimated, in 1836, to exceed 3,000 miles in length; but they were wholly inadequate to the wants of the commercial interests at that time. Much attention was bestowed on turnpike roads, many of the main lines having been brought to a high degree of excellence under the direction of Telford. Tramways, which existed long before canals, and in considerable numbers in the mineral districts, were mostly of cast iron, and belonged to private owners, few being applied to the general purposes of commerce. There were also some railways, distinguished from tramways, as their name implies, by being formed of rails instead of tramplates, among which was the well-known Stockton and Darlington Railway. The application of steam in locomotive engines was in an early experimental stage.

It is needless to mention George Stephenson. His name will always be associated with the early establishment of railways, not so much on account of the engineering ability he displayed, but because it was due to his strong convictions and his force of character, that the Liverpool and Manchester Railway Company adopted locomotive engines for their tractive power; and the commercial success of this enterprise formed the starting point of that great railway system which has spread its network and its ramifications in many parts of the world. That the discovery of a better system of locomotion by land was greatly needed is evinced by the extent to which the railway system has already been carried. The Liverpool and Manchester Railway was opened in 1830, and within forty-five years of that time Sir John Hawkshaw, Past-President Inst. C.E., in his address to the British Association,¹ estimated the total length of railways then existing at 160,000 miles, and the capital invested in their construction at £3,200

¹ Brit. Assoc. Rep., vol. xlv., 1875, pp. xcii. and xcix.

millions. Since then there have been considerable extensions; and when it is remembered that China has at present no railways, that Japan is only beginning to construct them, that Africa, with a population estimated by Mr. Brassey at between 350 and 400 millions, is almost without railways, as well as large parts of South America and Central Asia, and that many British colonies are badly provided, it must be obvious that the railway system will continue to increase. In the United States of America the construction of new lines is actively proceeding, and even in this country, which seems well supplied in proportion to its area and population, the increase proceeds, not so rapidly as it has done, but still it continues, as is evident from the following Table:—

				Miles.					£.
In the year 1846 the length was				2,765	and the traffic				7,565,569
"	"	1854	"	"	"	8,053	"	"	20,215,724
"	"	1862	"	"	"	11,551	"	"	29,128,558
"	"	1870	"	"	"	15,537	"	"	45,078,143
"	"	1878	"	"	"	17,333	"	"	62,862,674

The traffic receipts exhibit two separate elements of increase, one due to the greater length of lines in operation, the other to the continuous growth of traffic on lines already opened—a growth which is found to exist even on the oldest lines. It is not easy to separate these two elements in the traffic returns; but having devoted some pains to the inquiry, it appears that the traffic growth, on all the lines in the United Kingdom, over the whole period of thirty-two years, has averaged rather more than £100 per mile per annum. The traffic for the three years ending in 1878 has been almost stationary; but it was preceded by such very large receipts between 1870 and 1874 that at the date of the last annual returns, it was hardly back to its normal condition.

To meet the exigencies of this growth of traffic, a reconstruction of the permanent way, engines, and carriages has been necessary, as well as extensive additions to stations. The rails first laid were of wrought iron, weighing 35 lbs. per yard. Those now used on the main lines are of steel, weighing between 80 lbs. and 90 lbs. per yard, and on a large part of the principal railways four lines are laid, enabling the fast trains to be separated from those of lower speed, thus largely increasing the carrying capacity. The engines, originally limited to 5 tons in weight, and burning coke for fuel, have been replaced by others of greatly improved construction, weighing, with their tenders, from 50 to 75 tons, and burning a cheaper fuel, viz. coal. Carriages were first made after the pattern of coach-bodies, with three small compartments on four

wheels. These have been replaced by large commodious vehicles running on two six-wheeled bogie frames, and the Pullman carriage from America, with its drawing-room car and sleeping compartments, has been successfully introduced. While these improvements have added much to the comfort of railway travelling, a complete system of block-signalling, the employment of continuous brakes, and the interlocking of points and signals, have greatly increased the safety, notwithstanding the higher speed and the greater number of trains.

It is impossible to allude to railway travelling at this time, without the mind recurring to the late most lamentable accident at the Tay Bridge. This grave disaster is now the subject of a searching investigation, the results of which will necessarily be looked for with great anxiety. Should this inquiry reveal, as it may be hoped to do, the probable cause or causes which have contributed to such distressing results, it will afford information of the greatest value for future guidance.

Excepting this one unprecedented catastrophe, railway travelling exhibits highly satisfactory results as regards safety—whether considered in reference to the enormous numbers who travel, or to the distances accomplished by habitual travellers. The distances passed over by some of the older servants of the railway companies are remarkable. Thus, Mr. Allport states that guards on the Midland have ridden 2,000,000 miles, while Mr. Besley mentions two guards on the Great Western, one of whom is estimated to have travelled 2,400,000 miles, and the other 2,500,000 miles, a distance more than ten times that of the moon from the earth.

Street tramways, which have been in use for a long time in America, are now being largely introduced into the principal cities and towns of Europe. They are evidently a great convenience to a considerable class of the public; but whether from the mode of their construction or from insufficient care in the maintenance of the roads, some of them render the travelling of other carriages along the same lines of roads very unpleasant—a defect which it is hoped may be remedied. Efforts are being made to introduce some power upon them other than horse-traction. Among these are a modified form of the locomotive steam-engine, the compressed-air engine, and an ingenious arrangement called the fireless engine.

Steam navigation had made some progress in 1828. The number of steam vessels then existing was 344, with an aggregate tonnage of 30,912 tons, showing an average of about 90 tons

each. They were chiefly employed in river and coasting traffic. In the United States of America further progress had been made, the magnificent rivers of that country being among the earliest means developed for internal communication. At that time all ships, including ships of war, were of timber. With a few exceptions steam had not been introduced into the Royal Navy, and it was considered derogatory in the service to be appointed to the command of a steam vessel. Ocean steam navigation, which now forms the links of communication between distant countries, had not been attempted, and it constitutes another of those great achievements due to the application of steam to locomotion.

As the Liverpool and Manchester Railway was the starting point of the railway system, so were the almost simultaneous voyages of the "Sirius" and the "Great Western" in 1838 the starting point of ocean steam navigation. Its commercial success and the extent to which it has been carried are owing to improvements which involve a greater range of scientific knowledge than the construction of railways, and are the result of deep thought and unremitting perseverance of many able men. By improvements in the marine engine the consumption of fuel has been largely reduced; the screw-propeller has taken the place of the paddle-wheel, by which greater advantages in propulsion have been obtained; and by the substitution of iron and steel for timber, ships are now made of greater length and strength and carrying capacity.

The capital invested in ocean steamships, though large, has not been of the magnitude required for railways, but it is rapidly increasing, owing to the greater number of ships employed and to their being of larger dimensions and power. It appears that prior to 1836 the largest ships afloat were between 800 and 900 tons burthen, and about 220 HP. With the exception of the "Great Eastern," which, though grand in its conception, was in advance of the wants of the day, there has been an almost continuous growth in the dimensions and power employed. There is now in course of construction, entirely of Siemens-Martin steel, and nearly completed, the steamship "Servia," for the Cunard Company, of 7,500 tons burthen, 10,000 HP., 500 feet in length, and calculated for a speed of $17\frac{1}{2}$ knots per hour. The Allan Company is building another vessel of 5,500 tons burthen, also to be entirely of steel. These will, however, be surpassed in magnitude by the war ships now building. The "Inflexible," for the English navy, will be 11,600 tons burthen, 8,000 HP., and carry four 80-ton guns; and the "Italia," for the Italian navy, will be 13,200 tons burthen, 18,000 HP., and carry four 100-ton guns.

The great ocean steamships, combining sailing and steam propulsion, present in their structure, and in the various requirements necessary for the speed, regularity, and safety with which they are worked, a number of mechanical and scientific applications of high order, every one of which is the result of much study and mental labour. But the ponderous armour-plated turret-ships, mounted with powerful artillery, containing steam-engines for propulsion, others for turning the turrets, for steering, lifting anchors, working hydraulic machinery for moving the guns, and numerous applications of electricity for signalling and firing and electric lighting, constitute as a whole a most surprising combination of science and skill. In these ships the improvements are of two kinds, one directed to the ship itself, its structure and its propulsion, the other to performing different functions of manipulation; and as regards these latter, admitting the excellence of each of the individual contrivances, yet there is a point at which their advantages may be overbalanced by their number and complexity.

The extension of navigation has rendered necessary a considerable increase in docks and harbour works. These works, some of them of great magnitude and cost, are too numerous to be described in detail. They constitute a special branch of engineering of a very important character. Large extensions of docks have been made in London, Liverpool, Southampton, and Hull. New docks have been constructed at Avonmouth and at Portishead in connection with Bristol, besides many other like works in different localities. Among the principal harbour works are those of Portland, Holyhead, and Dublin. The progress in harbours, however, does not appear to have proceeded so rapidly as to meet the full requirements of the time. The number of wrecks that occur annually within British waters seems to show that more harbours of refuge are required on the coasts of the United Kingdom, and there is evidence that the development of steam navigation is impeded by an insufficiency of harbours. This is especially observable in regard to the communication between England and the Continent. The Channel passage, from its extreme discomfort, interferes prejudicially with the proper interchange of traffic between those countries, and has led to many suggestions for its amendment. It is satisfactory to learn that the French Government is about to improve the harbours on the coast of France—a movement which it is hoped will be followed by corresponding action on the part of the English Government. The steamboat called the “Calais-Douvres” is a praiseworthy, and to a certain extent successful,

attempt to make the best of the existing harbours, and to mitigate some of the inconveniences of this short sea passage; but this vessel only runs during summer, and the greater room and superior accommodation afforded by her is not attainable in the rough winter months.

Canals have ceased to extend in England, to any appreciable degree, since the establishment of the railway system; but they progress in many parts of Europe, where, in conjunction with river navigation, they afford great facilities for trade carried on in small vessels. The most remarkable work of inland navigation of modern times, one which has exercised a great influence on the ocean navigation of the East, is the Suez ship canal—a work which will always render famous the name of its author, M. de Lesseps. Another similar work affecting the trade of Eastern Europe is the deepening of the mouths of the Danube, by Sir Charles Hartley, M. Inst. C.E. There are also two important American works, not yet entirely completed, one the deepening of the channel between Long Island and the mainland, rendered specially interesting by the extensive blasting operations at Hell Gate; the other the improvement and deepening of the south channel of the Mississippi, by Mr. J. B. Eads, M. Inst. C.E. In this work, by the application of comparatively inexpensive means, the channel has been deepened so as to permit the passage of much larger ships to New Orleans.

The communication of public and private intelligence was formerly dependent on the speed at which a man could travel, and, excepting a limited application of the old semaphores, the Government were in like manner restricted in their intelligence department. The introduction of electricity for the purposes of telegraphy, and more recently for the production of light, and lastly for the transmission of power, is a matter of especial interest, as being one in which the labours of the philosopher, and the discoveries originating in his laboratory, are made directly applicable “for the use and convenience of man.” As in many other discoveries and new applications of science, the form which the telegraph ultimately received was preceded by various suggestions, showing the conception of the idea. Sir Francis Ronalds, as is well known, made a telegraph worked by frictional electricity, of which he published an account in 1823. A much nearer approach to the needle telegraph was an experiment by my father (Professor Barlow), who used a galvanic battery, and deflected small compass needles placed in different parts along the conducting wire. By

this experiment, which was recorded in the "Edinburgh Philosophical Journal for 1825," Professor Barlow found that considerable loss of power arose with increase of length, and he was in consequence discouraged from proceeding further than determining some of the laws on which that decrease depended, and also the relative conductivities of different sizes of brass or copper wire. Having been present at the experiment, I well remember, though only a lad at the time, that the large quantity battery, which had been employed in Professor Barlow's experiments on electro-magnetism, was used without any coil, and that the wires were hung to the posts without any insulation.

The form which the telegraph received at the hands of Sir Charles Wheatstone and Sir William Fothergill Cooke, and its application to signalling on the Blackwall railway in 1838, established its practicability. Through the influence of Mr. Robert Stephenson and of Mr. Bidder, Past-Presidents Inst. C.E., a company was formed to work the invention for commercial purposes, and from that time, by the aid of numerous inventions and adaptations, and especially by having overcome the difficulty of crossing the ocean, the system has spread with a rapidity to which there is no parallel. In 1875, the total length of wire in operation was estimated at 400,000 miles. Since then the Eastern Telegraph Company has extended its lines to the Cape of Good Hope; two new cables have been laid by Dr. Siemens, M. Inst. C.E., between France and America, and large extensions and duplications of land lines have been made. There are no means of tracing the traffic growth of telegraphy; but by the introduction of the duplex system and the automatic working, together with other ingenious contrivances, the traffic must have increased in a far greater proportion than the length of wire in operation. The diminution of power, arising from increase of length in the conducting wire, as pointed out by my father in 1825, renders it necessary to re-transmit telegrams at the end of long cables. On land lines, or in short cables working in connection with land lines, this difficulty has been surmounted by relays of power applied at fixed stations. By employing this ingenious expedient on the Indo-European telegraph, Calcutta has frequently been put into direct communication with London, a distance of 7,000 miles. Another application of the telegraph, now commencing in this country, but already in considerable use in America, is the telephone, first publicly exhibited by Professor Bell at the Philadelphia Exhibition in 1876. The power of transmitting the sound of the human voice and its articulation gives it a high scientific interest. Its

value as a commercial instrument consists in saving the time required to write, transmit and re-write telegrams. Since the date of the telephone, Mr. E. A. Cowper, M. Inst. C.E., has succeeded in making a most ingenious instrument, whereby hand-writing is transmitted and reproduced at the receiving station by telegraph. To Professor Morse is due what may be termed an extremely "happy thought," namely, the system called the "dot and dash." It constitutes a species of articulation, which conveys intelligible meaning by the relative intervals of continuance and discontinuance of action. It is applied in telegraphy, both in writing and in conveying messages by sound as well as by sight, and Sir William Thomson, M. Inst. C.E., has for some time past urged its adoption, where it would be of the greatest importance to the safety of navigation, namely, as a means of distinguishing lighthouses.

The brilliant electric light, which, in its present form, originated with the discoveries of Faraday, has latterly attracted much public attention. Some attempts were made to utilise this light when its source was derived from galvanic batteries, in which manner it was first produced by Sir Humphrey Davy; but the more recent electro-dynamic machines have placed lighting by electricity on a totally different footing to that on which it formerly stood. The exhibitions of this light in this city and in other cities during the last year, and the valuable evidence given in the Report from the Select Committee of the House of Commons of last session on Lighting by Electricity, leave no doubt of its applicability to many important purposes. It is, in fact, already established in lighthouses, where its intensity and power are of the highest value; and there are many examples of its application in public buildings and large shops, in railway stations and open spaces, and for street lighting. Whether it can be divided, so as to become equally economical and convenient for domestic purposes, has yet to be ascertained. In the evidence given before the Select Committee, and in the Report itself, there appears to be some confusion between the intensity of light and its illuminating power. The distinction ought not to be overlooked. The intensity of a light bears the same kind of relation to its illuminating power as the specific gravity of a substance does to its weight. Many powerful minds are now directing their attention to electric lighting, and there is daily evidence of its improvement and advance. The 20-HP. engine put down last year to work twenty lights in its immediate vicinity on the Thames Embankment has, by improvements since that time, been made to work sixty lights,

some of them at a distance of more than $1\frac{1}{2}$ mile measured along the conducting wire.

The latest application of electricity, namely, for the transmission of mechanical energy, was suggested by Dr. Siemens, in his address to the Iron and Steel Institute in 1877. The laws which govern the size of the conductor, and other features as to its economy as a transmitter, were fully explained at a subsequent meeting of this Institution, and have since received practical confirmation. Sir William Armstrong, V.-P. Inst. C.E., has availed himself of this force for working a circular saw placed at a distance of one mile from the waterfall which supplies the power. The deep-sea sounding line on board the telegraph ship "Faraday" is hoisted by mechanical energy thus transmitted from the engine; and Dr. Werner Siemens has succeeded in obtaining locomotive power sufficient to convey thirty persons by similar means. It appears that, including all sources of loss from converting and reconverting the energy, from friction in the machines and from resistance in the conductor, Dr. Siemens has ascertained that 50 per cent. of the original power can be realised at a distance of one mile, and that, with adequate provisions against heating, it will be no dearer to transmit electro-motive power to a greater than to a smaller distance.

The subject of improved communications have been treated at some length because, except printing and the steam engine, no applications of physical science appear to have produced such extensive and important effects. The penny postage, for which the name of Sir Rowland Hill will always be renowned in the annals of this country, could not have existed without the aid of railways. Neither would it have been possible without their aid, combined with that of telegraphs, to circulate over large areas, newspapers at the cost of one penny, containing telegraphic information of events which happened in distant parts of the world on the day of their publication.

The subjects of artillery and armour plates were ably brought forward twelve years ago in the address of Mr. Charles Hutton Gregory, C.M.G., Past-President Inst. C.E. Since that time the contest between guns and plates, and the unavoidable competition among nations for superiority of armaments, have led to gigantic apparatus for attack and defence. As the magnitude and power of guns have increased, changes have been required in the metal employed in their construction. In 1828 the largest guns and mortars were of cast iron. In the next stage of advancement

wrought iron was used. And now that guns weighing 80 tons and 100 tons are constructed, the metal employed is steel, which is universal, at least so far as regards its adoption for the interior lining. The controversial questions as to the employment of steel for the whole gun, instead of a lining of steel with an iron covering, and as to breech loading and muzzle loading, together with many other interesting and important inquiries relating to large guns, are now under investigation by a carefully selected tribunal, and the results of that inquiry are looked forward to with great interest.

Water supply and drainage form a branch of engineering which, as affecting sanitary conditions, is now receiving much attention. The address of the late President, Mr. Bateman, having been mainly directed to water supply, it only remains to add that his project for utilising Lake Thirlmere for the supply of Manchester received the sanction of Parliament last session. Important works of drainage and other improvements have been effected in most of the principal cities and towns of the kingdom.

By the action of the City of London, and at a later period of the Metropolitan Board of Works, the condition of the metropolis has been greatly improved and embellished. Old London, Blackfriars, and Westminster bridges, which in 1828 encumbered and obstructed the navigation of the Thames, have been replaced by others affording a much larger water-way. The sewage, which used to be delivered in black streams at intervals along both river fronts, has been intercepted by the great drainage works of Sir Joseph Bazalgette, V.-P., Inst. C.E., who has also carried out the embankment of the river Thames. Under his advice, and that of Colonel Haywood, M. Inst. C.E., numerous street improvements have been made, and in the new buildings bordering on them architects have added very greatly to the embellishment of the metropolis.

If Vauxhall bridge be taken as representing the boundary between London and its suburbs in a westerly direction, there have been three suburban bridges built, namely, the Chelsea, Albert, and Wandsworth bridges.

Eastward of Vauxhall, in what may be considered the active metropolitan area, the only additional public communications opened across the Thames during the last fifty years are the Hungerford Suspension bridge, of Mr. Brunel, V.-P. Inst. C.E., since removed and replaced by the public foot-way in connection with Charing Cross railway bridge, and the Lambeth bridge and the Tower Subway, the two latter constructed by Mr. Peter W. Barlow, M. Inst. C.E.

The extensive increase of traffic, and the general growth of the eastern and more commercial part of the metropolis, produce such difficulties at London bridge, that some other road communication to the eastward of that bridge cannot much longer be delayed.

In the more ordinary operations of building, one of the noticeable changes is in forming foundations by iron cylinders or caissons instead of by cofferdams as formerly used. This newer mode of construction was early employed in railway bridges by Sir William Cubitt, Past-President Inst. C.E., and Sir Charles Fox, M. Inst. C.E. and its most extended and most recent example is found in the great bridge across the Tay.

The use of concrete has largely increased with the improved knowledge of cements. Concrete was formerly employed chiefly in foundations and for the backing of walls; but in the large extension of the Victoria Docks by Mr. A. M. Rendel, M. Inst. C.E., it has been adopted for the entire walls, including the face-work and coping. About 450,000 yards have been used in these works with very successful results.

The employment of gas as a means of illumination, which was only beginning in 1828, has increased in a remarkable degree. The length of gas mains in the metropolis alone was, at the end of 1878, 2,500 miles, for supplying all the private consumers, and there are about 58,000 public lamps for street lighting. Mr. Harry Chubb informs me that in the same year the quantity of coal decarbonised was 1,715,000 tons, which produced nearly 17,500 million cubic feet of gas, besides residual products of the value of £745,000. The coal used appears to be about four-tenths of a ton per annum per head of the population. Of the gross revenue only 5 per cent. is derived from street lighting, while 20 per cent. arises from the sale of residual products, and 75 per cent. from private consumers. The capital invested in gas works in the United Kingdom is £40,000,000, of which about £12,000,000 may be taken to represent the capital of the London Gas Companies.

The application of wrought iron in the superstructure of engineering works commenced with suspension bridges, where the metal is only subjected to tensile action. Its employment in large tubular girders designed to resist rupture by transverse strain, originated with Robert Stephenson, Sir William Fairbairn having carried out the first experiments for him in 1845, and assisted materially with his valuable suggestions. In the tubular bridge at Conway, and in the subsequent larger work over the Menai

Straits, the iron was used in the form of riveted plates, a mode of construction since employed extensively in railway bridges. Before the completion of these works, another step was made in advance, by girders of this metal being framed together in open work. This description of girder involved problems in determining the amount of stress in each member of the structure, which are specially interesting from the exact manner in which the results can be ascertained, and the several parts proportioned to the work they have to perform. It is to these circumstances, and to the greater proportionate depth which can be given to this class of girder, that its economy is attributable.

The improvements effected in the manufacture of steel assume the character of new discoveries, which are tending to revolutionise the iron industries of the world. The Bessemer process, followed by that of Dr. Siemens and Mr. Martin, by producing good steel at a low rate of cost, has displaced a great deal of the iron formerly used in this country—a movement likely to be accelerated by the more recent labours of Mr. I. L. Bell, M. Inst. C.E., and Messrs. Thomas and Gilchrist, in the dephosphoration of the Cleveland ores. Besides the advantages which steel has over iron for rails, wheel tires, and other purposes where it is exposed to wear, and for structural purposes on account of its superior strength, there is a general gain to the community arising from the smaller quantity of coal required for its production. Thus, to make a ton of iron, about 6 tons of coal are necessary, but to make a ton of steel 3 tons of coal suffice; and as it is stated that nearly 50,000,000 tons of coal are annually consumed in iron and steel works, the saving by the substitution of steel for iron has been truly called a “national gain.”

The production of modern steel is a subject which I have followed from its commencement with great interest, being early impressed with the importance of introducing a stronger material than wrought iron into engineering structures. Acting as a member of a Committee of Engineers who made an extended series of experiments on steel, the results of which showed conclusively its applicability to structural purposes, and being aware that the consideration of the subject had been frequently urged upon the Government by Sir John Hawkshaw, I took the opportunity of having to make an address to the mechanical section of the British Association at Bradford, to bring the whole matter under notice.¹ The British Association then appointed a committee to

¹ Brit. Assoc. Rep., vol. xliii., 1873. Transactions of the Sections, p. 200.

confer with the Board of Trade, by whom, after much correspondence, the question was referred to Sir John Hawkshaw, Colonel Yolland, R.E., and myself. This resulted in the adoption of a coefficient for steel of $6\frac{1}{2}$ tons to the inch, that of iron being 5 tons, it being further understood that for steel of high qualities the coefficient should be raised by agreement, due precautions being observed in the testing. It would be superfluous to point out to members of this Institution, that in engineering works requiring wide spans, where the weight of the structure is large in proportion to the load to be carried, the economy of employing steel instead of iron will be in a much greater ratio than the relative strength of those metals.

Two great bridges are now in course of construction, one a public road bridge between New York and Brooklyn, designed by Roebling, having one span of 1,595 feet; the other a railway bridge across the Firth of Forth, designed by Sir Thomas Bouch, M. Inst. C.E., which will have two spans, each of 1,600 feet. In both these bridges the employment of steel becomes a necessity, because the weight required to make them in iron would render them impossible.

Although enough is known about steel for ordinary structural purposes, there are properties belonging to that material which greatly need further experimental inquiry. Untempered steel is very like good iron in two of its characteristics. First, it possesses nearly the same modulus of elasticity; and secondly, the force required to extend it to the limit of its elasticity, or the force at which an appreciable permanent set appears, is about half that required to produce rupture. The superior strength of untempered steel over that of good wrought iron is proportionate to the greater range of its elastic action; and the ratio which this greater range of elastic action bears to that of iron varies with different qualities of steel. But the strength of steel may be greatly increased by tempering in oil, a process now much in use. There are no experiments to show whether the increase of strength so obtained is due to a still further increase of the elastic range, or to a change in the modulus of elasticity. Experiments are also wanting to determine what change, if any, arises in the specific gravity of metal when under strain within the limit of its elastic action. This information is essential for the correct computation of the strength of cylinders subjected to internal pressure. Within certain limits the stretching either of iron or of steel, beyond its original elastic limit, increases the strength and the range of elastic action. The process of cold rolling is an example of

this effect. In the Philadelphia Exhibition a large amount of the shafting for driving the machinery was so made. It presents a highly-finished appearance, and is known to increase both the tensile and the transverse resistance.

Steel wire, drawn cold, exhibits remarkable strength. The pianoforte wire used by Sir William Thomson, in his deep-sea soundings, bore 149 tons to the inch, with an elastic range equal to $\frac{1}{88}$ part of its length. The result in this case shows about the same modulus as iron, and an increase of strength proportionate to the increased elastic range. It is probable, however, that in this case, as in some other cases, the increase of strength is accompanied by a great loss of ductility.

The employment of hydraulic machines has largely increased, some being used for producing great pressures and moving great weights, others are made of quicker movement, water motors, applicable to cranes, hoisting apparatus, opening lock gates, and many other purposes. One of the most striking applications of the hydraulic press is that employed by Sir Joseph Whitworth for the compression of molten steel. Those who have witnessed this process will be aware of the enormous difficulties which had to be overcome in subjecting large ingots of molten steel to a pressure amounting to 6 or 7 tons per square inch. The pressure thus obtained is kept up continuously for an hour or more, and completely closes up every air space, gas space or other interstice, and thus renders the ingot perfectly solid and sound. By a further application of the hydraulic press at these works, the use of the hammer is dispensed with in large forgings of steel; the red-hot metal is pressed into its required form by arrangements under easy guidance and control. Forging by hydraulic pressure has at least the appearance of being a far superior process to the rough and noisy hammering which accompanies ordinary forging. It is practised in Prussia, as well as in this country; several specimens of the work were exhibited at the Philadelphia Exhibition of 1876.

The United States Government have recently had constructed a powerful and accurate testing-machine, capable of exerting tensile and compressive strains of 400 tons. This machine has been especially arranged for the investigation of the mechanical properties of steel.

The great advances in practice have been accompanied by a marked extension in an accurate knowledge of the physical sciences; and within the last ten or fifteen years the educational

departments of the country have undergone important changes in this respect. By recent returns issued by the Science and Art Department of the Committee of Council on Education, it appears that the number of schools in which elementary scientific instruction is given has increased in eleven years from 212 to 1,297; that the number of students who came up for examination has increased during the last seven years from 18,750 to 40,086, and that the number of first classes in the elementary and advanced stages has risen in that interval from 2,431 to 11,488.

Mr. Fowler, Past-President Inst. C.E., in his address in 1866, dwelt at some length on the kind of education best suited for an engineer. Of late years, in several of the Universities, Professorships of Engineering have been established, and departments for scientific instruction have been created in different colleges, and the increasing area of scientific requirements renders it desirable that a yet wider field should be given to that class of instruction. It is obvious that pupils should be acquainted with the principles which lie at the foundation of mechanical science, and with the nature and properties of the materials employed, before they can enter with advantage upon actual work, which consists in applying those principles and those materials to practical use. The numerous colleges directed to this class of teaching in France, Germany, and Switzerland, give to the engineers of those countries some advantages in this respect. It is true that the best teaching will be given in vain to those who do not possess the qualities of mind fitted for their avocation; neither will any preliminary education suffice, unless it is accompanied by active observation and subsequent continued self-instruction.

Lord Shaftesbury, in a recent Paper, remarks, that "having given to every one the elements of knowledge, you have given him access to the means of acquiring more"; and he adds, "I am convinced that after all the best education a man gets is that which he gives to himself by his own exertions." There are many instances where power of observation and self-instruction have enabled men to rise without much other teaching. Young men taken from ordinary schools and placed at once as pupils in a workshop or on engineering works, are mainly dependent for their progress on those powers of mind; and what they learn in that way, though laboriously obtained, is rooted and grounded in a manner which probably no other teaching can accomplish. But there can be no doubt that their path would be made easier, and the scope of their observation much wider, by previous education specially directed to the class of subject with which they have to deal. So far as

my experience extends with regard to pupils, those who have come from colleges where applied science is taught, take at once a higher position, and have a much larger sphere of usefulness, than equally clever men who have not had that advantage.

In the early days of the Institution, the knowledge of the strength of materials, and of the laws which govern mechanical action and forces, were very imperfectly understood. There were many theories based on assumed but not always correct data, and many valuable experiments upon which useful but empirical rules had been founded. Smeaton, Telford, Rennie, Tredgold, Beaufoy, and others contributed much to the knowledge existing at that time. My father's essay on the Strength and Stress of Timber appeared in 1817. This book went through many editions under the title of "Barlow's Strength of Materials." It owed its popularity and success to the great want of systematic information which prevailed at that time, and to the fact that besides containing clear mathematical investigations of the several questions, it also gave concise rules for their application, written in simple language such as any well-educated workman could understand. It is curious to observe that until that work appeared, it was still a disputed point whether the deflection of a beam strained transversely varied as the square or as the cube of the length. Bernoulli's investigation gave one result, and Girard's so-called experiments another. My father made a totally independent investigation, accompanied by a series of clear and conclusive experiments, and thus put this question at rest for ever. This fact is one among many which might be cited, showing the necessity of carrying on investigations of this nature, not by theory alone, nor by experiment alone, but by both, so as to check and establish every point of the inquiry.

Professor Rankine, in his address to the Senate of the University of Glasgow in 1855, refers to the antagonism between theory and practice. He attributes its origin to the ancient Greek philosophers, who, in regard to physics and mechanics, entertained the fallacious notion of the existence of a double system of laws; one theoretical, discoverable by contemplation and applicable to celestial bodies, the other mechanical, discoverable by experiment and applicable to terrestrial bodies. And he goes on to show how the science of motion founded by Galileo, and perfected by Newton, overthrew this supposition and proved that celestial and terrestrial mechanics are branches of one science.

That some relics of this antagonism are yet to be found is true. There is a class of practical men who reject the adoption

of any principles except trial and error. But there are others, daily growing in numbers, who are desirous of availing themselves of theoretical knowledge. Among this latter class it is not a question of antagonism, but rather a want of confidence arising from the existence of theories founded on ideal or insufficient data.

There was, for example, a theory of the arch by David Gregory ("Phil. Trans.," 1697), in which it was assumed to be necessary that the line of pressure should coincide with the intrados of the arch. In another by La Hire and Atwood, called the wedge theory, it was supposed that the pressure must be at right angles to the surfaces of the voussoirs. It was not until the subject was taken up by Coulomb, and further elucidated by Professor Moseley, that a theory, based on the conditions existing in a real arch, was established.

Again, in the case of the solid beam strained transversely, Galileo, who, according to history, had his attention drawn to the subject during a visit to the arsenal and dockyards of Venice, promulgated a theory in 1633 assumed to be dependent on pure mathematical principles. This theory, afterwards illustrated by Girard in his "*Traité Analytique de la Résistance des Solides*," is thus commented upon by my father:—"Nothing can be desired more simple than the results obtained by this theory; but, unfortunately, it is founded on hypotheses, which have nothing equivalent to them in nature."¹ The errors of Galileo's theory were first pointed out by Mariotte, who subjected it to the test of experiment. Then followed Leibnitz, who applied to it Dr. Hooke's law of "*ut tensio sic vis*," but he restricted it to the action of tension, treating the fibres as incompressible. Bernoulli then took up the question, contending that part of the fibres were compressed and others extended. For some reason, probably because his results did not accord with experiment, he doubted the universal application of Dr. Hooke's law. But this law, which is found to be perfectly consistent with experience, when applied to direct tension or direct compression within the limit of elasticity, is again had recourse to by Dr. Robison, who next follows up the investigation, and by him the subject of the neutral axis is introduced, leaving its position undetermined. This theory of the beam has proved misleading. Tredgold was deceived by it while endeavouring to deduce the tensile strength of cast iron from bars of that metal strained transversely; the

¹ Vide "*A Treatise on the Strength of Materials*." By P. Barlow. New Edition, London, 1867, p. 31.

computed result giving him a tensile strength of 20 tons per inch, whereas it is only 8 tons per inch by experiment. My father, who had ascertained the tensile, compressive, and transverse resistances of wrought iron, was led by this theory into the supposition that the position of the neutral axis rose during strain above the centre of gravity of the section. Subsequent experiments of my own ("Phil. Trans.," 1855), on large rectangular beams of cast iron and wrought iron, proved by actual measurements that the neutral axis was in the centre of gravity of the section, and remained there throughout all the degrees of strain applied.

The subject of the transverse strength of beams has recently been treated by Mr. Charles Emery,¹ of New York, who suggests certain hypotheses which may lead to an amended theory. But there is still no adequate explanation by theorists of those causes which render a solid beam, whether of cast iron, wrought iron, or steel, so much stronger than the present theory of the beam would give it, as deduced from the tensile strengths of those materials.

In looking at the great progress of engineering science during the last half century, it will be observable that some of the most important advances have arisen in this country; among them, the application of steam to locomotion on railways, and in ocean navigation; the employment of wrought iron for ship building and for large girders; the screw propeller, the utilisation of some of the powers of electricity for telegraphs and electric lighting, and the production of modern steel.

But while Englishmen seem to possess in a high degree the power of initiating great and practical ideas, other countries are quick in adopting them, and in many cases improving upon them, so that new applications and adaptations of the greatest value, as well as many new and useful inventions, originate abroad. It is in fact impossible to study the works of foreign engineers without feeling, not only in regard to the magnitude of some of these undertakings, but also to the excellence of their execution and the fertility of resource displayed in overcoming local difficulties, that English engineers have now to deal with competitors with whom it will tax their best energies to keep pace; and in the varied conditions encountered in foreign countries, new and modified methods of treatment arise with which it is desirable that everybody connected with the Institution should be kept informed. It is with this object that the Council, aided by

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. lix., p. 329.

their Secretary, Mr. Forrest, have, of late years, added to the Minutes of Proceedings, abstracts of memoirs presented to foreign engineering societies, or printed in technical periodicals abroad. To me it seems of great importance that English engineers, many of whom must look in the future to employment abroad, should be well informed of what is passing in other countries. Much may be done to supply this information by books, and by the perusal of the valuable engineering periodicals of the day. But where practicable, a visit to the engineering works of other countries, and an examination of them considered in reference to the resources available for their execution, and a personal acquaintance and interchange of ideas with the engineers themselves, combine elements of instruction of the greatest value.

Many of the members have the advantage of acquaintance with the more important engineering works in Europe; but there is perhaps no country which presents such varied and extensive information as the United States of America. It became my duty in 1876 to go to America as one of the judges of the Philadelphia Exhibition, and I can not only speak of the great amount of valuable information to be obtained there, but also of the hearty welcome with which English engineers are received by their American brethren. American engineers are in advance of those in this country in regard to the application of steel in engineering structures. In Mr. Eads' great bridge at St. Louis of three arched spans, the centre opening being 520 feet and the side spans nearly as large, the arches are of steel. In a recent large railway bridge,¹ erected at Glasgow, U.S., by General Sooy Smith, the entire structure is of steel. Mr. T. C. Clarke's valuable Paper² on large span bridges for railway traffic, read at the Institution during the session 1877-78, shows how carefully the subject of iron open-work girders has of late years been studied and applied in America, and the numerous opportunities which that great country offers for works of that description.

In endeavouring to place on record some of the results of engineering progress during the last fifty years—results which have come more or less under my own observation—I am well aware how much has been omitted. Irrigation, mining, and numerous improvements in machinery, afford ample topics and examples of the general advance.

Taking Sir John Hawkshaw's estimate in 1875 as a basis, adding

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 328, and vol. lix. p. 337.

² *Ibid.*, vol. liv., p. 179.

the probable cost of steamships, and allowing for the extension of railways, telegraphs, docks, harbours, and other works since that time, the total capital invested in engineering works cannot have been less than 3,500 millions, or about 70 millions annually; of which about $\frac{1}{3}$ appear to belong to railways, steamships, docks, harbours, and telegraphs, all of which are directed to improving and extending the means of transport for passengers and merchandise and the communication of intelligence.

It is observable also that this great progress, which probably exceeds that of any like period in the history of the world, is due to improvements, new applications and discoveries, which are the result of experimental research and greater knowledge of natural laws. Beginning with some ascertained scientific fact, as the power of steam or the transmission of motion by electricity, the advance made by one man becomes the starting point of another; and thus step by step the point now reached has been arrived at, and will soon be passed by further developments in the future. Thus neither railways, telegraphs, steam navigation, nor other achievements, in their present advanced form, can be assigned to the credit of any one man, but they represent the cumulative result of the genius and perseverance of numerous individuals. The Institution is justified in regarding with satisfaction the number of contributors to this advance to be found among its past and present members.

In conclusion, I desire to acknowledge and to express the indebtedness all must feel to those men, both within and without the profession, in foreign countries as well as in this, who by study and experimental research are continually adding to an exact knowledge of the great sources of power in Nature—that power, the direction of which to the use and convenience of man, constitutes the fundamental element in the Charter of THE INSTITUTION OF CIVIL ENGINEERS.
